CHAPTER
9
Brainstorming Experimental Ideas

CONTENTS

INTRODUCTION

You have conducted multiple experiments, each of which was structured by your teacher or textbook authors. Now it is time for you to move to generating an original experiment. For many students, the thought of designing an original experiment is daunting. "What should I investigate? Why can't I think of an experiment? Hey, I've got it! But, who cares? What about . . . ? No, that would take too long and besides I don't have . . ." And, so it goes.

Although you know an original investigation will need an experimental design and procedure, do not worry about the specifics now. Instead, give yourself time to explore possible variations of a research topic. In this chapter, you will learn to brainstorm multiple ideas for experiments before deciding on potential experimental variables.

Learning Objectives

Specific learning objectives for Chapter 9 *Brainstorming Experimental Ideas*, include:

- Use your interests to identify potential topics for an original experiment;
- Use the *Four Question Strategy* to brainstorm ideas for an experiment;
- Identify potential experimental variables from a brainstormed list;
- Use a variety of prompts to brainstorm experimental ideas;
- Use a checklist to assess and strengthen brainstormed ideas; and
- Use argumentation skills to compare assessments of brainstormed ideas.

Correlations With Nationwide Standards

In Table 9-1, the chapter learning objectives and STEM concepts are correlated with nationwide learning standards. The correlations for "Exploring STEM Connections" are shown in italics. For a synopsis see Appendix A.

TABLE 9-1 Correlations With Nationwide Standards

NEXT GENERATION SCIENCE STANDARDS

- **Scientific & Engineering Practices:** Asking questions and defining problems; Planning and carrying out investigations; Engaging in argument from evidence; *Using mathematics and computational thinking; Constructing explanations and designing solutions*
- **Cross-Cutting Concepts:** Patterns; *Scale, proportion, and quantity*
- **Disciplinary Core Ideas:** Matter and its interactions; *Motion and stability; Earth's systems; Earth and human activity; Engineering design; Links among engineering, technology, science, and society*

COMMON CORE STANDARDS—MATHEMATICS

- **Mathematical Practices:** Construct viable arguments and critique the reasoning of others; Look for and express regularity in repeated reasoning; *Model with mathematics*
- **Mathematical Domains:** *Ratios and proportional relationships; Geometry; Similarity, right triangles, and trigonometry; Modeling with geometry*

COMMON CORE STANDARDS—LITERACY IN SCIENCE AND TECHNICAL SUBJECTS

- **Reading:** Follow multi-step procedure; Read and comprehend text; *Determine key ideas or conclusion; Determine meaning of symbols, key terms, etc.; Compare and contrast information from known sources*
- **Writing:** *Write information/explanatory texts; Conduct short research projects; Gather relevant information*

ISTE STANDARDS—STUDENTS

- **Creativity and innovation:** Apply existing knowledge to generate new ideas, products, or processes
- **Research and information fluency:** Plan strategies to guide inquiry; *Locate . . . use information from a variety of sources/media; Evaluate and use information sources and digital tools based on the appropriateness to specific tasks*
- **Critical thinking, problem solving, and decision making:** Identify and define authentic problems and significant questions for investigation; Use multiple processes and diverse perspectives to explore alternative solutions
- **Digital citizenship:** Advocate and practice safe, legal, and responsible use of information and technology; Demonstrate personal responsibility for learning; *Exhibit a positive attitude toward using technology that supports collaboration, learning, and productivity*

Source: Confrey & Krupa, 2012, p. 9; Morphew, V. N., 2011, pp. 299–300; National Governors Association Center for Best Practices, 2010, English language & literacy, pp. 64–66; National Governors Association Center for Best Practices, 2010, Mathematics, pp. 6–8; NGSS Lead States, 2013, Volume 1, p.1; NGSS Lead States, 2013, Volume 2, pp. 67–79.

BUILDING UPON YOUR INTERESTS

Scientists get ideas for experiments in many ways. They use their senses to observe the world and they learn about science by reading and using multimedia. Scientists do research in both the library and the laboratory and they also attend meetings where they share research ideas. Scientists study reports of experiments by others and sometimes get ideas for investigations in the unanswered questions in someone else's work.

You too can get ideas for experiments in many ways. Are there things you wonder about? Observe the world around you, search the Internet, or visit a library. Many science demonstrations and "tricks" are shown on the Internet, or described in print. Try learning a little about things that interest you. Think about how you use your free time. Are there experiments hidden in your hobbies?

Being interested in the things you do makes them fun. A science experiment that interests you can be fun, too. It may not be easy, but something that is too easy is no fun. You will enjoy an original experiment if you are interested in the topic you choose. Before choosing a topic to investigate, think about the following questions:

1. What is your favorite hobby?
2. What sports interest you?
3. What household chore is your responsibility?
4. What is your favorite school subject?
5. What science-related books or multimedia interests you?
6. What careers interest you?

Starting with something that interests you is a good place to begin. What have you wondered about that is related to an interest of yours? For example, if you were interested in running, have you ever wondered why runners begin some races standing up and others in a crouched down position? Does the position make any difference? What would happen if runners always started standing up?

Not many of us like doing household chores. If you wanted to find ways to make them easier, studies of products may interest you. Do some brands of paper towels clean better? Does stain guard in dryer-static sheets really work? Are there ways you can finish a chore more quickly? Think about mowing a lawn. What affects the time to mow the lawn? Look at your chores for science project ideas.

You can also use hobbies and clubs as sources of ideas for experiments. If you play with Frisbees think about what affects their flight. Do other brands fly the same? How does the angle of throw affect the flight? If you are a scout, is there a merit badge activity you can modify into an experiment? For example, you could investigate ways to collect solar energy while earning your outdoor cooking badge.

If science is a favorite subject, think of favorite topics you have studied or read about, an interesting experiment you conducted, or an amazing demonstration or phenomena you viewed. Perhaps, you heard a “claim” about a product, or interesting research on a topic. Scientific methods and tools are used to answer questions in multiple disciplines. So, if your interest is the humanities, arts, or a technical field talk with your teacher about research in these areas, or ask a librarian to help you find journals that summarize experimentation in the targeted discipline.

LEARNING THE FOUR QUESTION STRATEGY

Answering questions about your interests may have resulted in a variety of ideas such as remote-controlled planes, skateboarding, waxing the car, biology, gardening, or firefighting. Although these general topics are a good beginning, you need a way to change a general topic into potential experimental variables.

Brainstorming Variables

The *Four Question Strategy* is a technique for brainstorming multiple ideas before identifying potential experimental variables. To introduce the strategy, we will apply a sequence of four questions to a familiar topic, PLANTS.

Question 1: What materials are readily available for conducting experiments on (plants)?

Water, plants, containers, soil, seeds, fertilizer, light

You may have also listed warmth and other environmental conditions that plants need. The more things you list in your responses to Question 1, the better experiment you will be able to design. Choose materials that are inexpensive and easy to find. You may be able to borrow materials from your school, parents, or people in the community. Next, ask yourself Question 2.

Question 2: How do (plants) respond?

Plants grow, wilt, flower

The major thing that plants do is grow, but you may have brainstormed other actions as well. Plants also flower, wilt, produce fruit, and die. Continue on to Question 3.

Question 3: How can I change the set of (plant) materials to affect the response?

Water Amount Scheduling Method of application Source Composition pH	**Plants** Spacing Kind Age Size	**Containers** Location of holes Number of holes Shape Material Size Color
Soil Composition Amount Depth Compaction	**Seeds** Size Color Number Planting depth Age	**Fertilizer**
Light	**Environmental Conditions**	**Other?**

Responses to Question 3 are possible **independent variables** you could choose when designing an experiment. The independent variable is the variable you intentionally change or vary. The longer the lists, the more choices you will have. For water, maybe you also thought of temperature and time of watering. Did you think of any other ways to change plants or containers? What are other ways you could vary the soil or seeds? Similarly, you also need to develop lists for fertilizer, light, environmental conditions, and other categories of materials you identified. The last question in the *Four Question Strategy* is next.

Question 4: How can I measure or describe the response of (plants) to the change?

- Count the number of leaves
- Measure the length of the longest stem
- Count the number of flowers
- Determine the rate of growth
- Determine the mass or weight of the fruit produced
- Measure the diameter of the stems
- Record the time to germinate

The final question helps you decide on a **dependent variable**, which is the variable that responds in an experiment. From Question 4 you can decide on a specific way to measure or describe changes in the responses. Other potential dependent variables measure root development, record color, assess health quality, or still other ways to measure plant growth.

Identifying Potential Variables

To identify potential experimental variables, select an independent variable from your responses to Question 3, such as *amount of water*. Then, select a dependent variable from Question 4, perhaps *number of flowers*. Write a testable question you could ask: "*How does the amount of water impact the number of flowers on a plant*?" To make the experiment a fair test of the effect of water on the number of flowers produced, all other responses to Question 3 must be kept the same. They become **controlled variables** if a value is assigned to each and kept the same throughout the experiment. Remember, controlled variables are the things you intentionally keep the same in an experiment.

Many potential combinations of independent, dependent, and controlled variables exist. Each different combination of an independent variable (Question 3) and dependent variable (Question 4) leads to a different testable question.

- ➤ How does soil compaction affect the rate of plant growth?
- ➤ How does the spacing of plants affect the mass of fruit produced?
- ➤ How does the planting depth of seeds impact the time to germinate?

Once a set of potential independent and dependent variables are selected, all potential variables listed in response to Question 3 become controlled variables.

USING FAMILIAR TOPICS TO BRAINSTORM

The *Four Question Strategy* helped you think of many ways to experiment with plants. But, will the strategy work with other topics as well?

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Soft Drinks

Let's try the strategy with a familiar topic—soft drinks, also known as soda or pop.

> **Question 1:** What materials are readily available for conducting experiments on (soft drinks)?
>
> *Soft drinks, containers, people*

Question 2: How do (soft drinks) respond?

- Soft drinks fizz.
- Soft drinks quench thirst.
- Soft drinks taste.

Question 3: How can I change the set of (soft drink) materials to affect the response?

Soft drinks	People	Container
Brand	Age	Original
Flavor	Gender	Other containers
Container	Thirstiness	Size
Color	Fitness	Texture
Temperature	Prior use	Temperature
Sweetener		Shape
Caffeine content		
Carbonation		
Amount of ice		
Time uncovered		

Question 4: How can I measure or describe the response of (soft drinks) to the change?

- Taste preference
- Rate of bubbling
- Length of time it bubbles
- Requests for seconds

Identifying potential variables for an experiment on soft drinks is as easy as:

- Choosing one variable from Question 3 (say, *amount of ice*) as your independent variable;
- Choosing a variable from Question 4 (perhaps, *rate of bubbling)* as your dependent variable;
- Writing a testable question: "*How does the amount of ice affect the rate of bubbling?"*; and
- Keeping all other variables in Question 3 the same; they become your controlled variables.

Skateboards

Now, let's try the *Four Question Strategy* with a hobby, such as skateboards.

Question 1: What materials are readily available for conducting experiments on (skateboards)?

Skateboards, wheels, ramps

Question 2: How do (skateboards) respond?

- Skateboards travel long distances.
- Skateboards move.
- Skateboards turn and flip.

Question 3: How can I change the set of (skateboard) materials to affect the response?

Skateboards	Wheels	Ramps
Cost	Diameter	Height
Brand	Width	Length
Material	Tread design	Curvature
Length	Material	Surface
Width	Age	

Question 4: How can I measure or describe the response of (skateboards) to the change?

- Measure the total distance traveled
- Measure the time to go a certain distance
- Describe the ease in changing direction
- Measure the distance it will stay airborne off a ramp
- Measure how long the parts last

There are many combinations of experimental variables you could select to investigate. Below is just one option:

- Choose one variable from Question 3 (*wheel diameter*) as the independent variable;
- Choose a variable from Question 4 (*distance*) as the dependent variable;
- Write a testable question: "*How does wheel diameter affect the distance a skateboard will travel*?"; and
- Keep all other variables in Question 3 the same; they become your controlled variables.

Now that you have seen three examples of using the *Four Question Strategy* to brainstorm a familiar topic, practice the strategy by selecting one of the topics in Box 9-1, or a topic that interests you.

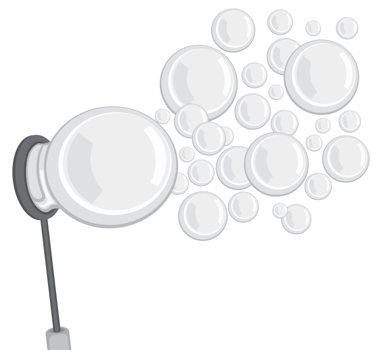
MY WORKSPACE

Name ______________________ Date __________

PRACTICE
Brainstorming Familiar Topics

DIRECTIONS Use the *Four Question Strategy* to brainstorm potential experimental variables on the following topics:

1. Bubbles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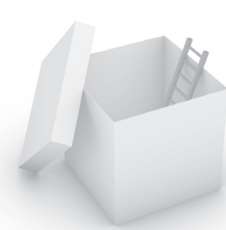
2. Earthworms

3. **Home insulation materials**

4. **Topic of interest**



EXPERIENCING THE PHENOMENA

Previously you used the *Four Question Strategy* with familiar topics. Because you had experience with the topic, either in or out of school, you had a basis for answering the questions. What if you were asked to brainstorm ideas for experiments with light sticks, silly putty, or bubbles? Although you may have played with these objects, you probably did not see them as a source of experiments. Even washable finger paint can be the basis of an experiment. Use the activity in Box 9-2, *Experiment—Nature's Art*, to explore this type of artist paint, which is officially called gouache. Then, use your observations and the *Four Question Strategy* to brainstorm potential experimental variables.


MY WORKSPACE

Name ______________________________ Date ____________

EXPERIMENT
Nature's Art

QUESTION

HYPOTHESIS *Contruct your own.*

MATERIALS

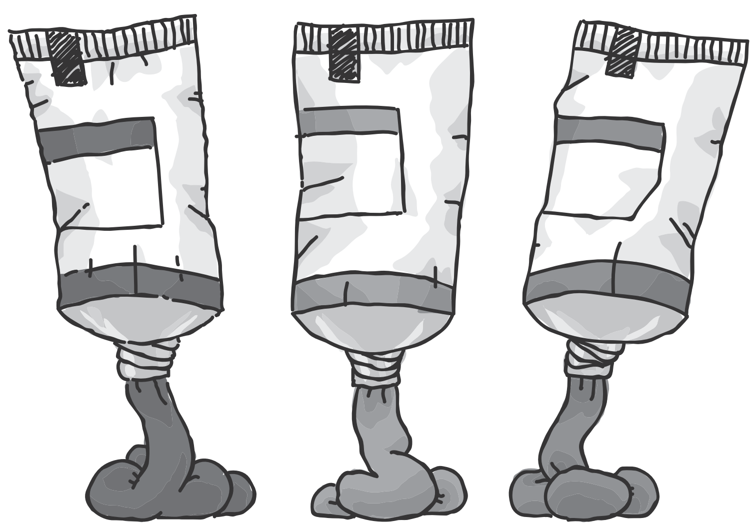
- Paper or foil to cover surface
- Watercolor paper, about 14 cm x 20 cm
- Washable finger paint (gouache), various colors
- Pencil or pen

SAFETY

- Wear safety goggles and appropriate protective clothing.
- Do not taste the paint.
- Wash hands after investigating.
- Follow your teacher's directions for safety, cleaning the laboratory, and disposing of materials.
- See Chapter10, *Addressing and Analyzing Safety Risks.*

PROCEDURE

1. Cover the surface of a table or desk.
2. Fold the watercolor paper in half. Crease the fold.
3. Open the paper. On one side, put a drop of finger paint.
4. Close the paper. Press with your hand, pencil, or another object.
5. Open the paper. Make observations. Put the paper where it can dry.
6. Play around with the paint, paper, and various pressing techniques.



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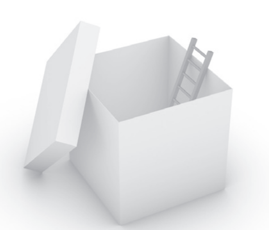
EXTENDING THE ACTIVITY

1. Use the *Four Question Strategy* to brainstorm ideas for conducting experiments with artist paints.

2. Select a potential set of variables and write a question to guide an experiment.

Adapted from Frame, Mandelbrot, & Neger, 2015; MathScience Innovation Center, 2011.

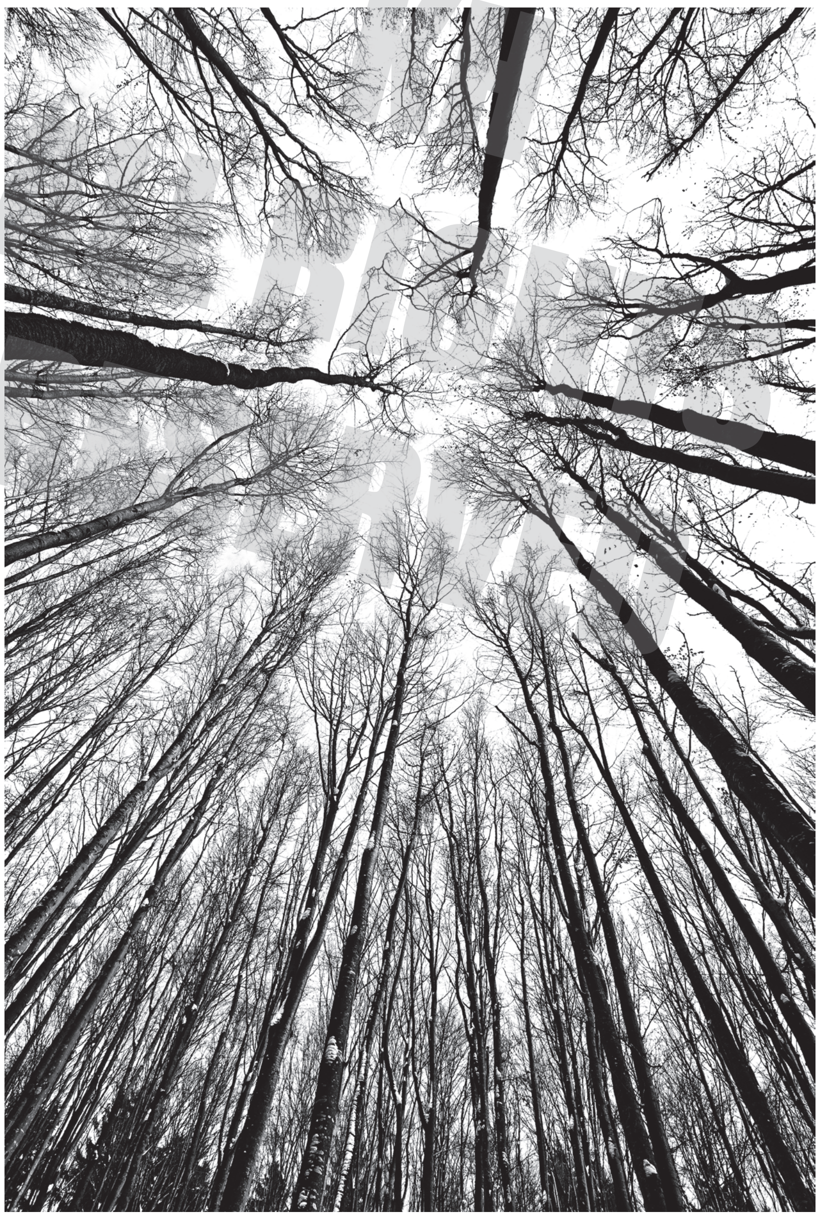


USING SCIENTIFIC PROMPTS TO BRAINSTORM

Scientists get ideas for experiments by using their senses to observe the natural world. Observations from prior activities, such as *Nature's Art,* can be the basis for brainstorming. The Internet and library are filled with videos and books of science demonstrations or "magic tricks." Each is a potential source of experimental ideas. Daily, you are bombarded with claims for products and news briefs about scientific studies. Each news item can also lead to a potential experiment.

Activities

Not all hands-on experiences involve experimentation. Some may be open-ended investigations of phenomena. Even so, they can serve as inspiration for an original experiment.



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Were you surprised by the beautiful patterns produced in *Nature's Art*? Often the patterns resembled natural phenomena—leaves, tree branches, insects, or drainage patterns. Let's use the *Four Question Strategy* to brainstorm ideas for experimenting with artist paints and these patterns.

Question 1: What materials are readily available for conducting experiments on (artist paints)?

Paper, paint, pressing, other surfaces, people

Question 2: How do (artist paints) respond?

- Make a pattern
- Branch
- Look like nature
- Make thick ridges
- Make mirror images

Question 3: How can I change the set of (artist paints) to affect the response?

Paper	Paint	Pressing
Type Texture Thickness Glaze Temperature Folded or separated sheets	Type Temperature Age Thickness Amount Location Method applying	Length of time Direction used Number of times object used Texture object
Other Surfaces	**People**	**Other (?)**
Smoothness Natural Artificial	Age Prior art experience Interest in art Hand used Part of hand used	

Question 4: How can I measure or describe the response of the (artist paints) to the change?

- Measure the thickness of lines
- Count the number of branches
- Measure total length of line
- Measure length between branches
- Describe the pattern
- Describe if mirror/non-mirror images

Because you explored different aspects of the phenomena, your brainstormed list will differ from ours. By combining your brainstormed list with ours, or other classroom groups, you will have a stronger list of potential variables. From the list you can select a unique independent variable and dependent variable to investigate, keeping the other variables constant.

The images produced in *Nature's Art* transcend multiple disciplines. They occur in art and nature and can be mathematically described using fractal geometry. Some of the STEM connections will be related to fractals. If you investigate fractals you will have a stronger basis for brainstorming experimental ideas.

Demonstrations

There are many collections of science demonstrations, tricks, and magic. Just search the Internet, or look in the science section of libraries. With the *Four Question Strategy* a demonstration can be easily changed into an interesting experiment. Suppose you read the following in a book of science "tricks."

1. Place a small wad of very fine uncoated steel wool (such as used to refinish furniture) in a clean, clear, plastic soft drink bottle.
2. Add 60 ml of warm water, cap the container, and shake the container.
3. Check the container periodically for several hours.
4. The sides of the container will collapse.

Use the *Four Question Strategy* to brainstorm potential variables for experiments with collapsing bottles. Then, select a potential set of variables to investigate.

Question 1: What materials are readily available for conducting experiments on (collapsing bottles)?

Plastic soft drink bottle, liquids, steel wool

Question 2: How do (collapsing bottles) respond?

- ► Bottles collapse.
- ► Bottles change shape.

Question 3: How can I change the set of (collapsing bottle) materials to affect the response?

Plastic Container	Liquid	Steel Wool
Size Brand Age Color Shape	Kind Amount Temperature Method of mixing Strength pH	Amount Kind Location in bottle Coarseness

Question 4: How can I measure or describe the response of (collapsing bottles) to the change?

- Measure the time for the reaction to begin
- Measure the total time for the bottle to collapse
- Describe the amount of collapse
- Describe how the collapse occurred
- Measure the depth the bottle caved in
- Describe the appearance of the contents of the bottle

News Items

From media you can obtain news about product claims, scientific experiments, and medical findings. In every discipline there are news feeds to which you can subscribe. Suppose you read the following news article.

> *Relief City:* Pharmacist, John Pill, reported that sales of antacids increased 30% during the Thanksgiving holidays. When asked how to choose the best antacid, he replied: "Brand is important; brand names are more effective than generic brands." He also said, "Liquids tend to be better than gel caps or solids, especially when taken with water. Carbonated beverages or fruit juices slow the effectiveness."

The article provides information that can be used to brainstorm and identify a potential set of variables to investigate.

Question 1: What materials are readily available for conducting experiments on (antacids)?

Antacids, liquids

Question 2: How do (antacids) respond?

Antacids neutralize acids.

Question 3: How can I change the set of (antacid) materials to affect the response?

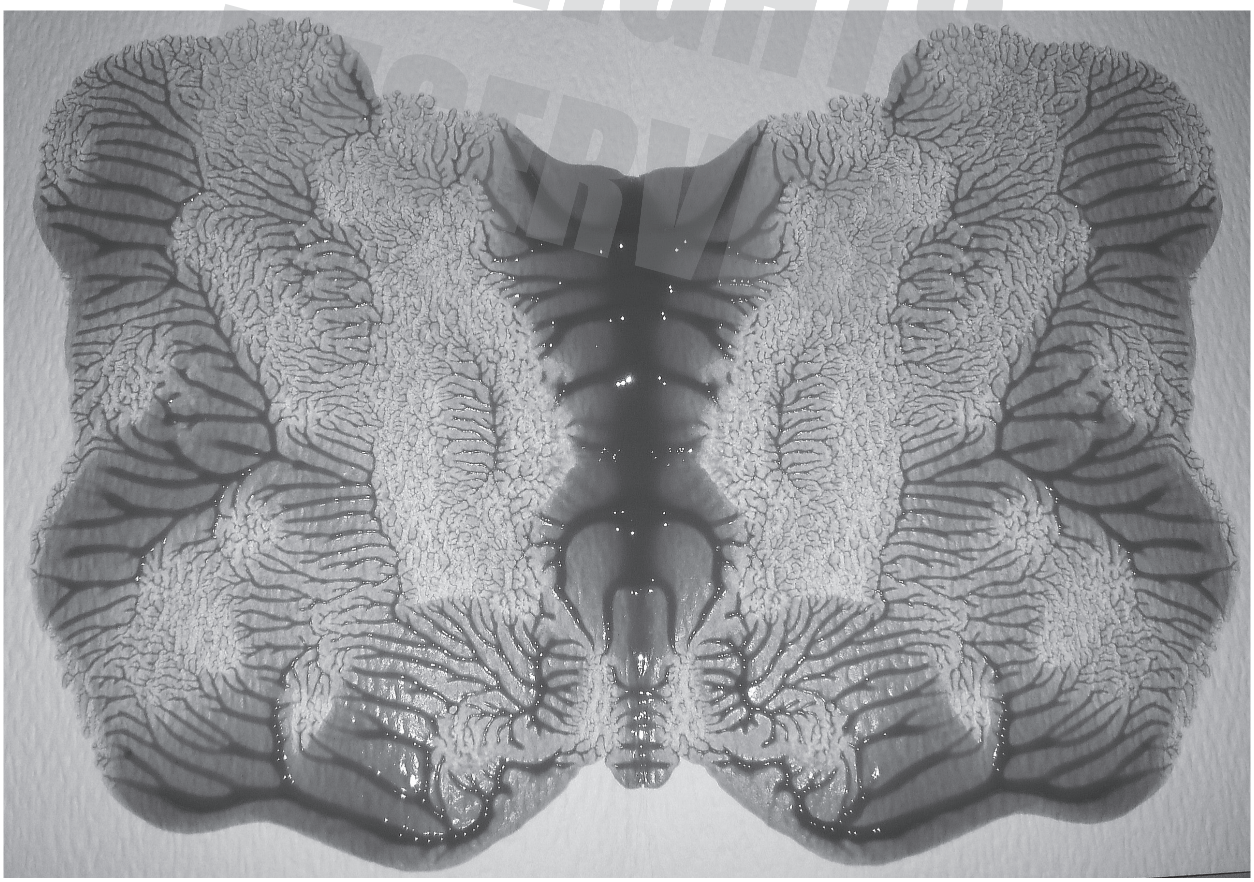
Antacids	Liquid
Brand	Kind
Amount	Amount
Age	Temperature
Chemical makeup	Source
Method of use	pH
Amount of crushing	Agitation
Type	

Question 4: How can I measure or describe the response of (antacids) to the change?

- Measure the pH of the liquid before and after adding the antacid
- Measure the amount of antacid that must be added to the liquid to achieve a neutral pH
- Measure the time required for an antacid to reach the maximum effectiveness
- Measure changes in pH over time to find the best one for quick and long-term relief
- Describe how the antacid disintegrates
- Describe changes in the solution

Experiments

Hands-on experiments with materials enable you to quickly change variables and observe the interactions. Then, you have a better basis for brainstorming. In school you have conducted many experiments, each of which can be the basis of an original experiment. Consider extending experiments you enjoyed, or that produced unanswered questions. Apply your brainstorming skills to one of the items in Box 9-3, *Brainstorming With Scientific Prompts*, or an interesting activity, experiment, demonstration, or reading you found.



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MY WORKSPACE

Name ______________________________ Date __________

PRACTICE
Brainstorming With Scientific Prompts

DIRECTIONS Use the *Four Question Strategy* and the prompts below to brainstorm potential experimental variables.

1. Heaping Water

Materials: Glass, water, coins, food coloring, safety goggles

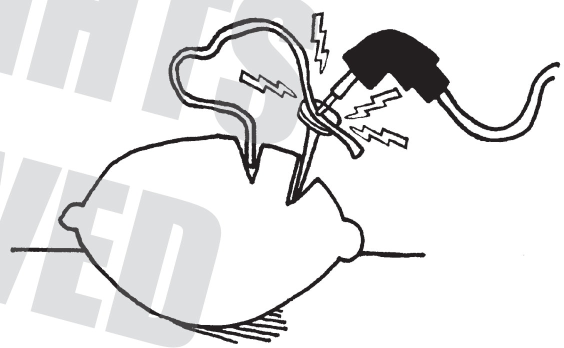
Instructions

1. Fill a glass with water until the water is level with the rim.
2. Add a little food coloring so the water is easier to see.
3. From a distance of about 1 cm slowly drop pennies edgewise into the glass. See how high you can make the water rise without spilling over.

2. An Electric Lemon

Materials: Lemon, galvanized nail, piece of bare copper wire, earphone plug

Instructions



©Kendall Hunt

1. Make the lemon juicy inside by rolling it against a surface several times.
2. Carefully cut two slits in the lemon along one side of the lemon, about 3 cm apart.
3. Put the nail in one slit and the bare copper wire in the other slit. Be sure the nail and wire do not touch inside the lemon.
4. Touch the earphone plug to both the nail and the copper wire at the same time. You should be able to hear static sounds in the earphone, which indicates an electric current is flowing.

3. Wharf City:

Fishing guide, Captain Suzi Sinker, reported that fishing season is in full swing. When asked the best way to fish, she replied, "Time is important; the hour just after sunrise and just before sunset is best." She also said, "Use blue colored artificial bait or 6-inch blue plastic worms. Cast your lures within a foot of the shore."

4. Pulse City:

Mr. I. B. Beat, a self-proclaimed exercise specialist, addressed the Pulse City Health Club. His topic was "Exercise and the Heart." He stated:

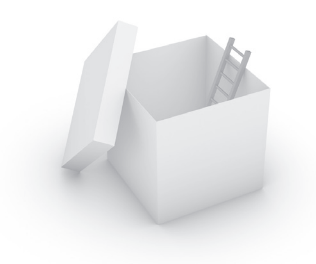
- The faster you walk or jog, the faster your heart will beat.
- Using a step of 10 or 20 cm in height for step aerobics affects the heart rate the same.
- The temperature and humidity of the exercise room do not affect heart rate for a given exercise.
- Women's heart rates do not change as much as men's heart rates for a given exercise.
- The longer you perform an exercise, the faster your heart will beat.
- Sit-ups and jumping jacks increase the heart rate by the same amount.

In the question and answer period that followed, Dr. A. Orta, a heart specialist, challenged several of Mr. Beat's statements.

5. Experiments from Volume 1, *Understanding Scientific Experimentation, Engineering Design, and Mathematical Relationships.*

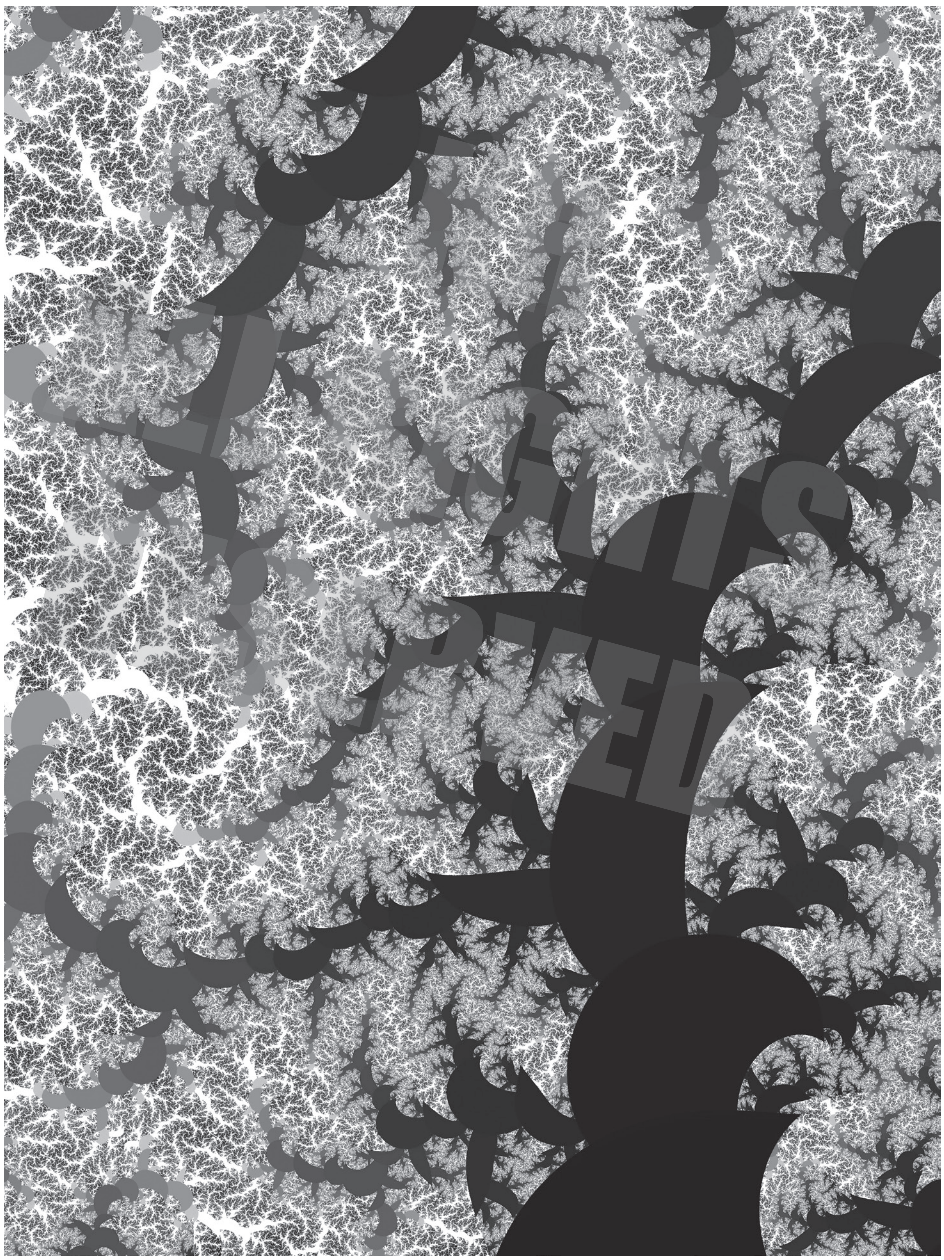
- *Swinging Pendulums*
- *Floating Eggs*
- *Huff, Puff, and Slide*
- *Sudsational Experience*
- *Paper Worms*
- *Stretching to the Max*
- *Fresh Water Pearls and Pearly Environments*

BRAINSTORMING IDEAS



ASSESSING BRAINSTORMED IDEAS

In brainstorming all responses are accepted. The idea is to get as many ideas as possible listed, and to be creative. Do not confine yourself to typical examples. Use criteria, such as the ones in Box 9-4, *Checklist—Brainstormed Ideas,* to review your list and add additional items. Some prompts are easier to brainstorm than others, so you may need to adjust the criteria for poor, average, or excellent.



CHECKLIST
Brainstormed Ideas

	SELF CHECK	PEER CHECK	POINT VALUE	GRADE
QUESTION 1: READILY AVAILABLE MATERIALS (15 POINTS MAXIMUM)				
1. Is the list: *Poor:* 1 example? *Average:* 2–3 examples? *Excellent:* 4+ examples?			10	
2 Does the list represent typical materials available in students' households or the school?			5	
QUESTION 2: RESPONSE OF MATERIALS (15 POINTS MAXIMUM)				
3. Is the list: *Poor:* 1 example? *Average:* 2–3 examples? *Excellent:* 4+ examples?			10	
4. Does the list include a mix of descriptive and measurable responses?			5	
QUESTION 3: WAYS TO VARY MATERIALS (40 POINTS MAXIMUM)				
5. Is the list: *Poor:* 5 or fewer variations *Average:* 6–12 variations? *Excellent:* 13+ variations?			20	
6. Does the list include many different types of variations?			5	
7. Are creative unusual variations included?			5	
QUESTIONS 4: WAYS TO MEASURE OR DISCRIBE RESPONSE (30 POINTS MAXIMUM)				
8. Is the list: *Poor:* 1-2 examples? *Average:* 3–4 examples? *Excellent:* 5+ examples?			20	
9. Does the list include a mix of quantitative (measurable) and qualitative (descriptive) responses?			15	
10. Are creative, unusual responses included?			5	
TOTAL			100	
COMMENTS				

REFINING EXPERIMENTAL VARIABLES

Even though the *Four Question Strategy* enables you to identify potential experimental variables, you need to learn about the variables before deciding on an experimental topic. For example, we identified a potential question about plants, "How does the amount of water affect the number of blossoms on plants?" But, multiple questions remain:

- ➤ How do plants use water? Is there an optimal amount of water? What happens if a plant gets too little or too much water?
- ➤ How are blossoms impacted by water? Is the number of blossoms a valid, dependent variable? What other quantitative or qualitative variables can be used to describe blossoms?
- ➤ What plant could be used in the experiment? How long does it take to produce flowers? What environmental conditions are required for flowering?
- ➤ What are reasonable values for the potential controlled variables?

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By researching the potential variables you can determine if the selected variables are worth investigating. If not, you may learn about another variable, such as the method of watering, that would be a better choice. Remember, a hypothesis is not a wild guess. An understanding of related scientific concepts is needed to construct a strong explanatory hypothesis ("if . . . , then . . . because . . . ") that can guide your experimental design and procedure. In Chapters 11 and 12, we will discuss techniques for researching potential experimental variables.

EXPLORING STEM CONNECTIONS

Many scientific concepts and innovations, as well as art, are related to the *Nature's Art* activity. As before, select among the options, complete a teacher-assignment, or identify a topic you want to explore.

MY WORKSPACE

STEM PERSPECTIVE

Nature's Art

Science

Explaining how the natural world works

1. **Matter and its interactions . . . Links among science . . . and society.** Explore the following connections. Then, use key concepts to explain your experimental findings.

   a. Various artist paints are available, each of which has a different chemical composition and physical properties. How do the chemical composition and properties of gouache differ from other paints? Based upon properties, what other artist paints would you recommend for experiments based upon *Nature's Art*? Justify your recommendations.

   b. Decalcomania is an art technique for making an image by applying paint to a surface and pressing folded, or loose, surfaces together. Although used as early as the sixteenth century in European art, the technique was an important part of Surrealism.

   - What prominent artists have used decalcomania? How did they vary the properties of paints and surfaces to generate different artistic images?
   - Create an original work of art using your artistic talents and knowledge of the properties of paints and surfaces.

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2. **Earth and human activity.** Various earth movements involve changes in viscosity, e.g., mud slides, avalanches, quicksand, and the impact of earthquakes on clay soils. Investigate one of these phenomena and explain how it occurs. Why is it important to understand the phenomena?
3. **Earth's systems.** For numerous examples of fractal patterns on the earth's surface, see the website, *Google Earth Fractals,* developed by Paul Bourke. Investigate one of the images and describe which earth processes led to the fractal pattern.
4. **Matter and its interactions.** Viscosity is a physical property of fluids and is related to the fluid's internal structure. Distinguish between Newtonian and non-Newtonian fluids, and give examples from daily life. For each example explain how the viscosity can be changed.

Technology and Engineering

Modifying the world to meet human needs and wants

5. **Links among engineering, technology, science, and society.** Explore the following connections.
   a. In mechanical devices oils are used as lubricants. Different types of oils are used for various machines.
      - For a car engine what determines the appropriate type of oil?
      - What happens if the viscosity of the oil becomes too thin or too thick?
      - How are changes in viscosity, and other properties, related to the need to change an engine's oil?

   b. Advances in computer technology were important to the development of fractal geometry and underlie its expanded usage today. Investigate why computer technology is a critical element of this mathematical field and its applications throughout STEM (as well as art).

   c. Psychologists have determined that fractal patterns are inherently more interesting to people because of their complexity. How has this knowledge impacted the design of structures, such as shopping malls and gardens?

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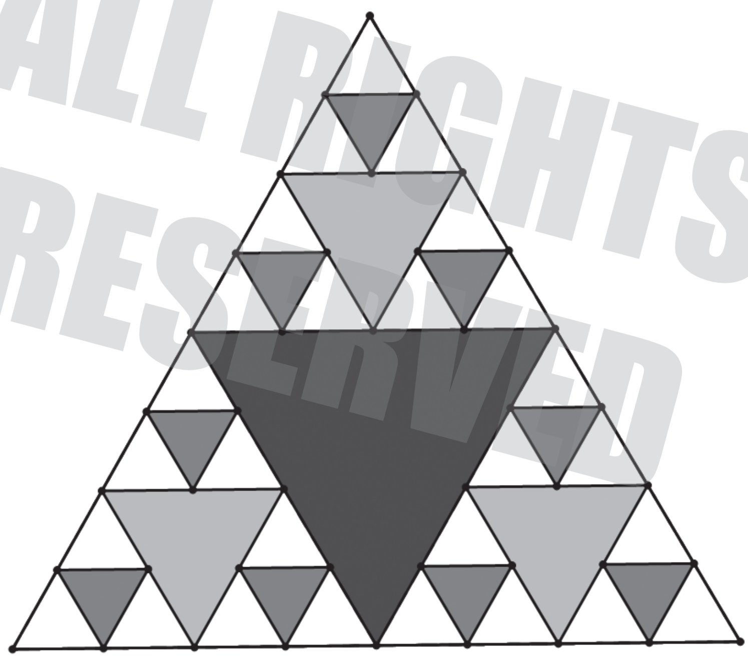
Mathematics

Describing, analyzing, and interpreting patterns and relationships

6. **Scale, proportion, and quantity.** Whereas traditional Euclidean geometry focuses on smooth surfaces, fractal geometry focuses on describing and measuring "rough" edges, surfaces, and solids. Characteristics of fractal images include:
   - Self-similar;
   - Formed by repetitive processes;
   - Look the same at any scale; and
   - Have dimensions which can be mathematically described.

   Use the web to learn what these terms mean. Then, select a natural fractal image and apply the terms to it. The chapter references include websites on fractals.

7. **Geometry.** The figure below is a Siepinski Triangle created using geometry software. The Sierpinski Triangle is a well-known fractal.



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   a. *Extending the pattern.* This fractal began with one large black triangle drawn inside the outlined triangle. Three medium triangles (light grey) were added to the pattern and then nine small triangles (medium grey). If you were to repeat the pattern to add very small triangles, how many of these very small triangles do you predict you will draw?

b. *Congruent triangles.* Measure the sides and angles of a medium triangle (light grey) to determine the type of triangle. Are the medium triangles congruent? How do you know? Are there any other triangles in the figure that are congruent?

c. *Investigating ratios.* Measure the ratio of the length of a side of the large black triangle to the length of a corresponding side in a medium (light grey) triangle. Measure the ratio of the length of the side of one of the medium triangles (light grey) to the length of the corresponding side of one of the small triangles (medium grey). What do you notice about the two ratios you have calculated? How can you use the ratios you found to continue this recursive pattern? Use a different colored pencil or marker to extend the pattern with one more set of triangles.

d. *Looking for a recursive pattern.* Describe a recursive method that when repeated will produce a Sierpinski Triangle.

e. *Examining your artwork.* Do you see a fractal pattern in any of the artwork created for the *Nature's Art* activity? If you see a fractal pattern measure the ratios in corresponding parts of the artwork. What do you notice about the ratios?

8. Using algebra to represent patterns. In Chapter 15 learn about exponential models. Use this information to predict the number of triangles in successive iterations of the Sierpinski Triangle.

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