Neurolab Lessons & Activities

The Scientific Method

Lessons and Activities

GRADES 5–12

Part II

The Scientific Method

Scientists aim to gain knowledge and reach an understanding of the world around us. To achieve this goal, scientists must be curious, make observations, ask questions, and try to solve problems. Early scientists tended to draw conclusions from observations that were largely speculative (e.g., the Earth was flat or that the sun circled the Earth). By the mid-sixteenth century, some scientists began to realize that far more knowledge could be obtained by using a systematic approach to obtaining information and solving problems.

One ground-breaking scientist was Andreas Vesalius (1514–1564), the first physician to write an extensive text about human anatomy based on meticulous dissections of human bodies. In 1620, Sir Francis Bacon published his *Novum Organum* in which he attempted to provide a complete method for studying science. From these early beginnings, the Scientific Method evolved as an orderly, systematic process for solving problems.

By the mid-nineteenth century, Charles Darwin and other scientists were following what has become the modern scientific method. According to this method, the first step is to speculate or create a hypothesis. The second step consists of carrying out experiments and/or making comparative observations to test the hypothesis.

Steps of the Scientific Method

1. **Identify the problem**
2. **Collect information about the problem**
3. **Propose a hypothesis**
4. **Test the hypothesis by conducting experiments, making comparative observations, and collecting data**
5. **Evaluate the data collected through investigation**
6. **Draw conclusions based on data and determine whether to accept or reject the hypothesis**
7. **Communicate results and ask new questions**

The **problem** is a statement of the question to be investigated. Observations and curiosity help to define exactly what problem should be investigated and what question(s) answered. Once a problem is defined, a scientist should collect as much information as possible about it by searching journals, books and electronic information sources. This information will provide a basis for forming the hypothesis.

A **hypothesis** is often considered to be an "educated guess." The word "guess" is inappropriate, however, because a hypothesis should be based on information gathered. A hypothesis can be defined more accurately as a "proposed answer to the problem." The hypothesis is then tested through experimentation and observation. The results of experimentation provide evidence that may or may not support the hypothesis.

To be effective, experiments must be properly planned. The plan is called the **procedure**, which describes the things that actually will be done to perform the investigation. This is where decisions are made about which variables will be tested and which will be kept constant, what to use as a control, how many samples to use, how large the sample sizes should be, safety precautions needed, and how many times to run the experiment. Many scientists investigate questions that cannot be answered directly through controlled experiments in laboratories. For example, scientists studying global warming, the AIDS epidemic and losses of biodiversity must use comparative methods to examine differences that occur in the natural world.

When developing the procedure for an experiment, consider the following:

1. Test only one variable at a time.

A scientist wanting to find out "why trees shed their leaves in the fall" would have to consider the factors that affect trees, such as the type of tree, the amount of water they receive, the temperature, the length of daylight to which they are exposed, and the type of soil in which they are growing. These are the variables which can cause changes to occur in an experiment. To obtain reliable results, only one variable should be tested at a time. All others should be kept constant, whenever possible.

If the scientist's hypothesis states that shorter daylight hours cause trees to shed their leaves in the fall, trees of the same age should be tested. They should be placed in the same size pots with the same type of soil, given the same amount of water, and kept at the same temperature. The only thing changed should be the number of hours of light to which different groups of trees are exposed. Any variable that the experimenter chooses to change, such as the hours exposed to light, is referred to as the **independent variable**. The change in the experiment that happens as a result of the independent variable, such as the length of time that it takes for the leaves to fall, is referred to as the **dependent variable**.

2. Use controls.

The **control** is used for comparing the changes that occur when the variables are tested. If a number of young oak trees are placed in a greenhouse and exposed to 10 hours of light to simulate fall conditions, how will the scientist know if a loss of leaves is due to the amount of light? It could be due to the temperature that he/she chose, or the amount of carbon dioxide in the air. To avoid such uncertainty, two identical experiments must be set up: one in which the trees are exposed to 10 hours of light and the other, the control, in which they are exposed to light for a longer period of time to simulate summer conditions. All factors for the control are exactly the same as for the test, except for the variable being tested, the amount of light given to each tree.

3. Use several samples.

Using a number of samples prevents errors due to differences among individuals being tested. Some trees are more hearty than others. If only a few trees are tested, some may lose leaves for reasons that are not related to the amount of light. This will produce misleading results. Larger numbers of samples will provide more accurate results.

4. Always use appropriate safety measures.

Safety measures to be followed vary according to the type of experiment being performed. For example, laboratory-based experiments frequently require that participants wear protective clothing and safety goggles, and that dangerous volatile chemicals be used only under a vented fume hood.

5. Repeat the experiment several times.

To make valid conclusions, the scientist must have reproducible results. Ideally, comparable results should be obtained every time the experiment is run.

After the plan, or procedure, is complete, the experiment is run. It is essential that careful and accurate records be kept of all observations during an experiment. The recorded observations and the measurements comprise the **data**. It is always useful to present data in the form of charts, tables, or graphs, as these provide a visual way to analyze and interpret the results (Figure 20). When drawing graphs, the independent variable is conventionally plotted on the horizontal axis, and the dependent variable is plotted on the vertical axis.

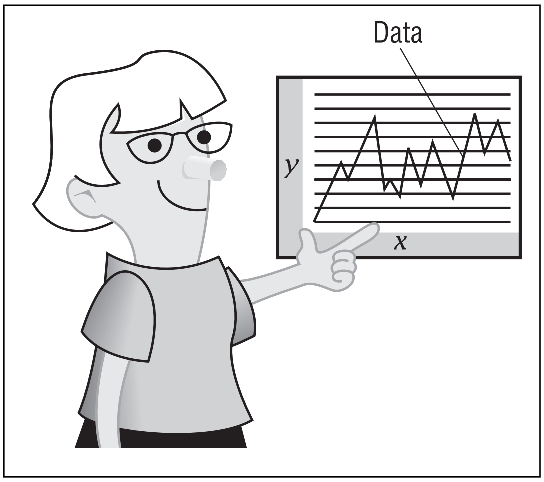

Figure 20 *Diagram of teacher using graph representing data.*

Analysis of data from the experiment allows the scientist to reach a **conclusion**. The scientist determines whether or not the data support the hypothesis and decides whether to accept or reject the hypothesis. The conclusion should provide an answer to the question asked in the problem. Even if the hypothesis is rejected, much information has been gained by performing the experiment. This information can be used to help develop a new hypothesis if the results repeatedly show that the original hypotheses is inappropriate.

After performing many investigations on a particular problem over a period of time, a scientist may come up with an explanation for the problem, based on all the observations and conclusions made. This is called a **theory**. A Scientific Theory is an explanation, supported by data, of how or why some event took place in nature.

Students should be encouraged to understand that the scientific method can be applied to solving everyday problems, such as "Under what conditions do I study best?" or "What type of lunch box will keep my lunch coldest?" The activities in this manual allow students to understand and experience many of the problems addressed, and hypotheses proposed, by Neurolab scientists. Activities, such as the Escher Staircase (Pages 95 – 99), simulate actual experiments that were performed on board Neurolab. It will be exciting for students to compare the results of the control experiments performed on Earth with the results of tests performed in space.

LEARNING ACTIVITY I:
Introduction to the Scientific Method

OVERVIEW

Students will learn to make observations, formulate hypotheses and design a controlled experiment, based on the reaction of carbon dioxide with calcium hydroxide.

SCIENCE & MATHEMATICS SKILLS

Making and recording qualitative observations, drawing conclusions

PREPARATION TIME

10 minutes to gather equipment; 30 minutes to prepare calcium hydroxide solution

Preparation of one liter of lime water
(Teacher should prepare a day ahead of time):

MATERIALS

- 10 grams calcium hydroxide powder
- One liter of water
- Filter paper
- Filter funnel
- Large bottle (2 liters)
- Flasks or small bottles

1. Add 10 grams calcium hydroxide $Ca(OH)_2$ powder to one liter of water.
2. Cover and shake well. Calcium hydroxide is very slightly soluble in water and 10 grams will provide more solid than will dissolve.
3. Allow the suspension formed to settle for a few minutes.
4. To separate the lime water from the suspension, use a filter paper and filter funnel apparatus to filter the suspension.
5. If the lime water filtrate is still slightly cloudy, filter for a second time, using a new filter paper.

$Ca(OH)_2$	= Calcium Hydroxide
CO_2	= Carbon Dioxide
$CaCO_3$	= Calcium Carbonate
H_2O	= Water
H_2CO_3	= Carbonic Acid Gas
Ca^{++}	= Calcium

* $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

† $CaCO_3 + H_2CO_3 \rightarrow Ca^{++} + 2HCO_3$

MAJOR CONCEPTS

- Our exhaled breath contains carbon dioxide gas.
- The carbon dioxide we exhale reacts with calcium hydroxide in solution to form insoluble calcium carbonate and water.*
- Formation of calcium carbonate precipitate can be used as a test for the presence of carbon dioxide.
- If carbon dioxide continues to be bubbled into lime water (calcium hydroxide solution) after a period of time, the white precipitate disappears. The excess carbon dioxide forms carbonic acid in the water and the calcium carbonate reacts with the carbonic acid to form calcium ions and bicarbonate ions, which are soluble in water.†

6. Keep the lime water tightly closed when not in use, as it will react with carbon dioxide from the air and become cloudy.
7. The calcium hydroxide and water suspension can be stored in a large bottle, and lime water filtered off when needed.
8. The filtered lime water can be stored in smaller bottles or flasks, 500 milliliters in volume, for use in class. One (1) liter will be sufficient for one class of 24 students for days one and two.

CLASS TIME

Two or three periods of 40 – 45 minutes

MATERIALS
Day 1: Per student

- 1 plastic test tube, 50 milliliters (ml) in volume
- 1 straw
- 10 – 15 ml lime water solution (calcium hydroxide solution)
- Goggles

MATERIALS
Day 2 and Day 3: Per student

The materials will vary depending on the design of the students' experiments. All students will require test tubes, lime water, foil, and straws.

BACKGROUND

Carbon dioxide comprises only 0.033 percent of Earth's atmosphere, yet it is the principle inorganic source of carbon for living organisms. Carbon dioxide and water are the raw materials required by plants for the synthesis of sugars through photosynthesis. Organisms release carbon dioxide back into the atmosphere as a waste product of respiration and other cellular processes.

This activity allows students to test for the presence of carbon dioxide in exhaled air. On Day 1, each student will blow through a straw into a solution of calcium hydroxide. The carbon dioxide in the air will combine with the calcium hydroxide to produce a white precipitate of calcium carbonate. Students will compare their solutions to those of the teacher, in which a precipitate will not be visible. (Students will not immediately be able to observe that if they continue to blow into the calcium hydroxide solution, the white precipitate will disappear.) Students will then generate hypotheses to explain the divergent results.

The second part of this activity (Day 2) involves designing an experiment to test the hypotheses determined in the class discussion on Day 1. It may be handled in different ways depending on the age of the students.

GRADES 10–12

For homework, have each student (or team of students) formulate a hypothesis to explain why they had a precipitate and the teacher did not. They should design a simple controlled experiment to test the hypothesis. On Day 2, review students' procedures and allow them to perform their experiments, record their observations and draw conclusions. Grades 10 – 12 should be able to complete the activity in two days, grades 5 – 9 in three days.

GRADES 7–9

Have students work in groups of three to four to formulate a hypothesis about the disappearance of the precipitate and design an experiment to test the hypothesis. Encourage each group to investigate a different variable. The hypothesis and procedure proposed by each group should be presented to the class and discussed, based on the questions on pages 41 – 42 under Day 2. The students will then run the experiments they designed on Day 3.

FOR GRADES 5–6

Before proceeding, have the whole class participate in a teacher-directed discussion to determine possible hypotheses about the precipitate and how to design experiments to test each hypothesis. This will help to prepare them to conduct their experiments the next day.

Note to Teacher: *The students' answers to the discussion questions will vary, depending on the hypothesis tested and the design of the experiment. The questions are intended to be a check list to help students determine whether or not they have designed a valid experiment.*

DAY 1

PROCEDURE

1. Explain to students that it is important for scientists to make careful observations, and inform them that they will practice making observations.

2. Direct each student to fill a test tube with 15 ml of the calcium hydroxide solution that you have prepared in advance and to use a straw to bubble their breath into the liquid slowly. (Make sure that the solution is clear.) Caution them against blowing into the liquid too vigorously.

   Note to Teacher: *For grades 5 and 6, the test tubes of liquid could be set up ahead of time. Students should wear goggles while bubbling into the solution.*

3. Have the students observe the solution after blowing through the straws for approximately 1 – 2 minutes. Students should record their observations in their notebooks. Explain that these observations will make up students' data.

   Note to Teacher: *Most students will get a white precipitate and stop bubbling. Those in higher grades may know exactly what happened.*

4. Use the following questions as a basis for a class discussion.
   - **What gases are present in exhaled air?**
     Carbon dioxide gas (nitrogen, water vapor and small amounts of oxygen are also present).
   - **What is the clear liquid?**
     Lime water
   - **How can we test for the presence of carbon dioxide?**
     Bubble the gas into the lime water.
   - **What is a positive test for carbon dioxide?**
     Carbon dioxide turns clear lime water cloudy.
   - **Why is a precipitate formed?**
     Lime water is a solution of calcium hydroxide. It chemically reacts with carbon dioxide to form solid calcium carbonate (chalk).

5. When the students are convinced that they know exactly what happened, bring out the "teacher's results." Explain that you did the exact same experiment, but got very different results! Your test tube has no white precipitate—it is clear. The class now has a problem to solve: **How can there be no white precipitate when the teacher performed the same experiment?**

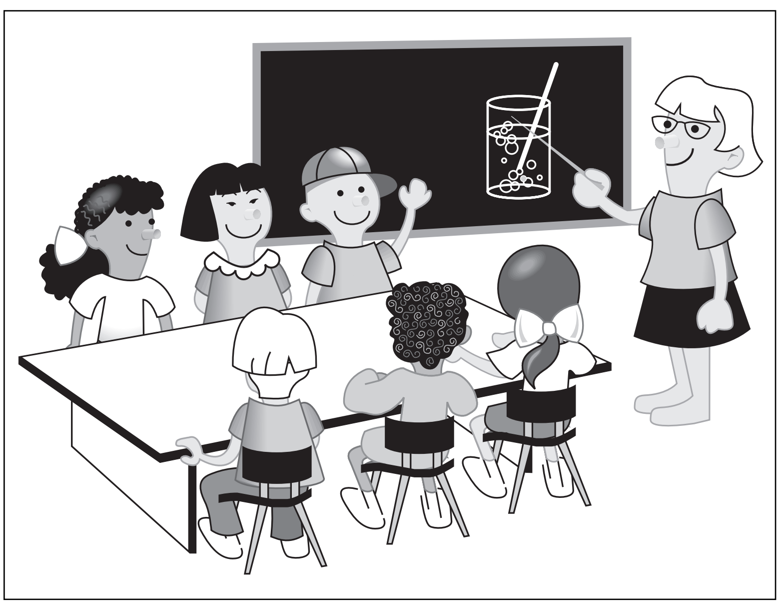

Figure 21 *Diagram of teacher-directed discussion with class.*

6. Discuss with students what factors might affect the production of a precipitate. (DO NOT tell the students how you obtained your results.)

   Possible answers might be:
   - Time—how long exhaled air was bubbled into the solution.
   - Adults vs. teenagers.
   - Rate of bubbling.
   - Light vs. dark.
   - Temperature of the liquid.
   - Any other conditions at time of breathing.

7. Explain that all of the factors identified by students are known as **variables**.

DAY 2

PROCEDURE

1. Use the following questions to guide students or groups of students in the development of their hypotheses and experimental designs.

- **Does the hypothesis offer an answer to the problem?**
  Yes it does. The problem was, "Why was there no white precipitate when the teacher performed the experiment?" The hypothesis states that the teacher may have exhaled into the solution for a longer time than the students.

- **Does the experiment have a control?**
  Yes. The control is the average length of time that the students exhaled into the solution of lime water (possibly about one minute).

- **Which materials are needed? Are the materials readily available?**

- **What conditions are being kept constant?**
  The conditions kept constant are the temperature of the liquid, the size of the straws, the rate of bubbling into the liquid and the amount of lime water used for each test.

- **What is the independent variable being tested?**
  This is the variable that the experimenter chooses to change. In the example given, it is the increased length of time that the students choose to exhale into the lime water.

- **What is the dependent variable being measured?**
  The dependent variable is the amount of precipitate present after exhaling into the tube of lime water.

- **How will each group present its data?**
  The data may be presented in the form of a chart (Figure 22). *This can be indicated by using + to represent the density of the precipitate.*

Exhale Time (observations)	Amount of Precipitate
0.25 min.	+
0.5 min.	++
1.0 min.	+++
1.5 min.	+++
2.0 min.	+++
2.5 min.	+++
3.0 min.	++
3.5 min.	++
4.0 min.	+

Figure 22 *Sample of data sheet for recording precipitate.*

DAY 3

1. Allow individuals or teams of students to perform their experiments, collect data and draw conclusions. A post-experiment discussion is recommended to review the conclusions made by each group. Each group's experiment should be evaluated based on the appropriateness of the experimental design to test the group's hypothesis (not whether the group actually found the "correct" solution).

2. For a typical experiment to test the hypothesis that "the length of time that air was blown into the solution" caused the teacher's results to be different, each student in a group of four should use the same size tube, the same amount of lime water, run the experiment at the same temperature, use the same size straws and attempt to bubble at the same rate. Students could estimate how long they exhaled into their liquid the first day. This could be the control time. One student in each group could blow into his/her tube for the control time. Each following student in the group could increase his or her time by two to four minutes.

POST-LAB DISCUSSION

3. Compare the experiments performed by each group of students. For each experiment designed, discuss the variable tested, the control, the factors kept constant, and the results obtained. Note that the amount of lime water used, and the size of the straws and test tubes should be the same for each experiment. A chart, such as the one below, can be developed on an overhead projector.

Independent Variable Tested	Control	Constants	Observations
1. Length of time breath was bubbled into the solution (from .25 mins. to 4 mins.)	2 mins.	Room temperature Bubble slowly Keep tube in the light	The precipitate formed, increased, then decreased
2. Temperature of the water (warm/cold)	Room temperature	Bubble for 2 mins. Bubble slowly Keep tube in the light	Precipitate formed, did not decrease
3. Rate of bubbling (slowly/quickly)	Bubble slowly	Room temperature Bubble for 2 mins. Keep tube in the light	Precipitate formed, did not decrease
4. Amount of light (light/dark)*	Keep tube in the light	Room temperature Bubble for 2 mins. Bubble slowly	Precipitate formed, did not decrease

Figure 23 *Example of chart comparing experiments.*

* *Cover test tube with foil to create darkness.*

4. From the class observations, it can be seen that only the length of time affects the amount of precipitate formed. At this point, explain that excess carbon dioxide bubbled into lime water forms carbonic acid which dissolves the precipitate of calcium carbonate.

The use of the scientific method to systematically test different hypotheses will enable the students to determine which hypothesis is correct in answering a problem.