Scientific Investigation

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CONCEPT 1

Scientific Investigation

Lesson Objectives

- List the steps of a scientific investigation.
- Describe the relationship of ethics to scientific research.

Lesson Vocabulary

- control
- ethics
- experiment
- field study
- hypothesis
- manipulated variable
- observation
- replication
- responding variable

Introduction

Investigation is at the heart of science. It is how scientists do research. Scientific investigations produce evidence that helps answer questions and solve problems. If the evidence cannot provide answers or solutions, it may still be useful. It may lead to new questions or problems for investigation. As more knowledge is discovered, science advances.

Steps of a Scientific Investigation

Scientists investigate the world in many ways. In different fields of science, researchers may use different methods and be guided by different theories and hypotheses. However, most scientists, including physical scientists, usually follow the general approach shown in **Figure** 1.1. This approach typically includes the following steps:

- Identify a research question or problem.
- Form a hypothesis.
- Gather evidence, or data, to test the hypothesis.
- Analyze the evidence.
- Decide whether the evidence supports the hypothesis
- Draw conclusions.
- Communicate the results.

Scientists may follow these steps in a different sequence. Or they may skip or repeat some of the steps. Which steps are repeated in **Figure** 1.1?

Asking Questions

A scientific investigation begins with a question or problem. Often, the question arises because a scientist is curious about something she has observed. An **observation** is any information that is gathered with the senses. People often have questions about things they see, hear, or observe in other ways. For example, a teen named Tara has a bracelet with a magnetic clasp, like the one shown in **Figure** 1.2. Tara has noticed that the two magnets in the clasp feel harder to pull apart on cold days than on warm days. She wonders whether temperature affects the strength of a magnet.

Forming Hypotheses and Making Predictions

Tara is curious. She decides to investigate. She begins by forming a hypothesis. A **hypothesis** is a potential answer to a question that can be tested by gathering information. If it isn't possible to gather evidence to test an answer, then it cannot be used as a scientific hypothesis. In fact, the question it addresses may not even be answerable by science. For example, in the children's television show *Sesame Street*, there was a large Snuffalufagus (kind of like an elephant). But Snuffy would disappear whenever people came around. So if someone said "Is there a Snuffy on Sesame Street?," that question would be unanswerable by science, since there isn't any test that can be performed – because Snuffy would disappear as soon as a scientist showed up. Can you think of other examples of questions outside the realm of science?

This important distinction, that evidence taken in by observation is experimented on by a scientist, is what separates legitimate science from other things which may pretend to be science. Fields which claim to be scientific but don't use the scientific method are called "pseudoscience." If a person can't gather data through some sort of instrument or sense information, they can't form a scientific conclusion. If there is no way to prove the hypothesis false, there is no scientific claim either. For example, if a friend told you that Snuffy visited him every day, but he was invisible whenever anyone walked into the room, this claim is not scientific, *since there is no way to prove him false*. Developing a hypothesis may require creativity as well as reason. However, in Tara's case, the hypothesis is simple. She hypothesizes that a magnet is stronger at lower temperatures. Based on her hypothesis, Tara makes a prediction. If she cools a magnet, then it will pick up more metal objects, such as paper clips. Predictions are often phrased as "if-then" statements like this one. Is Tara's prediction correct? She decides to do an experiment.

Doing Experiments

An **experiment** is a controlled scientific study of specific variables. A variable is a factor that can take on different values. There must be at least two variables in an experiment. They are called the manipulated variable and the responding variable.

- The **manipulated variable** (also called the "independent variable") is a factor that is changed by the researcher. For example, Tara will change the temperature of a magnet (see **Figure** 1.3). Temperature is the manipulated variable in her experiment.
- The **responding variable** (also called the "dependent variable") is a factor that the researcher predicts will change if the manipulated variable changes. Tara predicts the number of paper clips attracted by the magnet will be greater at lower temperatures. Number of paper clips is the responding variable in her experiment.

Tara wonders what other variables might affect the strength of a magnet. She thinks that the size and shape of a magnet might affect its strength. These are variables that must be controlled. A **control** is a variable that is held constant so it won't influence the outcome of an experiment. By using the same magnet at different temperatures,

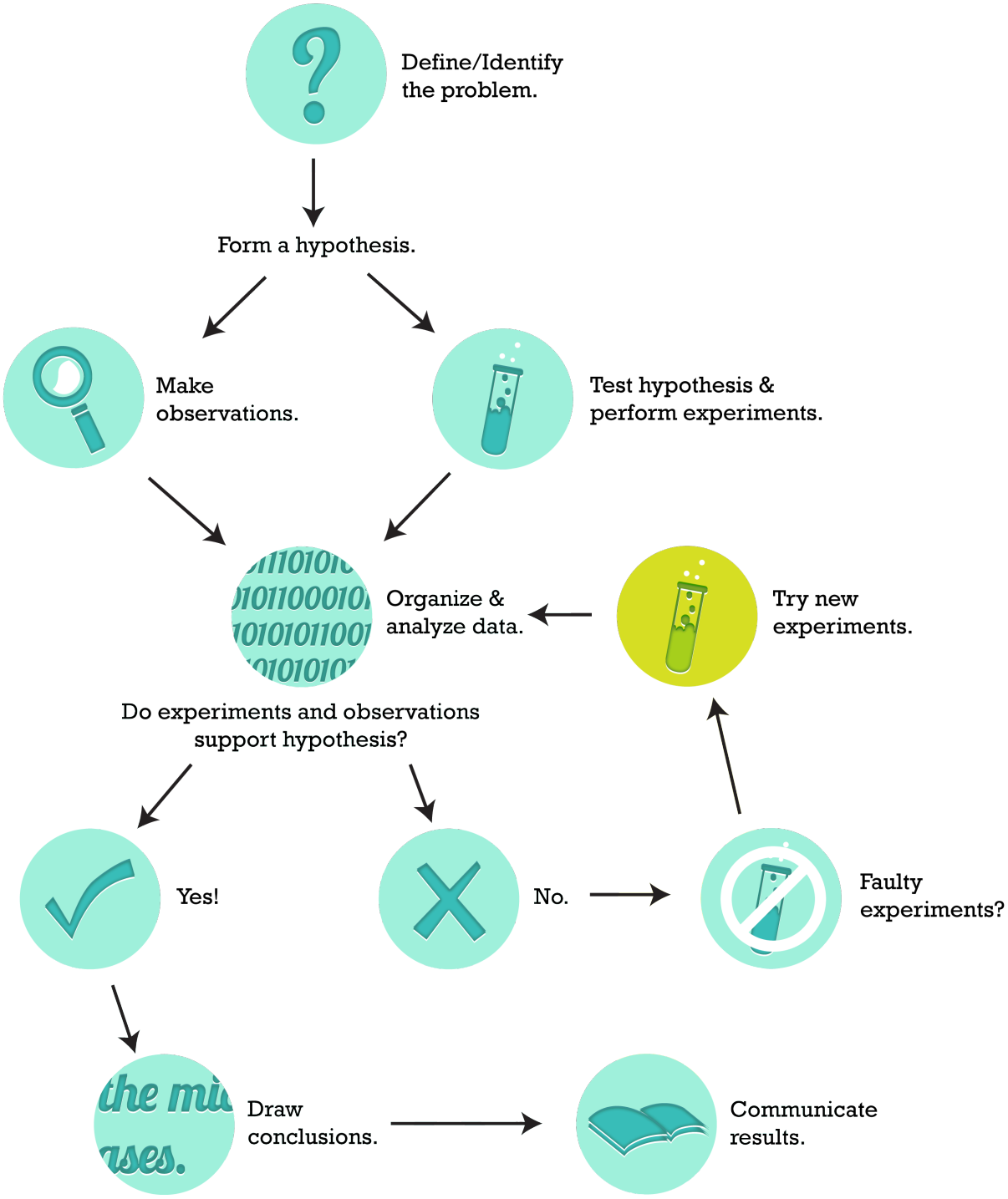
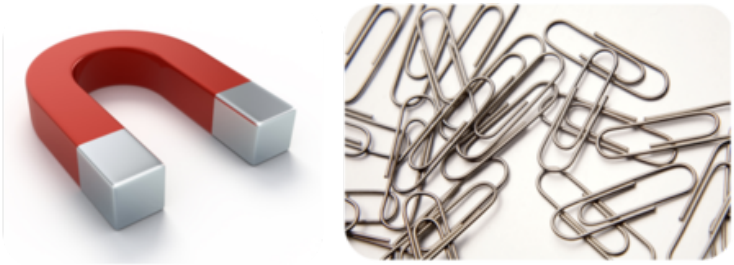


FIGURE 1.1

This diagram shows the steps of a scientific investigation. Other arrows could be added to the diagram. Can you think of one? (*Hint*: Sometimes evidence that does not support one hypothesis may lead to a new hypothesis to investigate.)

FIGURE 1.2

Each end of this bracelet contains a small magnet. The magnets attract each other and hold together the two ends.



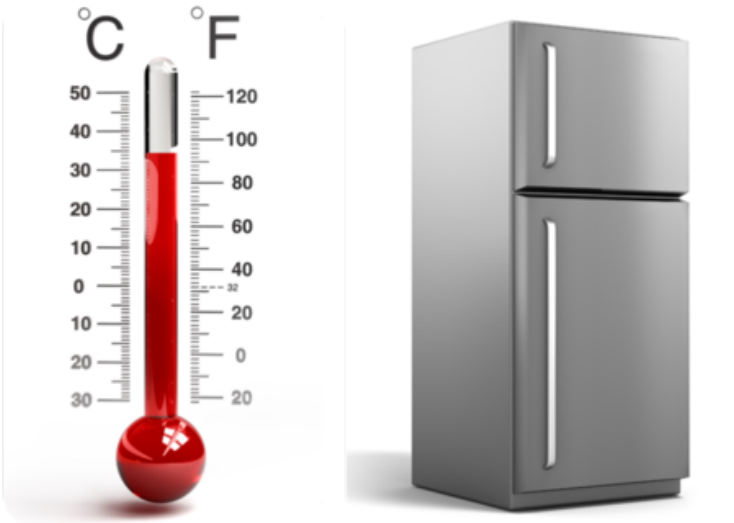


FIGURE 1.3

These are the materials Tara will use in her experiment. Can you explain how she will use them?

Tara is controlling for any magnet variables that might affect the results. What other variables should Tara control? (*Hint*: What about the paper clips?)

Doing Other Types of Studies

Not everything in physical science is as easy to study as magnets and paper clips. Sometimes it's not possible or desirable to do experiments. There are some things with which a person simply cannot experiment. A distant star is a good example. Scientists study stars by making observations with telescopes and other devices. Often, it's important to investigate a problem in the real world instead of in a lab. Scientists do **field studies** to gather real-world evidence. You can see an example of a field study in **Figure** 1.4. You can learn about another example by watching this video:

http://transcanada.essentialtalk.com/media/7/.

FIGURE 1.4

This environmental chemist is investigating causes of river pollution. He is collecting and analyzing samples of river water. How might the evidence he gathers in the field help him solve the problem?

Communicating Results

Researchers should always communicate their results. By sharing their results, they may be able to get helpful feedback from other scientists. Reporting on research also lets other scientists repeat the investigation to see whether they get the same results. Getting the same results when an experiment is repeated is called **replication**. If results can be replicated, it means they are more likely to be correct. Replication of investigations is one way that a hypothesis may eventually become a theory.

Scientists can share their results in various ways. For example, they can write articles for peer-reviewed science journals. Peer review means that the work is analyzed by peers, in this case other scientists. This is the best way to ensure that the results are accurate and reported honestly. Another way to share results with other scientists is with presentations at scientific meetings (see **Figure** 1.5). Creating websites and writing articles for newspapers and magazines are ways to share research with the public. Why might this be important?

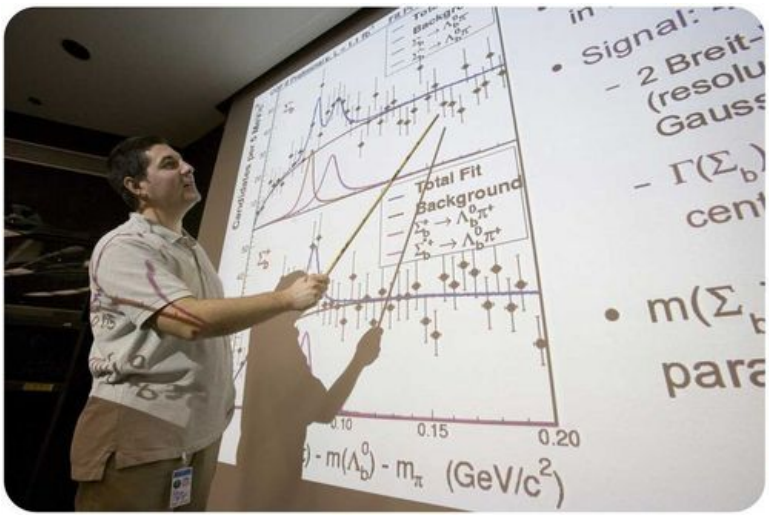


FIGURE 1.5

This researcher is presenting his results to a group of other scientists in his field.

Ethics and Scientific Research

Ethics refers to rules for deciding between right and wrong. Ethics is an important issue in science. Scientific research must be guided by ethical rules, including those listed below. The rules help ensure that the research is done safely and the results are reliable. Following the rules furthers both science and society. You can learn more about the role of ethics in science by following the links at this URL: http://www.files.chem.vt.edu/chem-ed/ethics/index.html#resources.

Ethical Rules for Scientific Research

- Scientific research must be reported honestly. It is wrong and misleading to make up or change research results.
- Scientific researchers must try to see things as they really are. They should avoid being biased by the results they expect or want to get.
- Researchers must be careful. They should take pains to avoid errors in their data.
- Researchers studying human subjects must tell their subjects about any potential risks of the research. Subjects also must be told that they can refuse to participate in the research.
- Researchers must inform coworkers, students, and members of the community about any risks of the research. They should proceed with the research only if they have the consent of these groups.
- Researchers studying living animals must treat them humanely. They should provide for their needs and do what they can to avoid harming them (see **Figure** 1.6).

FIGURE 1.6

This scientist is studying lab rats. He keeps them in comfortable cages and provides them with plenty of food and water.

Sometimes, science can help people make ethical decisions in their own lives, although science is unlikely to be the only factor involved. For example, scientific evidence shows that human actions are affecting Earth's climate. Actions such as driving cars are causing Earth to get warmer. Does this mean that it is unethical to drive a car to work or school? What if driving is the only way to get there? As this example shows, ethical decisions are likely to be influenced by many factors, not just science. Can you think of other factors that might affect ethical decisions such as this one?

Lesson Summary

- Steps of a scientific investigation include identifying a research question or problem, forming a hypothesis, gathering evidence, analyzing evidence, deciding whether the evidence supports the hypothesis, drawing conclusions, and communicating the results.
- Scientific research must be guided by ethical rules. They help ensure that the research is done safely and the results are reliable.

Lesson Review Questions

Recall

1. List the steps of a typical scientific investigation.
2. State why communication is important in scientific research.
3. Identify three ethical rules for scientific research.

Apply Concepts

4. Write a hypothesis based on this question: Do vinegar and water freeze at the same temperature? Make a prediction based on your hypothesis.
5. Describe an experiment you could do to test your prediction in question 4. Identify the variables and controls in your experiment. Include a list of materials. With your teacher's approval, conduct your investigation.

Think Critically

6. In Tara's experiment with the magnet, she measured and recorded the data in the **Table** 1.1.

TABLE 1.1: Tara's Data Table

Magnet Temperature (°C)	Number of Paper Clips Picked up by Magnet
24	8
4	6
3	6

Based on these data, Tara wrote this conclusion:

> Magnets get stronger at cooler temperatures, but only down to 4°C. Below 4°C, the strength of magnets does not change.

Do you agree with Tara's conclusion? Why or why not? Suggest an alternative explanation for the data.

7. Describe a better experiment to test Tara's original hypothesis. (*Hint*: You might include more measurements, a wider range of temperatures, and more than one magnet.)

Points to Consider

Scientific investigations often involve measuring. For example, Tara measured the temperature of a magnet with a thermometer. Thermometers may have different scales. You may be most familiar with the Fahrenheit and Celsius scales.

- Do you know how the Fahrenheit and Celsius scales differ? For example, what are the freezing and boiling points of water on each scale?
- Do you know how to convert a temperature from one scale to the other?