1.3 Thinking Like a Scientist

Connecting to Your World

In 1928, Alexander Fleming, a Scottish scientist, noticed that a bacteria he was studying did not grow in the presence of a yellow-green mold. Other scientists had made the same observation, but Fleming was the first to recognize its importance. He assumed that the mold had released a chemical that prevented the growth of the bacteria. That chemical was penicillin, which can kill a wide range of harmful bacteria. In 1945, Fleming shared a Nobel Prize for Medicine with Howard Florey and Ernst Chain, who led the team that isolated penicillin. In this section you will study the methods scientists use to solve problems.

Alchemy

The word chemistry comes from alchemy. Long before there were chemists, alchemists were studying matter. Alchemy arose independently in many regions of the world. It was practiced in China and India as early as 400 B.C. In the eighth century, Arabs brought alchemy to Spain, from where it spread quickly to other parts of Europe. Alchemy had a practical side and a mystical side. Practical alchemy focused on developing techniques for working with metals, glass, and dyes. Mystical alchemy focused on concepts like perfection. Because gold was seen as the perfect metal, alchemists were searching for a way to change other metals, such as lead, into gold. Although alchemists did not succeed in this quest, the work they did spurred the development of chemistry.

Alchemy

Students who have read the Harry Potter books will be familiar with the name of one alchemist, Nicolas Flamel (1330–1414), who wrote a book about the philosopher’s stone. Alchemists believed that the philosopher’s stone could change base metals into gold.

Section Resources

Print

- Guided Reading and Study Workbook, Section 1.3
- Core Teaching Resources, Section 1.3 Review
- Transparencies, T5–T6
- Laboratory Manual, Lab 1
- Small-Scal Chemistry Laboratory Manual, Lab 1

Technology

- Interactive Textbook with ChemASAP, Assessment 1.3
- Go Online, Section 1.3
An Experimental Approach to Science

By the 1500s in Europe, there was a shift from alchemy to science. Science flourished in Britain in the 1600s, partly because King Charles II was a supporter of the sciences. With his permission, some scientists formed the Royal Society of London for the Promotion of Natural Knowledge. The scientists met to discuss scientific topics and conduct experiments. The society’s aim was to encourage scientists to base their conclusions about the natural world on experimental evidence, not on philosophical debates.

In France, Antoine-Laurent Lavoisier did work in the late 1700s that would revolutionize the science of chemistry. Lavoisier helped to transform chemistry from a science of observation to the science of measurement that it is today. To make careful measurements, Lavoisier designed a balance that could measure mass to the nearest 0.0005 gram.

One of the many things Lavoisier accomplished was to settle a long-standing debate about how materials burn. The accepted explanation was that materials burn because they contain phlogiston, which is released into the air as a material burns. To support this explanation, scientists had to ignore the evidence that metals can gain mass as they burn. By the time Lavoisier did his experiments, he knew that there were two main gases in air—oxygen and nitrogen. Lavoisier was able to show that oxygen is required for a material to burn. Lavoisier’s wife Marie Anne, shown in Figure 1.16, helped with his scientific work. She made drawings of his experiments and translated scientific papers from English. Figure 1.17 shows a reconstruction of Lavoisier’s laboratory in a museum in Paris, France.

At the time of the French Revolution, Lavoisier was a member of the despised royal taxation commission. He took the position to finance his scientific work. Although he was dedicated to improving the lives of the common people, his association with taxation made him a target of the revolution. In 1794 he was arrested, tried, and beheaded.

Checkpoint What long-standing debate did Lavoisier help settle?

Facts and Figures

How Oxygen Got Its Name

The ancient Greeks thought that flammable objects contained the element fire, which George Stahl (1660–1734) named phlogiston. During burning, phlogiston transferred to the air. Phlogiston-rich air (now called nitrogen) did not support burning; objects burned brightly in phlogiston-poor air.

Lavoisier measured the mass of metals before and after heating in a closed container. He showed that the mass gained by the metal was lost by the air. Thus, the process of burning involved a gain of matter, not a loss of phlogiston. Lavoisier named the portion of air that supported combustion oxygen.

Checkpoint how materials burn

Answers to...

Figure 1.17 Students are most likely to recognize the two-pan balance.
The Scientific Method

A Nobel Prize winner in science once said that science is about “ordinary people doing ordinary things.” Scientists have a powerful tool that they can use to produce valuable, sometimes spectacular, results. Like all scientists, the biochemist shown in Figure 1.18 is using the scientific method to solve difficult problems. The scientific method is a logical, systematic approach to the solution of a scientific problem. Steps in the scientific method include making observations, testing hypotheses, and developing theories. Figure 1.19 shows how these steps fit together.

Making Observations

The scientific method is useful for solving many kinds of problems because it is closely related to ordinary common sense. Suppose you try to turn on a flashlight and you notice that it does not light. When you use your senses to obtain information, you make an observation. An observation can lead to a question: What's wrong with the flashlight?

Testing Hypotheses

If you guess that the batteries are dead, you are making a hypothesis. A hypothesis is a proposed explanation for an observation. You can test your hypothesis by putting new batteries in the flashlight. If the flashlight lights, you can be fairly certain that your hypothesis is true. What if the flashlight does not work after you replace the batteries? A hypothesis is useful only if it accounts for what is actually observed. When experimental data does not fit a hypothesis, the hypothesis must be changed. A new hypothesis might be that the light bulb is burnt out. You can replace the bulb to test this hypothesis.

Replacing the bulb is an experiment, a procedure that is used to test a hypothesis. When you design experiments, you deal with variables, or factors that can change. The variable that you change during an experiment is the manipulated variable, or independent variable. The variable that is observed during the experiment is the responding variable, or dependent variable. If you keep other factors that can affect the experiment from changing during the experiment, you can relate any change in the responding variable to changes in the manipulated variable.

For the results of an experiment to be accepted, the experiment must produce the same result no matter how many times it is repeated, or by whom. This is why scientists are expected to publish a description of their procedures along with their results.

Word Origins

Experiment comes from a Latin word comparare, meaning “to make equal with.” When you compare two items, you focus on how they are similar. Then say that contrast means “against” in Latin. Ask, When you contrast two items, what do you focus on? (how the objects differ)

Discuss

Students often think that an experiment is a failure if they do not get the “right” (expected) results. As students do experiments, help them analyze results that do not fit a hypothesis or vary widely from those of other students. Often, you can identify experimental errors that explain deviation. Also point out that scientists can gain important insights from “failed” experiments.

Using Visuals

Figure 1.19 If students are not clear on the difference between compare and contrast, tell students that compare comes from a Latin word comparare, meaning “to make equal with.” When you compare two items, you focus on how they are similar. Then say that contrast means “against” in Latin. Ask, When you contrast two items, what do you focus on? (how the objects differ)
Developing Theories  Once a hypothesis meets the test of repeated experimentation, it may be raised to a higher level of ideas. It may become a theory. A theory is a well-tested explanation for a broad set of observations. In chemistry, one theory addresses the fundamental structure of matter. This theory is very useful because it helps you form mental pictures of objects that you cannot see. Other theories allow you to predict the behavior of matter.

When scientists say that a theory can never be proved, they are not saying that a theory is unreliable. They are simply leaving open the possibility that a theory may need to be changed at some point in the future to explain new observations or experimental results.

Scientific Laws  Figure 1.19 shows how scientific experiments can lead to laws as well as theories. A scientific law is a concise statement that summarizes the results of many observations and experiments. In Chapter 14, you will study laws that describe how gases behave. One law describes the relationship between the volume of a gas in a container and its temperature. If all other variables are kept constant, the volume of the gas increases as the temperature increases. The law doesn’t try to explain the relationship it describes. That explanation requires a theory.

Checkpoint  When can a hypothesis become a theory?

Bubbles!  After completing this activity, students will be able to:

• test the hypothesis that bubble making can be affected by adding sugar or salt to the bubble-making mixture.

Skills Focus  Observing, formulating hypotheses, drawing conclusions

Prep Time  5 minutes  
Class Time  15 minutes

Safety  Remind students to be careful not to draw any liquid into their mouth through the straw.

Expected Outcome  Students conclude that sugar has no effect on bubble production and salt prevents bubble production.

Analyze and Conclude

1. no
2. Yes; no bubbles formed from the liquid in cup 3.
3. Sugar has no effect on bubble production, but salt stops it completely.
4. Answers might include examining the effect of temperature or dilution of the bubble-making mixture. For example, diluting the mixture can reverse the salt effect.

For Enrichment  Facilitate a class discussion about the experiments that students proposed for Question 4. Discuss whether or not the experiments will work. Perform two of the experiments and discuss the results. Emphasize the need to learn from “failed” experiments.

Checkpoint  When a hypothesis meets the test of repeated experimentation, it may become a theory.
Collaboration and Communication

Researching Collaborative Science Projects

Have students do research to find examples of successful collaborative projects that involved a multidisciplinary approach to solving a scientific problem. One example is the series of NASA missions to the moon in the 1970s.

Discuss

Stress that students should not avoid reading about science, but they should look for reliable sources and approach the news with a certain amount of healthy skepticism. Ask, *How can the Internet help people learn about advances in science? (Anyone can access information on the Internet.)*

What is one disadvantage of getting information from the Internet? *The information is not always reliable.*

Collaboration and Communication

No matter how talented the players on a team, one player cannot ensure victory for the team. Individuals must collaborate, or work together, for the good of the team. Think about the volleyball players in Figure 1.20. In volleyball, the person who spikes the ball depends on the person who sets the ball. Unless the ball is set properly, the spiker will have limited success.

Many sports recognize the importance of collaboration by keeping track of assists. During a volleyball game, the players also communicate with one another so it is clear who is going to do which task. Strategies that are successful in sports can work in other fields, such as science. *When scientists collaborate and communicate, they increase the likelihood of a successful outcome.*

Collaboration

Scientists choose to collaborate for different reasons. For example, some research problems are so complex that no one person could have all the knowledge, skills, and resources to solve the problem. It is often necessary to bring together individuals from different disciplines. Each scientist will typically bring different knowledge and, perhaps, a different approach to bear on a problem. Just talking with a scientist from another discipline may provide insights that are helpful.

Collaboration isn’t always a smooth process. Conflicts can arise about use of resources, amount of work, who is to receive credit, and when and what to publish. Like the students in Figure 1.21, you will likely work on a team in the laboratory. If so, you may face some challenges. But you can also experience the benefits of a successful collaboration.

Applying Concepts

*What steps in the scientific method are these students using?*
Communication  The way that scientists communicate with each other and with the public has changed over the centuries. In earlier centuries, scientists exchanged ideas through letters. They also formed societies to discuss the latest work of their members. When societies began to publish journals, scientists could use the journals to keep up with new discoveries.

Today, many scientists, like those in Figure 1.22, work as a team. They can communicate face to face. They also can exchange ideas with other scientists by e-mail, by phone, and at international conferences. Scientists still publish their results in scientific journals, which are the most reliable source of information about new discoveries. Articles are published only after being reviewed by experts in the author’s field. Reviewers may find errors in experimental design or challenge the author’s conclusions. This review process is good for science because work that is not well founded is usually not published.

The Internet is a major source of information. One advantage of the Internet is that anyone can get access to its information. One disadvantage is that anyone can post information on the Internet without first having that information reviewed. To judge the reliability of information you find on the Internet, you have to consider the source. This same advice applies to articles in newspapers and magazines or the news you receive from television. If a media outlet has a reporter who specializes in science, chances are better that a report will be accurate.

1.3 Section Assessment

16. **Key Concept** What did alchemists contribute to the development of chemistry?
17. **Key Concept** How did Lavoisier revolutionize the science of chemistry?
18. **Key Concept** Name three steps in the scientific method.
19. **Key Concept** Explain why collaboration and communication are important in science.
20. How did Lavoisier’s wife help him to communicate the results of his experiments?
21. Why should a hypothesis be developed before experiments take place?
22. Why is it important for scientists to publish a description of their procedures along with the results of their experiments?
23. What is the difference between a theory and a scientific law?
24. What process takes place before an article is published in a scientific journal?
25. In Chapter 2, you will learn that matter is neither created nor destroyed in any chemical change. Is this statement a theory or a law? Explain your answer.

**Connecting Concepts**

**Being an Informed Citizen** Write a paragraph explaining how you can learn about the research that is done by scientists. Then explain how this information could help you be an informed citizen.

**Interactive Textbook**

Assessment 1.3 Test yourself on the concepts in Section 1.3. with ChemASAP

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**FYI**

The peer review of journal articles can be painful for a scientist, but it is good for science as a whole because work that is not well founded is usually not published. Some journals publish preliminary results on the Internet because the review process can take from six months to a year, or even longer. Preliminary results should be treated with caution because such results are subject to change.

**ASSESS**

Evaluate Understanding

Ask students to choose an everyday type of problem and explain how they would use the scientific method to solve the problem.

Reteach

Students may mistakenly infer that a theory “grows” into a law by constant testing and refinement. Or they may confuse a theory with a hypothesis. To clarify these concepts, ask students to describe theory and law in their own words.

**Connecting Concepts**

Students can learn about research from news reports, from specialized journals, and from the Internet. The more reliable information people have, the better able they are to effectively address public issues related to technology.

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 1.3.

**Answers to...**

Figure 1.21 testing a hypothesis and making observations

Introduction to Chemistry 25
Laboratory Safety

Objective After completing this activity, students will be able to
• demonstrate their knowledge of safe laboratory practices.

Class Time 40 minutes

Skills Focus Observing, communicating results

Teaching Tips
• Students need to read Appendix D to answer the questions in the lab.
• Use this activity as part of an orientation in which you present your rules for working in the laboratory.
• Provide a floor plan of the room and have students record the location of safety equipment such as an eyewash fountain or a fire extinguisher.
• After you discuss the safety rules, have students sign a safety contract. For an example, see the safety contract in the Small-Scale Chemistry Laboratory Manual, p. 15.

Answers to Questions

What should safety goggles be worn?

When should safety goggles be worn?

What should you do if glassware breaks?

What precautions should you take when working near an open flame?

If you accidentally spill water near electrical equipment, what should you do?

Wear safety goggles at all times when working in the lab.

Tell your teacher and nearby classmates. Dispose of the glass as instructed by your teacher.

Stand back, notify your teacher, and warn other students.

Tie back long hair and loose clothing. Never reach across a lit burner. Keep flammable materials away from the flame.

Wash your hands thoroughly with soap and water.

It isn’t always appropriate to dispose of chemicals by flushing them down the drain. Follow your teacher’s instructions for disposal.

Purpose To demonstrate your knowledge of safe laboratory practices.

Procedure While doing the chemistry experiments in this textbook, you will work with equipment similar to the equipment shown in the photographs. Your success, and your safety, will depend on following instructions and using safe laboratory practices. To test your knowledge of these practices, answer the question after each safety symbol. Refer to the safety rules in Appendix E and any instructions provided by your teacher.
Background
The small-scale chemistry experiments in this book are designed to help you teach students important chemical principles, not just process. For most experiments, the procedure is short and simple. In many cases students are asked to construct a grid, place a small-scale reaction surface over the grid, do the experiment, and record their results in a similar grid. Sometimes the students are told to mark the grid with black Xs. These Xs provide black and white backgrounds against which students can observe reaction mixtures. The YOU'RE THE CHEMIST activities ask students to apply what they learned in the basic experiment. Some of these activities could be used for performance-based assessment.

For Enrichment
Have students look at the safety rules in Appendix D. Have each student choose five of the rules in Appendix D and make a list of what things could happen if the rule is not followed. Divide students into groups of 3 and have them share their answers with each other.