1 Producing Circuit Boards

INVESTIGATION

2–3 CLASS SESSIONS

ACTIVITY OVERVIEW

NGSS CONNECTIONS

Students analyze and interpret data to compare the initial and final substances when a copper-coated circuit board is etched. This begins a series of activities that reveal patterns of changes indicating that chemical reactions have taken place.

Prepare to teach the unit by reviewing *A Quick Start to Issues and Science*, found at the front of this Teacher Edition. This guide breaks down the resources and equipment needed to teach the unit. It calls out critical tools for planning the unit such as the *NGSS Overview*, the *Phenomena, Driving Questions, and SEPUP Storyline* overview and the *SEPUP Scoring Guides*. For more detailed information on the program as a whole, see the "Issues and Science Program Overview" section of the *Teacher Resources*.

If this is your **first** SEPUP unit, read through "Planning for First-Time Users," found on the last page of the *Quick Start*.

Teacher's Note: This unit assumes that students have already completed the *Issues and Physical Science* CHEMISTRY OF MATERIALS or another unit about the structure and properties of matter, including atoms and molecules as the characteristic particles of elements and compounds, as described in the NGSS dimensions of Performance Expectations MS-PS1-1, MS-PS1-3, and MS-PS1-4.

NGSS CORRELATIONS

Performance Expectations

Working toward MS-PS1-2: Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

Working toward MS-PS1-5: Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.

Disciplinary Core Ideas

MS-PS1.A Structure and Properties of Matter: Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.

MS-PS1.B Chemical Reactions: Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.

Science and Engineering Practices

Analyzing and Interpreting Data: Analyze and interpret data to determine similarities and differences in findings.

Connections to Nature of Science: Scientific Knowledge Is Based on Empirical Evidence: Science knowledge is based upon logical and conceptual connections between evidence and explanations.

Crosscutting Concepts

Patterns: Macroscopic patterns are related to the nature of microscopic and atomic-level structure.

Common Core State Standards—ELA/Literacy

RST.6-8.1: Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

RST.6-8.9: Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.

INVESTIGATIVE PHENOMENA AND SENSEMAKING

Teacher Resources

Investigative Phenomenona, Sensemaking

Sometimes when we make a product, we get side products that we don't want.

Students are introduced to a scenario in which chemicals are used to make a useful product, but they also produce unwanted wastes. Students discuss their ideas about solutions to the waste produced and develop questions that need to be answered before they can fully understand and engage in sensemaking about the problem in the scenario.

WHAT STUDENTS DO

After a brief introduction to the function of a circuit board in a computer and other electronic devices, students mask a circuit board and etch it with an acidic copper-etching solution. They read about the etching process and consider the copper-containing waste it produces.

MATERIALS AND ADVANCE PREPARATION

- *For the teacher*

  1 Visual Aid 1.1, "Keeping a Science Notebook" (optional)
  1 Visual Aid 1.2, "Developing Communication Skills" (optional)
  1 Visual Aid 1.3, "Group Interactions Classroom Rubric" (optional)
  1 Visual Aid 1.4, "Writing a Formal Investigation Report" (optional)
  1 battery harness with light bulb
  1 piece of copper-coated plastic
  1 bottle of etching solution (25,000 ppm copper [II] chloride [$CuCl_2$] dissolved in 1M hydrochloric acid)
  1 pair of plastic forceps
  1 50-mL graduated cylinder
  8 30-mL empty dropper bottles labeled "Used Copper Chloride"
  Driving Questions Board cards and instructions
  * 1 9-volt alkaline battery
  * 1 piece of plastic
  * 1 pair of disposable latex gloves
  * 1 pair of chemical splash goggles
  * 1 capped 1-L bottle labeled "Used Copper Chloride" to store the used copper chloride etching solution generated in the activity
  * 1 beaker with 50 mL of water for initial rinse of circuit boards
  * paper towels
  * wide open glass or plastic container
  * 1 circuit board (optional)

- *For the class*

  1 etching tray
  * 1 waste container labeled "Copper Waste"

- *For each group of four students*

  1 piece of copper-coated plastic
  1 felt-tip permanent marker
  1 piece of steel wool
  1 battery harness with light bulb
  * 1 9-volt alkaline battery

- *For each pair of students*

  * 1 piece of paper

- *For each student*

  1 Student Sheet 1.1, "Three-Level Reading Guide: Etching Circuit Boards"
  1 Student Sheet 1.2, "Guidelines for Safety in the Science Classroom" (see Safety Note below)
  1 Student Sheet 1.3, "Evaluating Group Interactions" (optional)
  * 1 pair of chemical splash goggles

* *not included in kit*

The Driving Questions Board cards and instructions can be found in the front pouch of your printed Teacher Edition or as a download on the "Tools and Resources" page in your online Teacher Portal. Students can find "Keeping a Science Notebook" in Appendix E: Literacy Strategies in the Student Book.

Students can find "Developing Communication Skills" and "Writing a Formal Investigation Report" in Appendix E: Literacy Strategies in the Student Book.

Before beginning the unit, contact your local environmental regulatory office or school safety officer to determine the local guidelines for the disposal of copper-containing compounds.

Avoid beginning this activity the day before a weekend or holiday, as students need to observe the results 24 hours after they begin the investigation.

You may want to acquire a circuit board to share with students during the investigation. Secondhand thrift shops often have inexpensive computers that you can disassemble in front of the class to reveal the circuit board.

After the etching is complete, there will be up to 80 mL of used copper chloride solution per class that you will need to store until it is used in later activities. A capped 1-L bottle works well. Label it "Used Copper Chloride." In preparation for the activities "Recovering Copper" and "Another Approach to Recovering Copper," you will fill and refill the empty 30-mL dropper bottles labeled "Used Copper Chloride" with this solution.

Teacher's Note: When you collect the used copper-etching solution, if less than 400 mL remains due to evaporation, add water so that 400 mL of the solution is available for use in these activities.

Fill a beaker with 50 mL of water. You will dip circuit boards into this for an initial rinse rather than wash any of the copper down the drain. Store this rinse liquid in a container labeled "Copper Waste." See the instructions below for properly disposing of all copper-containing solutions in this unit.

SAFETY NOTE

Develop a classroom safety plan. Review any safety materials provided by your district. Select the safety contract and guidelines that you will use in this course—either developing your own, using those provided by your district, or using Student Sheet 1.2, "Guidelines for Safety in the Science Classroom." Copy the materials for each student. Students can find "Science Safety Guidelines" in Appendix B: Science Safety in the Student Book.

Wear chemical splash goggles during the investigation. The copper chloride etching solution (25,000 parts per million [ppm] copper chloride dissolved in 1M hydrochloric acid) is toxic and corrosive. Avoid contact with skin and eyes. Some people might have an allergic reaction to the copper chloride etching solution and could experience itching and redness in an affected area for a short time. Wash any affected area with water for 2 min. Rinse eyes for 15–30 min, and consult a doctor.

Wear latex gloves while handling the circuit boards that have been placed in the etching solution. After the circuit boards have been in the etching solution overnight, dip them in the beaker of water for an initial rinse to greatly reduce the copper that will be washed down the drain, and then rinse thoroughly under the tap.

DISPOSING OF THE HEAVY METAL WASTE

The solutions used in this activity, and in the "Recovering Copper" and "Another Approach to Recovering Copper" activities, contain copper—a regulated heavy metal—in concentrations ranging from 1 to 100,000 ppm. It is necessary to dispose of all wastes in this unit in accordance with your local regulations. Check with your school district and local Environmental Protection Agency (EPA) office regarding additional regulations in your school. Most communities require wastewater to have a maximum copper concentration of 1–10 ppm. This means that you **must not** pour the solution down the drain.

Teach students that to clean equipment containing copper-containing solutions, they should first pour any solutions into the class waste container. Next, they should rinse the equipment once with water, and place the rinse water into the waste container. Any remaining solution in the tray should be removed with a dropper or pipette and also placed in the waste container. If solution still remains, it should be blotted with a paper towel, and the towel put in the trash. Demonstrate this cleanup procedure for students. Once all the copper has been removed, the equipment can be rinsed and dried.

If appropriate for your local regulations, SEPUP recommends that you pour the waste into an open, flat, glass or plastic container and allow the contents to evaporate to dryness. Then take the waste to a local hazardous-waste-disposal day. Many municipalities sponsor regular disposal days for the public to turn in such waste as old batteries, motor oil, and pesticide containers at a designated location.

TEACHING SUMMARY

GET STARTED

1. Engage students' interest by introducing the issue used to drive the learning in this unit.
   a. Have students read the vignette that opens the unit.
   b. Identify the societal issue that students will explore in the unit.
   c. Begin a Driving Questions Board.

2. Initiate students' sensemaking by eliciting and building on their ideas about the scenario related to circuit boards.

    a. Ask students to briefly discuss in their groups the question, "What are circuit boards, and why are they important?"

    b. Expand the discussion to include the concept of electrical conductivity by asking, "What does a circuit board do? What is it made of?"

    c. Show students a circuit board or photo of a circuit board, and explain that the board has a number of electrical circuits.

    d. Explain that most metals are excellent conductors of electricity, and this is one reason that metals such as copper are used in circuit boards.

DO THE ACTIVITY

3. Introduce or review safety procedures.

    a. Introduce or review general science classroom safety procedures.

    b. Explain the safety considerations for this activity.

4. If you have not previously done so, introduce the SEPUP model for collaborative work.

    a. Introduce SEPUP's 4–2–1 model for model for collaborative work.

    b. Clarify which situations are appropriate for collaboration and which are appropriate for working independently.

    c. (SENSEMAKING) Introduce strategies for effective group interaction.

5. Introduce the use of a science notebook and the preparation of lab reports.

6. Students design a circuit and prepare their circuit boards for etching.

    a. Explain that each group of four students is going to prepare a very simple circuit.

    b. Have students work in pairs to come up with a circuit design on paper.

    c. Have students develop a data table and prepare their circuit boards for etching.

    d. Begin the etching process.

    e. Allow the etching to continue for approximately 24 hours at about 21°C (70°F).

7. The next day, the class observes the results.

    a. Remove each group's circuit board from the etching solution, and rinse it before returning it to the group.

b. Have students observe the etching solution.

c. Students remove the black ink that has masked the remaining copper, test their circuits, and complete their data tables.

8. (LITERACY) Support students' reading comprehension with a Three-Level Reading Guide.

   a. Pass out Student Sheet 1.1, "Three-Level Reading Guide: Etching Circuit Boards."

   b. Have students complete the Student Sheet after they complete the reading.

BUILD UNDERSTANDING

9. Review the results of the investigation, and encourage students' analysis and interpretation of data to provide evidence of a chemical reaction.

   a. Prepare a sample data table, and record in it data from the class.

   b. Point out the "before" and "after" columns, and ask, "Based on your data, do you think the substances after the etching are the same as or different from the substances before the etching?"

   c. Emphasize that the disappearance of one or more starting substances and the appearance of one or more new substances means that a chemical change, or chemical reaction, has taken place.

   d. Use the production of circuit boards as a springboard for students to add to their questions on the Driving Questions Board.

   e. Discuss options for disposal of the waste copper chloride etching solution.

   f. Explain to the class why the amounts of copper contained in these liquids are a problem.

10. Introduce evidence and trade-offs.

   a. If you have not previously done so, introduce the meaning and use of evidence in science.

   b. Distinguish evidence from opinion.

   c. Discuss the sources, quality, and quantity of evidence.

   d. Use Analysis item 3 to introduce the idea that decisions about solutions to scientific and engineering problems often involve trade-offs.

   e. Provide an example of trade-offs.

   f. Develop some examples of trade-offs in students' lives.

   g. Use Analysis item 4 to elicit students' ideas about what might be done to reduce the waste from circuit board production, and use item 5 to elicit students' questions about the use of chemicals.

TEACHING STEPS

GET STARTED

1. Engage students' interest by introducing the issue used to drive the learning in this unit.

   a. Have students read the vignette that opens the unit.

   Anchoring Phenomenon

   The vignette of Janice and her family watching fireworks is related to the front cover photo on the Student Book. After reading the text, have students examine the photo closely and/or read the description of the photo on the back cover. Ask them to generate some questions about the phenomena presented in the vignette. If students are not familiar with the term *phenomenon* (or its plural form, *phenomena*), explain that a *phenomenon* is an observable fact or event. In this unit, the anchoring phenomenon is: Chemical reactions can be used to solve problems but can also create problems. The vignette introduces chemical reactions, and the Procedure will introduce both the creation and the solution of problems by chemical reactions. Students will construct explanations and models based on disciplinary core ideas and crosscutting concepts related to chemical reactions.

   b. Identify the societal issue that students will explore in the unit.

   Defining Issues

   Have students read the description of what they will investigate in this unit (following the vignette) and discuss how the unit may or may not answer their questions. Most importantly, identify the unit issue: How do people use chemical reactions to solve problems? Through their exploration of the production of electronic components, students will investigate how chemical reactions can be used to make useful products and solve problems, while at the same time they generate other problems, including the production of undesirable wastes. Explain this issue in broad terms, and let students know that they will look at a specific example of this issue and how the production or impact of wastes might be reduced.

   c. Begin a Driving Questions Board.

   Driving Questions Board

   In SEPUP, the Driving Questions Board elicits students' initial wonderings about the unit issue and the investigative phenomena. Throughout the unit, the class is prompted to revisit the Driving Questions Board. Ideally, student questions generated at the start of each learning sequence can be condensed through class discussion into a unified driving question. As a scaffold to teachers who are new to this teaching strategy, Driving Questions cards are provided for each learning sequence and can be displayed as the unified driving question.

The driving questions are also identified on the Phenomena, Driving Questions, and SEPUP Storyline overview found in the NGSS and Common Core tab in the back of this Teacher Edition.

2. Initiate students' sensemaking by eliciting and building on their ideas about circuit boards.

   a. Ask students to briefly discuss in their groups the question, "What are circuit boards, and why are they important?"

      Give them just 1–2 min, and then call on a few groups to give their answers. Expect that at least some of them will know that circuit boards are found in electronic devices, including cell phones, computers, and game systems, and that we would not have these devices without this technology.

      Be sure students understand that nearly all modern technology, including cell phones, vehicles, and medical equipment, relies on this technology.

   b. Expand the discussion to include the concept of electrical conductivity by asking, "What does a circuit board do? What is it made of?"

      Expect that a few students will know that circuit boards have something to do with conducting electricity and that they are made of plastic support material with metal circuits on the surface. Circuit boards (point out the picture in the introduction in the Student Book) take up far less space than the mass of wiring that would be needed to run a computer or other electronic device.

   c. Show students a circuit board or photo of a circuit board, and explain that the board has a number of electrical circuits.

      Using a battery and light bulb, demonstrate an electrical circuit. Connect the battery harness to a 9-V battery (connect the red wire to the positive terminal and the black wire to the negative terminal), and hold the ends of the two clips together. This completes the circuit and lights the bulb. Explain that the circuit is conducting electricity from the battery to the light bulb.

      Ask students, "What do you think will happen when we insert a piece of plastic between the clips?" Ask them to predict, by a show of hands, if the light bulb will light. Put a piece of plastic between the clips to demonstrate that certain materials do not conduct electricity. In this case, the plastic interrupts the flow of energy through the circuit, and the bulb does not light. Ask students, "What will happen if we insert a piece of copper-coated plastic between the clips?" Place a piece of copper-coated plastic between the clips to demonstrate that the copper plating on the plastic conducts electricity and creates a circuit that lights the light bulb.

A circuit board directs energy within the computer in a way that is very similar to a network of electrical wires.

d. Explain that most metals are excellent conductors of electricity, and this is one reason that metals such as copper are used in circuit boards.

Explain that the copper on the plastic is the solid form of the element *copper*, which is composed of copper atoms. If you have an actual circuit board, show students the copper metal pathways on the board that conduct electricity.

DO THE ACTIVITY

3. Introduce or review safety procedures.

a. Introduce or review general science classroom safety procedures.

Explain that students are required to know and understand all classroom expectations for safety. If you have previously introduced these procedures, review them as you think necessary.

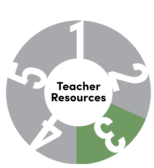
If you have not previously introduced safety, distribute the safety contract and guidelines you are using, and review your expectations for classroom safety. Point out the location of safety gear in the classroom, and review when and how to wear all basic safety gear, such as chemical splash goggles and gloves. Demonstrate how to use emergency safety equipment, including the eye-and-face wash. Provide plenty of time for students to ask questions, and have them sign the safety agreement. Have them take it home for a parent or guardian's signature, and tell them to return the signed agreement before the date you plan to conduct the next laboratory activity.

b. Explain the safety considerations for this activity.

Explain that you will handle the chemicals used in this activity, and that they must wear chemical splash goggles when they observe the laboratory demonstrations. The chemical solution you will use is corrosive and must be handled with caution.

4. If you have not previously done so, introduce the SEPUP model for collaborative work.

a. Introduce SEPUP's 4–2–1 model for collaborative work.



4–2–1 Model

Explain that many activities in this unit use the SEPUP 4–2–1 cooperative learning model. Students work in groups of four or in pairs to share, discuss, compare, and revise their ideas and to conduct investigations and activities. In all cases, each student is responsible for contributing ideas, listening to others, recording and analyzing their results, and monitoring their own learning.

b. Clarify which situations are appropriate for collaboration and which are appropriate for working independently.

In science, collaboration is essential to the development of new ideas and a better understanding of scientific concepts. However, scientists must publish only their own work and must give others credit when they build on their ideas.

c. (SENSEMAKING) Introduce strategies for effective group interaction.

Teacher Resources
Facilitating Group Work

Explain or model what productive group interactions (both agreement and constructive disagreement) look like and sound like. Use Student Sheet 1.3, "Evaluating Group Interactions," and Visual Aid 1.2, "Developing Communication Skills," for this and subsequent activities. For more support on group interaction, use Visual Aid, 1.3, "Group Interactions Classroom Rubric," to evaluate how groups are interacting during the activity.

5. Introduce the use of a science notebook and the preparation of lab reports.

Teacher Resources
Science Notebook

Introduce science notebooks. Explain your expectations for the type and organization of students' notebooks. Keeping a science notebook helps students track data; record their predictions, hypotheses, and questions as they investigate; process ideas; build their scientific writing skills; and write lab reports. "Keeping a Science Notebook" in Appendix E of the Student Book provides suggested guidelines. You may also want to share optional Visual Aid 1.1, "Keeping a Science Notebook," with students.

Teacher Resources
Formal Investigation Report

If you plan to have students prepare laboratory reports, use Visual Aid 1.4, "Writing a Formal Investigation Report," and refer them to "Writing a Formal Investigation Report" in Appendix E of the Student Book.

6. Students design a circuit and prepare their circuit boards for etching.

a. Explain that each group of four students is going to prepare a very simple circuit.

Display the small pieces of copper-coated plastic, and explain that students will use these to make their own small circuit boards. The purpose of a circuit board is to provide pathways to conduct electricity to the components of a computer. The first few steps of Part A of the Procedure ask students to plan the circuit they will etch on their circuit boards. The circuits students design should conduct electricity from one end of a board to another. Be sure students understand that they will need to design a continuous copper path in order for it to conduct electricity from one side of the board to another. In this case, they will only need to design a path and will not have to consider the number of devices that will receive electricity through it.

b. Have students work in pairs to come up with a circuit design on paper.

In pairs, students should come up with a circuit board design that will conduct electricity. It is important to note that for the circuit board to function, all that is required is a single continuous path. Commercial circuit boards usually have many paths, since several are needed to direct electricity to more than two computer components. Make sure that the copper paths that students design touch the edge of the copper-coated plastic piece in at least two places so that the clips on the battery harness can contact the copper path when students are testing the circuit. Ask the two pairs in a group to share their designs and decide which they will etch onto the copper-coated piece of plastic.

c. Have students develop a data table and prepare their circuit boards for etching.

Support students as necessary in developing a data table similar to this one (also shown in the Sample Student Response provided in Build Understanding):

Substance	Properties before etching	Properties after etching
Copper	*Reddish-brown solid metal*	*Is no longer on the board except where there was ink*
Copper chloride etching solution	*Blue liquid*	*Green-blue liquid*

Emphasize the need to clean the copper-coated plastic to remove any surface dirt and other impurities that might interfere with the etching. Be sure that students handle the copper-coated plastic piece only at the edges because the oil from human hands will prevent the copper from being etched. Make sure students understand that the black ink will protect the copper that it is covering. Their black lines should be about 1 millimeter (mm) wide. After the boards are soaked overnight in etching solution, the only copper left on the boards will be under the ink.

d. Begin the etching process.

Pour 80 mL of the etching solution into an etching tray. Each tray can hold up to eight boards, enough for one class. Draw students' attention to the copper chloride etching solution in the bottle and in the trays. Ask students to make observations about the solution before the etching begins and to record their observations in their science notebooks.

Once groups have prepared their boards, have all students put on chemical splash goggles before they bring you the prepared boards for etching. Have one or two groups at a time bring you the prepared boards.

Students should observe as you use plastic forceps to carefully place their copper-coated plastic piece flat in the etching tray with the design facing up. Be sure that the boards do not touch. The circuit boards should soak in this solution overnight.

Teacher's Note: Do not soak the boards for more than 24 hours as this might result in removal of all the copper.

e. Allow the etching to continue for approximately 24 hours at about 21°C (70°F).

The etching process is temperature dependent. When the room temperature is about 21°C (70°F), leaving the circuit boards in the etching solution overnight should produce good results. If room temperature is significantly less than 21°C (70°F), more than 24 hours may be needed to complete the etching. If the temperature is greater than 21°C (70°F), the boards may need to be removed from the etching solution before 24 hours have elapsed.

To promote even etching, mix the etching solution several times during the etching process by gently shaking the etching tray.

7. The next day, the class observes the results.

a. Remove each group's circuit board from the etching solution, and rinse it before returning it to the group..

Fill a beaker with 50 mL of water. As the class watches, put on gloves and use forceps to remove the circuit boards from the copper chloride etching solution. Blot the edge of each board on a paper towel, and then swirl it in the beaker of water for a thorough first rinse. This will minimize the copper entering the drain. Run the boards under the tap for a final rinse.

b. Have students observe the etching solution.

Draw students' attention to the used copper chloride etching solution in the tray, and prompt them to compare their observations now to their observations of the etching solution yesterday. Be sure they notice that the solution has turned green.

c. Students remove the black ink that has masked the remaining copper, test their circuits, and complete their data tables.

Have students follow Part B of the Procedure in the Student Book. While you circulate, have them compare what happens when both clips are attached to the metal circuit (the bulb should light due to the compete circuit), and when one clip is attached to the plastic only (the bulb will not light). Students should complete their data tables. A sample response is shown in Build Understanding.

8. (LITERACY) Support students' reading comprehension with a Three-Level Reading Guide.

   a. Pass out Student Sheet 1.1, "Three-Level Reading Guide: Etching Circuit Boards."

      You might wish to review each statement and clarify it as needed. The Reading Guide presents students with statements that require three levels of understanding: literal, interpretive, and applied. Students are asked to determine which statements are supported by the text. Explain that the statements under number 3 (applied) do not always have a single correct response. Students may interpret information differently and agree or disagree with each statement. Regardless of their perspectives, it is important for students to be able to explain and support their positions.

      Three-Level Reading Guide

      Note that this strategy is not asking students to discern which statements are true or false, as many of them are true. It is asking them to determine which statements are portrayed in the content of the reading.

      Each statement on the Student Sheet provides evidence for students to cite specific text for the Level 1 items, and relevant text and their reasoning for the Level 2 and Level 3 items.

   b. Have students complete the Student Sheet after they complete the reading.

      Possible responses to the Reading Guide are shown at the end of this activity. Clarifying notes are provided for the statements that do not accurately represent the content in the reading.

BUILD UNDERSTANDING

9. Review the results of the investigation, and encourage students' analysis and interpretation of data to provide evidence of a chemical reaction.

   a. Prepare a sample data table, and record in it data from the class.

      A sample student data table is shown below.

PROCEDURE STEPS 4–8 SAMPLE STUDENT RESPONSE

PROPERTIES BEFORE AND AFTER ETCHING

Substance	Properties before etching	Properties after etching
Copper	*Reddish-brown solid metal*	*Is no longer on the board except where there was ink*
Copper chloride etching solution	*Blue liquid*	*Green-blue liquid*

b. Point out the "before" and "after" columns, and ask, "Based on your data, do you think the substances after the etching are the same as or different from those before the etching?"

Students should describe changes in the properties of the copper coating on the board and in the etching solution. For the copper, they should be able to say that some of the original copper metal is no longer there. They might think that it has reacted to form something else, or they might say that it dissolved. To distinguish between these options, have them explain what happened to the solution, which should now be a greener shade than the original etching solution. Help them realize that the evidence suggests that the original orange-brown solid copper metal is no longer present, but a new substance with a new property—a greenish color—has been produced. The result is that some of the solid copper metal is removed from the surface of the circuit board and is in the copper chloride etching solution as a greenish copper compound. As a result, the used copper chloride solution has a higher concentration of copper than the original solution.

c. Emphasize that the disappearance of one or more starting substances and the appearance of one or more new substances means that a chemical change, or chemical reaction, has taken place.

Emphasize that changes in properties indicate that starting substances have changed and new substances have formed. Evidence for change of the starting substance is the disappearance of the reddish-brown solid copper. Evidence for production of a new substance is the change in color of the solution. This provides evidence that a chemical change, or chemical reaction, took place. Chemical reactions and chemical changes are formally defined in the Student Book in the "Evidence of Chemical Change" activity.

Introduce the idea that the pattern of change at the observable level during a chemical reaction reflects patterns of change at the atomic/ molecular (particle) level, which students will explore throughout the unit. Students will learn more about the atomic/molecular-level changes that lead to patterns of reactivity in subsequent activities. For information about the chemical reaction that occurs, see the Background Information.

d. Use the production of circuit boards as a springboard for students to add to their questions on the Driving Questions Board.

Display the Anchor Phenomenon Card: Chemical reactions can be used to solve problems, but can also create problems. Ask students to connect this phenomenon to the production of circuit boards. Elicit students' additional questions about circuit board production and other uses of chemicals that might solve and/or create problems. Students are likely to include questions related to the driving question for this learning sequence: What are the wastes from producing circuit boards, and is there anything we can do about them? (In this case, the chemical reaction is the copper etching reaction.)

Copper's characteristic chemical properties are used for two key steps in preparing circuit boards: isolating copper metal from copper ore and then etching the metal coating on the circuit board to produce pathways.

Have students compare the process they used with the process for etching circuit boards in the reading. Explain that the etching solution used commercially is somewhat different, but the process is very similar.

e. Discuss options for disposal of the waste copper chloride etching solution.

Ask, "What should be done with the used copper chloride etching solution?" Their answers may include dumping the solution down the drain, or diluting it with water and dumping it. However, based on the reading, others might realize that this is a risky option.

The goal at this point is not for students to arrive at a solution; rather, it is for them to understand that getting rid of the used copper chloride solution is not as easy as dumping it down the drain. Copper-containing liquid and solid wastes from copper plating, etching, and rinsing make up a lot of the waste generated by circuit board manufacturers. Students will return to this issue and develop a solution in the "Recovering Copper" and "Another Approach to Recovering Copper" activities. Connect this specific phenomenon—the production of useful circuit boards generates undesirable chemical waste—to the more general anchoring phenomenon of this unit: Chemical reactions can be used to solve problems, but they can also create problems.

If students have completed the *Issues and Physical Science* CHEMISTRY OF MATERIALS unit, they should be familiar with product life cycles and the importance of evaluating the impact of a product from the initial phase of obtaining resources to producing the product to disposal of the product. The waste produced during the manufacture of circuit boards is part of the life cycle of the circuit board.

f. Explain to the class why the amounts of copper contained in these liquids are a problem.

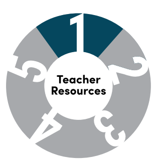
If copper-containing wastes are released into the environment by dumping them or pouring them down a drain, they can get into the water supply and affect drinking water. They can accumulate in water supplies and harm humans and animals. By doing the activity, students, like circuit board manufacturers, have created toxic waste. Explain that *toxic* means poisonous or harmful to living things. Materials that are toxic are also referred to as hazardous. Because of the potential for the copper in the waste to accumulate in water systems, not all disposal methods are safe. Let students know that they will explore different methods of handling the waste, how those methods affect the environment, and how circuit board manufacturers might safely reuse the waste.

For more information on the toxic nature of copper, see the Background Information. Tell students that one of the main themes of this unit is the question of how to handle the waste that results from the manufacture of all the electronic products we use every day.

10. Introduce evidence and trade-offs.

    a. If you have not previously done so, introduce the meaning and use of evidence in science.

    Analysis item 2 provides an opportunity to introduce the definition of *evidence* provided in the Student Book. Explain that scientists collect information (data) with various tools and strategies, including observation and experimentation. Science knowledge is based on making logical and conceptual connections between this evidence and explanations. Like scientists, students will use evidence to develop explanations, construct scientific arguments, and recommend solutions to problems.



Evidence and Trade-Offs

    b. Distinguish evidence from opinion.

    Explain that *evidence* is information that supports a claim. In contrast, an *opinion* is the view someone takes about a certain issue based on their own judgment. An opinion might not be based on evidence. An informed opinion might be based on evidence; however, another person may have a different opinion based on the same evidence. To distinguish evidence from opinion in science, it is helpful to determine if a statement describes information gathered through reliable and appropriate procedures and is likely to be reproducible. The question is: Could someone else gather similar information under similar circumstances? If the answer is yes, the statement is not opinion and is likely to be evidence.

    c. Discuss the sources, quality, and quantity of evidence.

    When evaluating evidence, scientists consider the source, quality, and quantity of the evidence available. Biased or insufficient evidence compromises the validity of scientific conclusions. Scientific conclusions should logically follow the evidence collected and should not be overly generalized beyond the context of the investigation.

The criteria for quality evidence may vary among the scientific disciplines. However, evidence is generally considered of higher quality if it is obtained through systematic investigation and is reproducible, meaning that another investigation under the same set of circumstances would obtain similar data.

Criteria for quantity also vary but might include the sample size or number of trials in an experiment, the number of observations that support a conclusion, or the availability of multiple studies or multiple lines of evidence that lead to the same conclusion.

d. Use Analysis item 3 to introduce the idea that decisions about solutions to scientific and engineering problems often involve trade-offs.

This unit includes issues that relate to science and/or engineering and that may lead to decisions about the best solutions or designs for solving problems. One goal of this curriculum is to teach students that decisions about possible solutions often involve trade-offs and that identifying trade-offs involves analyzing evidence.

Explain to students that in this unit, they will make several decisions about choosing materials. In this activity, students begin to consider trade-offs related to producing products such as circuit boards for electronic devices. In a decision involving trade-offs, something positive (or desirable) is given up to gain another positive (or desirable) outcome. Since many decisions involve trade-offs, students should understand that a perfect choice is often not possible. For example, a perfect solution would be to produce desirable products with no negative impact on the environment, but this is not really possible. It is possible, however, to recognize and analyze the trade-offs associated with each decision and to use that analysis to help identify the best option.

Responses to Analysis item 3 will likely vary and might include the following: Let the liquid evaporate and throw the solid part in the garbage; pour it down the drain; contact a local waste agency and ask them what to do with it; find someone else who might be able to use it; and recycle it for future classes. Accept all responses for now, and explain that they will return to their ideas later in the unit.

e. Provide an example of trade-offs.

For example, when asked, “Paper or plastic?” at a store checkout counter, most shoppers make the choice quickly. But there are several trade-offs attached to choosing paper or plastic. A shopper who chooses paper over plastic may do so to avoid generating plastic waste. In requesting the paper bag, though, they are contributing to other environmental problems, such as increased water and energy use, and the higher amounts of solid waste and CO_2 emissions associated with making paper bags. Neither choice is ideal, and both choices have a downside. In fact, many places now charge for bags, encouraging shoppers to bring reusable bags. Identifying the trade-offs helps clarify the reasoning that is being applied to make a decision.

f. Develop some examples of trade-offs in students’ lives.

To further explore trade-offs, brainstorm with the class a list of decisions they make every day that involve trade-offs. Choose one, and talk through the associated trade-offs of deciding one way or another. This practice will familiarize students with ways to identify and consider trade-offs in this and subsequent activities.

g. Use Analysis item 4 to elicit students’ ideas about what might be done to reduce the waste from circuit board production, and use item 5 to elicit students’ questions about the use of chemicals.

For Analysis item 4, any answer that involves a stage in the life cycle of a circuit board, or even the device it will ultimately be in, should be considered. Encourage students to be creative. Their ideas might include the following:

- Recycle the used copper chloride solution.
- Find a less toxic etching solution to use instead.
- Reduce the demand for circuit boards.
- Find a way to recycle circuit boards that are no longer in use.
- Find a way to dispose of the copper chloride waste solution that completely rids it of any toxic contents.
- Increase legal penalties for producing toxic waste.

For Analysis item 5, elicit students’ questions about how and why chemicals are used, their safety, and what might be done about the undesired products of their use. Connect the specific scenario in this unit—the production of both a useful product (circuit boards) and undesired wastes—to other uses of chemicals that are of interest to students.

STRATEGIES FOR TEACHING DIVERSE LEARNERS

Differentiated Instruction

Below are suggestions for differentiating instruction and assessment in this activity for diverse learners in your classroom:

- Students with learning disabilities: Allow students to provide their answers orally before they attempt to transfer their ideas to paper.
- English learners: Introduce a class word wall for the CHEMICAL REACTIONS unit as a visual reminder of the new key scientific terms and to make these words easily accessible. Begin constructing the word wall for this activity, and continue to add terms throughout the unit. Consider adding an explanatory picture or diagram for some (or all) of the terms.
- Academically gifted students: Have students do additional research on the use of copper and other metals in the production of electronic components.

These icons, ● ● ●, indicate opportunities to formatively assess students' proficiency with the three dimensions: ● = SEP, ● = DCI, ● = CCC.

SAMPLE RESPONSES TO ANALYSIS

1. Describe the changes that occurred to the properties of the following during the etching process:

   a. Your circuit board

   Students' responses will likely vary. A sample response is shown here:

   Some of the copper came off the copper-coated side of the circuit board after it was placed in the copper chloride etching solution. After etching, the circuit board had a copper pattern on it underneath where we drew with the marker.

   b. The copper chloride etching solution

   Originally, the copper chloride was blue. After etching, the solution was green.

● ● 2. **Evidence** is factual information or data that supports or refutes a claim. How does your answer to item 1 provide evidence about whether the starting and final substances changed during the etching process?

   Substances can be identified by their properties. The changes in properties of the substances provide evidence that the substances have changed. In this activity, the presence of the copper-colored solid metal and the color of the etching solution were the properties that changed.

3. **Revisit the issue:** The etching process produced waste etching solution.

   a. What do you think should be done with this waste?

   Students' responses will likely vary. A sample response is shown here:

   I think the copper should be diluted with a lot of water and poured down the drain.

b. A **trade-off** is a desirable outcome given up to gain another desirable outcome. What is one trade-off of your suggestion in 3a?

Students' responses will likely vary. A sample response is shown here:

A trade-off might be that the copper waste would be in the water and might get in drinking water. So the water wouldn't be pure, but the copper would be more spread out and not as harmful.

4. **Revisit the issue:** Etching circuit boards creates large amounts of copper-containing toxic waste. What ways can you think of to reduce the amount of copper-containing waste produced?

   Students' responses will likely vary. A sample response is shown here:

   I think if circuit boards were recycled, that would reduce copper-containing waste because fewer circuit boards would need to be made from scratch.

5. **Revisit the issue:** The phenomena you are investigating relate to what happens when chemicals are used to make products and solve problems. Think about what you know about how chemicals are used to produce circuit boards and other products. What questions do you have about chemicals and the wastes from using them?

   Students' responses will likely vary. A sample response is shown here.

   I have questions about why we use chemicals so much, and whether they are causing pollution. I wonder if all chemicals are dangerous, or if some are safer than others. I know that there are some old chemicals in our garage, and I wonder how we are supposed to get rid of them.

REVISIT THE GUIDING QUESTION

What happens when chemical processes are used to produce electronic devices?

Chemical processes are used to etch (remove) copper from the boards, leaving behind a conductive circuit. This produces waste copper solutions.

ACTIVITY RESOURCES

KEY VOCABULARY

circuit board

etch

evidence

trade-off

BACKGROUND INFORMATION

CIRCUIT BOARD MANUFACTURING

A circuit board is a collection of circuitry in multiple layers. It is an essential component of computers and other electronic devices, such as cell phones. There are several methods of producing circuit boards that either add copper to the board in a specific pattern (additive process) or subtract the unwanted copper, leaving the desired copper path on the board (subtractive process). In this activity, students work through a simulation of the subtractive process using an etching-resistant ink to protect the copper they want to remain on the board.

The first step in producing a circuit board involves coating both surfaces of a plastic sheet with copper foil. Holes are then drilled through the board to attach electronic components to the board and to provide a conductive circuit from one layer of the board to another. Once the holes are drilled, the board is scrubbed and rinsed to remove the fine copper dust left by the drill. Rinse water from the factory scrubber unit can be a significant source of copper-containing waste. The copper can be recycled, however, if it is removed and recovered from the rinse water by filtration or centrifugation.

In the additive process, after the scrubbing, the board is plated with another layer of copper, producing more copper-containing waste in a process called *electroplating*. A photographic process creates an image of everything except the designed circuit on the copper foil; this is known as the *photoresist*. The photoresist is then placed over the board, covering all but the circuit design. Copper is next plated onto the exposed part of the board, creating the circuit design. It is then covered in a layer of tin to protect the copper during further processing.

In the subtractive process modeled in this activity, a mask of ink covers areas of the metal plate that will not be etched off. The exposed copper not masked with resistant ink is etched off with chemical etching solutions. The solutions and rinse water from electroplating and etching are additional major sources of copper-containing waste in the circuit board industry. Rinse water and other rinse solutions usually make up the largest copper waste streams by volume, but they are generally lower in concentration than other waste solutions produced during circuit board manufacture.

In this activity, copper (II) chloride etching solution reacts with copper metal on the plastic piece, as shown in the equation below.

$$Cu + CuCl_2 \rightarrow 2\ CuCl\ (s)$$

The reaction of copper metal on the plastic piece with copper (II) chloride in the etching solution is an example of an oxidation–reduction reaction. The solid metallic copper loses an electron in solution to form a Cu^+ ion, and the Cu^{2+} ion (in the copper chloride etching solution) gains this electron to form a Cu^+ ion.

Both of these Cu^{+} ions combine with the chloride ions in solution to form an insoluble white precipitate of copper (I) chloride.

Teacher's Note: The copper chloride etching solution supplied in the kit contains 2 M hydrochloric acid. The HCl prevents a precipitate from forming, making the etching solution easier to work with throughout the unit.

COPPER

Copper and some other metals, such as lead and mercury, are part of a group of industrial pollutants often referred to as heavy metals. Ingesting large amounts of heavy metals can impair a person's or animal's mental abilities and cause certain types of cancer, kidney problems, and even death. Waste that contains large amounts of compounds composed of heavy metals is considered toxic. Almost all substances have the potential to be toxic. For example, even table salt (sodium chloride) can be toxic if taken in a large enough quantity, but because it is such a large quantity, salt is not considered very toxic. Other materials, such as cyanide, are considered highly toxic because only a small amount can cause death. Heavy metals are considered very toxic. The EPA recommends that public drinking water contain less than 1.3 milligrams of copper per liter of water (1.3 mg/L). While the specific toxicity of copper depends on its form and the species, copper chloride has an LD50 (meaning that 50% of a given population would die of a lethal dose) in rats at doses of 140 mg/kg of body weight. (Compare this to table sugar, which has an LD50 in rats at doses of 20,000 mg/kg.) It is important to note that despite such risks, human beings do need a small amount of certain metals, such as copper, in order to live.

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Name____ Date___________

STUDENT SHEET 1.1

THREE-LEVEL READING GUIDE: ETCHING CIRCUIT BOARDS

1. Put an X next to the statements below that you believe agree with what the reading says. Sometimes the exact words found in the reading are used. At other times, other words may be used to communicate the same meaning.

   Under each statement, either quote the text from the reading that is the same or agrees with the statement OR explain why the statement is incorrect.

   ________ a. The waste from etching circuit boards is toxic.

   ________ b. Government agencies have stopped the production of toxic waste from computer manufacturing.

   ________ c. At each stage in the life of a product, from making it to using it to disposing of it, waste is produced.

   ________ d. Etching involves a chemical reaction.

2. Put an X next to the statements below that you believe represent the intended meaning of the reading. Under each statement, quote the text from the reading that supports or contradicts the statement.

   ________ a. Copper can have many effects on human health.

   ________ b. The raw materials needed to manufacture circuit boards can be used in their natural form.

Name____ Date___________

STUDENT SHEET 1.1 *(continued)*

THREE-LEVEL READING GUIDE: ETCHING CIRCUIT BOARDS

_______ c. In circuit board etching, one of the starting substances is copper chloride solution.

_______ d. The toxic effects of copper are not yet known.

_______ e. The etching solution is different after etching than it was before etching.

3. Put an X next to the statements below that you agree with, and under each statement support your choices with ideas from the reading and from your own knowledge and experience.

_______ a. The toxic wastes generated from etching circuit boards are worth the hazards they pose to humans.

_______ b. People should be willing to pay more for products that are manufactured in ways that do less damage to the environment.

_______ c. It is better to use recycled copper chloride etching solution for making circuit boards than it is to mine new copper ore from Earth's surface.

Name____ Date__________

STUDENT SHEET 1.2

GUIDELINES FOR SAFETY IN THE SCIENCE CLASSROOM

Before the Investigation

- Listen carefully to your teacher's instructions, and follow any steps recommended when preparing for the activity.
- Use only those materials or chemicals needed for the investigation.
- Know the location of emergency equipment, such as a fire extinguisher, fire blanket, and eyewash station.
- Tie back or remove dangling or bulky items, such as long hair, jewelry, sleeves, jackets, and bags. Do not wear open-toed shoes in the science lab.
- Tell your teacher if you wear contact lenses, or have allergies, injuries, or any medical conditions that may affect your ability to perform the lab safely.
- Make sure both the work surface and floor in your work area are clear of books, backpacks, purses, or any other unnecessary materials.

During the Investigation

- Follow all written and spoken instructions.
- Read the activity procedure carefully.
- Don't eat, drink, chew gum, or apply cosmetics in the lab area.
- Wear chemical splash goggles when using chemicals.
- Do not wear contact lenses when using chemicals. If your doctor says you must wear them, notify your teacher before conducting any activity that involves chemicals.
- Read all labels on chemical bottles, and be sure you are using the correct chemical.
- Keep all chemical containers closed when not in use.
- Do not touch, taste, or smell any chemical unless you are instructed to do so by your teacher.
- Mix chemicals only as directed.
- Use caution when working with hot plates, hot liquids, and electrical equipment.
- Follow all directions when working with live organisms or microbial cultures.
- Be mature and cautious, and don't engage in horseplay.
- Report any accidents to your teacher immediately.
- Not sure what to do? Ask!

After the Investigation

- Dispose of all materials as instructed by your teacher.
- Clean up your work area, wash out trays, replace bottle caps securely, and follow any special instructions.
- Return equipment to its proper place.

I, ____________________________, have read the Guidelines for Safety and have discussed them in my classroom. I agree to follow all these rules during science investigations.

____ ____________________
Student Signature Date

____ ____________________
Parent/Guardian Signature Date

In case of accident or emergency, contact:

____ (_____)______________
Name Phone Number

____ (_____)______________
Name Phone Number

Please list any known allergies or health problems: ______________________________________

____

Name____ Date____________

STUDENT SHEET 1.3

EVALUATING GROUP INTERACTIONS

Procedure

Use the following table to rate your group's performance.
Give evidence for your scores by answering questions 1 and 2.

GROUP INTERACTIONS	SCORE
Group stays on task and mananges time efficiently	
Group shares opportunities	

1. Give some examples of how your group stayed on task and managed the time efficiently.

2. Give some examples of how your group shared opportunities to contribute to the activity. Your examples might include times when you or your group members respected and treated others with courtesy, helped one another do the work, shared the work (not having one person do all the work alone), or stayed open-minded and willing to compromise.

Name *Sample student response* Date

STUDENT SHEET 1.1

THREE-LEVEL READING GUIDE: ETCHING CIRCUIT BOARDS

1. Put an X next to the statements below that you believe agree with what the reading says. Sometimes the exact words found in the reading are used. At other times, other words may be used to communicate the same meaning.

   Under each statement, either quote the text from the reading that is the same or agrees with the statement OR explain why the statement is incorrect.

   X a. The waste from etching circuit boards is toxic.

   "But in much larger amounts, copper and other metals can be toxic."

   ____ b. Government agencies have stopped the production of toxic waste from computer manufacturing.

   Production is still occurring: "But manufacturing products that people want, like circuit boards, still produces toxic waste."

   X c. At each stage in the life of a product, from making it to using it to disposing of it, waste is produced.

   "Each step in the process from raw materials to finished circuit board creates some form of waste."

   X d. Etching involves a chemical reaction.

   "A chemical process etches a copper circuit on a piece of plastic."

2. Put an X next to the statements below that you believe represent the intended meaning of the reading. Under each statement, quote the text from the reading that supports or contradicts the statement.

   X a. Copper can have many effects on human health.

   "Eating or drinking even higher amounts of copper can cause liver and kidney damage. Inhaling copper dust over long periods of time can cause dizziness, headaches, diarrhea, and irritation of the nose, mouth, and eyes."

   ____ b. The raw materials needed to manufacture circuit boards can be used in their natural form.

   No, the copper must first be isolated from the ore: "After ore containing copper is mined, the copper must be extracted from the ore."

Name *Sample student response* Date

STUDENT SHEET 1.1 *(continued)*

THREE-LEVEL READING GUIDE: ETCHING CIRCUIT BOARDS

X c. In circuit board etching, one of the starting substances is copper chloride solution.

"To make your circuit board, you used a process very similar to that used in the circuit board industry. This process is based on the chemical characteristics of copper. A chemical process etches a copper circuit on a piece of plastic. To ***etch*** *a copper circuit board means to use a corrosive solution to create a circuit for the flow of electricity."*

____ d. The toxic effects of copper are not yet known.

They are known: "Eating or drinking even higher amounts of copper can cause liver and kidney damage. Inhaling copper dust over long periods of time can cause dizziness, headaches, diarrhea, and irritation of the nose, mouth, and eyes."

X e. The etching solution is different after etching than it was before etching.

"As you observed in this activity, after a circuit board is etched, the used etching solution and rinse water contain copper in a different form than you began with."

3. Put an X next to the statements below that you agree with, and under each statement support your choices with ideas from the reading and from your own knowledge and experience.

X a. The toxic wastes generated from etching circuit boards are worth the hazards they pose to humans.

It seems like it would be impossible to do without etching circuit boards, because the reading says they are in all electronic devices, and people use technology in so many ways.

____ b. People should be willing to pay more for products that are manufactured in ways that do less damage to the environment.

I'm not sure about this one, because I don't know if there are better ways to manufacture products.

X c. It is better to use recycled copper chloride etching solution for making circuit boards than it is to mine new copper ore from Earth's surface.

I think it's always better to use recycled material than new material, although the reading doesn't say whether that is possible.

VISUAL AID 1.1

KEEPING A SCIENCE NOTEBOOK

- Write in blue or black ink.
- Cross out mistakes or changes with a single line. Do not erase or use correction fluid.
- Write neatly.
- Record the date of each entry.
- For each new investigation, record the following:

Title:

Purpose:
Rewrite the guiding question in your own words.
Hint: What are you going to do? Why are you going to do it?

Materials:
Note: Place a "√" here after you have collected the necessary materials.

Procedure:
Write down whether you understand the procedure.

Data:
Record your observations, measurements, and other lab work.
Include relevant data tables, charts, diagrams, and/or graphs.
Be sure to label your work clearly.

- Sometimes, you may want to:

Make inferences or draw conclusions based on the data:
I think my results mean …
I think that this happened because …

Reflect on how the activity worked in your group:
This is what went well … This is what did not go well …
If I could do this activity again, I would …

Think about what questions you still have:
I wonder if …
I'm not sure about …

Keep track of new vocabulary and ideas:
A key word I learned is …
I would like to find out what happens when …
One interesting thing to do would be to …

KEEPING A SCIENCE NOTEBOOK

The following is a guide to help you conduct investigations. However, depending on the investigation, you may not always use all of steps below or use them in the same order each time.

Title: Choose a title that describes the investigation.

Purpose: What am I looking for? Write what you are trying to find out in the form of a question.

Background: What do I know about the topic? Write a summary of background information you have on the topic that led to the purpose for the investigation.

Hypothesis: Write a statement about what you predict you will see as data in the experiment to answer the question in the "Purpose" and why you are making that prediction.

Experimental Design: How will you answer the question?
Describe the methods you will use (what you will do) to answer the question.
Use short numbered steps that are easy to follow in the lab.
Make a list of the materials you will use to answer the question.
Outline the variables:

- Independent variable (what is being changed)
- Dependent variable (what is being measured)
- Control (what will be used as baseline comparison)

Data: What did you find?
Record observations and measurements.
Use a data table where appropriate to organize the data.
Don't forget to include proper units and clear labels.

At the end of your investigation:

Make inferences or draw conclusions about the data:
I think my results mean …
I think this happened because …

Think about any errors that occurred during the investigation:
What did not go as planned?
What steps were hard to follow while doing the investigation and why?

Think about questions you still have that could lead to new investigations:
I wonder if …
I'm not sure about …

Keep track of new vocabulary and new ideas that could lead to new investigations:
I would like to find out what happens when …
One interesting thing to do would be to …

Reflect on how the activity worked in your group:
This is what went well … This is what did not go well …
If I could do this investigation again, I would …

VISUAL AID 1.2

DEVELOPING COMMUNICATION SKILLS

COMMUNICATION	SENTENCE STARTERS
To better understand	*One point that was not clear to me was . . .* *Are you saying that . . .* *Can you please clarify . . .*
To share an idea	*Another idea is to . . .* *What if we tried . . .* *I have an idea—we could try . . .*
To disagree	*I see your point, but what about . . .* *Another way of looking at it is . . .* *I'm still not convinced that . . .*
To challenge	*How did you reach the conclusion that . . .* *Why do you think that . . .* *How does it explain . . .*
To look for feedback	*What would help me improve . . .* *Does it make sense, what I said about . . .*
To provide positive feedback	*One strength of your idea is . . .* *Your idea is good because . . .*
To provide constructive feedback	*The argument would be stronger if . . .* *Another way to do it would be . . .* *What if you said it like this . . .*
To discuss information presented in text and graphics	*I'm not sure I completely understand this, but I think it may mean . . .* *I know something about this from . . .* *A question I have about this is . . .* *If we look at the graphic, it shows . . .*

VISUAL AID 1.3

GROUP INTERACTIONS CLASSROOM RUBRIC

When to use this rubric:
This classroom rubric is used when students work together as a group toward a common goal.

What to look for:
- Group members work together as a team.
- The ideas of all members are valued and considered by the whole team in working toward the common goal.

Level	Description
Level 4 Accomplished	Group members accomplish Level 3 and actively collaborate by doing the following: • Asking questions about one another's ideas • Helping one another accomplish the task • Building on one another's ideas
Level 3 Almost there	All group members participate equally, and respectfully consider one another's ideas.
Level 2 On the way	Unequal group participation OR group respectfully considers some, but not all, ideas.
Level 1 Getting started	Significantly unequal group participation OR group totally disregards some members' comments and ideas.
Level 0	Members do not work together OR single individual does entire task.
x	Student had no opportunity to work as part of a group.