1–2 How Scientists Work

Guide for Reading

Key Concepts
- How do scientists test hypotheses?
- How does a scientific theory develop?

Vocabulary
spontaneous generation
controlled experiment
manipulated variable
responding variable
theory

Reading Strategy: Outlining As you read, make an outline of the main steps in a controlled experiment.

▼ **Figure 1–7** About 2000 years ago, a Roman poet wrote these directions for producing bees. **Inferring** *Why do you think reasonable individuals once accepted the ideas behind this recipe?*

Have you ever noticed what happens to food that is left in an open trash can for a few days in summer? Creatures that look like worms appear on the discarded food. These creatures are called maggots. For thousands of years people have been observing maggots on food that is not protected. The maggots seem to suddenly appear out of nowhere. Where do they come from?

Designing an Experiment

People's ideas about where some living things come from have changed over the centuries. Exploring this change can help show how science works. Remember that what might seem obvious today was not so obvious thousands of years ago.

About 2300 years ago, the Greek philosopher Aristotle made extensive observations of the natural world. He tried to explain his observations through reasoning. During and after his lifetime, people thought that living things followed a set of natural rules that were different from those for nonliving things. They also thought that special "vital" forces brought some living things into being from nonliving material. These ideas, exemplified by the directions in **Figure 1–7,** persisted for many centuries. About 400 years ago, some people began to challenge these established ideas. They also began to use experiments to answer their questions about life.

Asking a Question For many years, observations seemed to indicate that some living things could just suddenly appear: Maggots showed up on meat; mice were found on grain; and beetles turned up on cow dung. People wondered how these events happened. They were, in their own everyday way, identifying a problem to be solved by asking a question: How do new living things, or organisms, come into being?

Forming a Hypothesis For centuries, people accepted the prevailing explanation for the sudden appearance of some organisms, that some life somehow "arose" from nonliving matter. The maggots arose from the meat, the mice from the grain, and the beetles from the dung. Scholars of the day even gave a name to the idea that life could arise from nonliving matter—**spontaneous generation.** In today's terms, the idea of spontaneous generation can be considered a hypothesis.

In 1668, Francesco Redi, an Italian physician, proposed a different hypothesis for the appearance of maggots. Redi had observed that these organisms appeared on meat a few days after flies were present. He considered it likely that the flies laid eggs too small for people to see. Thus, Redi was proposing a new hypothesis—flies produce maggots. Redi's next step was to test his hypothesis.

Setting Up a Controlled Experiment In science, testing a hypothesis often involves designing an experiment. The factors in an experiment that can change are called variables. Examples of variables include equipment used, type of material, amount of material, temperature, light, and time.

Suppose you want to know whether an increase in water, light, or fertilizer can speed up plant growth. If you change all three variables at once, you will not be able to tell which variable is responsible for the observed results. **Whenever possible, a hypothesis should be tested by an experiment in which only one variable is changed at a time. All other variables should be kept unchanged, or controlled.** This type of experiment is called a **controlled experiment.** The variable that is deliberately changed is called the **manipulated variable.** The variable that is observed and that changes in response to the manipulated variable is called the **responding variable.**

Based on his hypothesis, Redi made a prediction that keeping flies away from meat would prevent the appearance of maggots. To test this hypothesis, he planned the experiment shown in **Figure 1–8.** Notice that Redi controlled all variables except one—whether or not there was gauze over each jar. The gauze was important because it kept flies off the meat.

CHECKPOINT *What was the responding variable in Redi's experiment?*

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Figure 1–8 In a controlled experiment, only one variable is tested at a time. Redi designed an experiment to determine what caused the sudden appearance of maggots. In his experiment, the manipulated variable was the presence or absence of the gauze covering. The results of this experiment helped disprove the hypothesis of spontaneous generation.

Redi's Experiment on Spontaneous Generation

OBSERVATIONS: Flies land on meat that is left uncovered. Later, maggots appear on the meat.

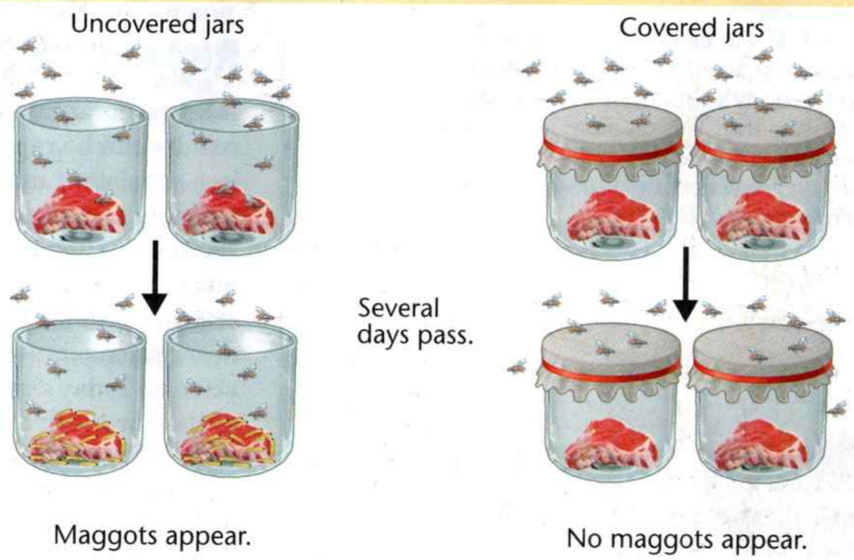
HYPOTHESIS: Flies produce maggots.

PROCEDURE

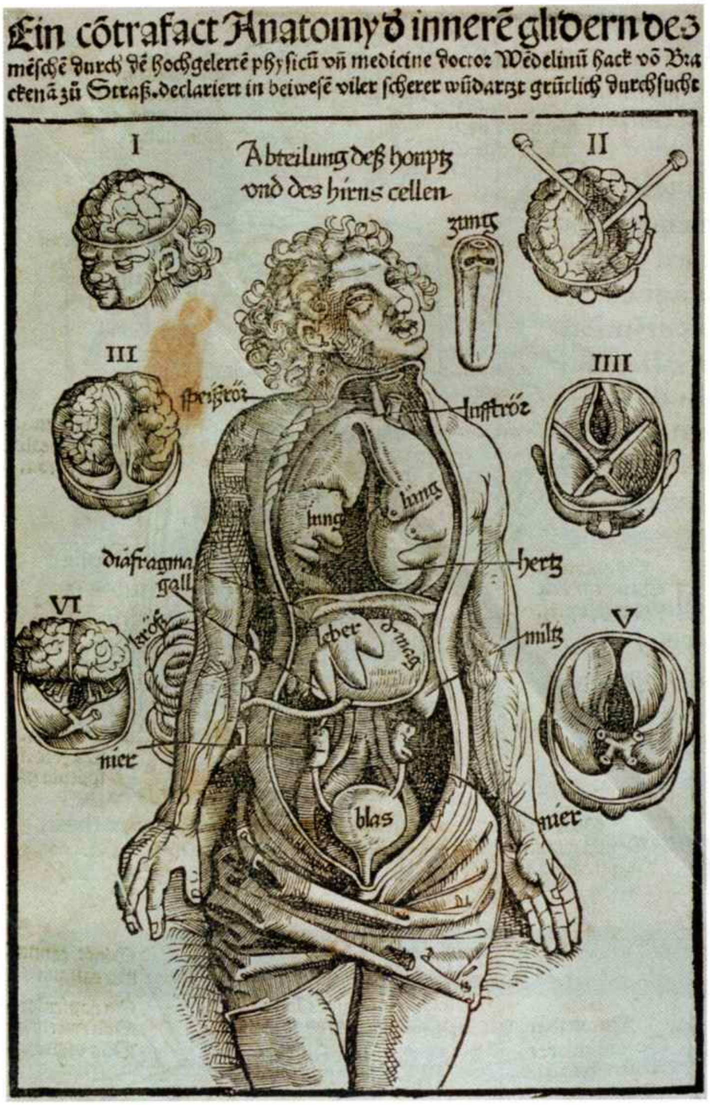
Controlled Variables: jars, type of meat, location, temperature, time

Manipulated Variable: gauze covering that keeps flies away from meat

Responding Variable: whether maggots appear



CONCLUSION: Maggots form only when flies come in contact with meat. Spontaneous generation of maggots did not occur.



▲ **Figure 1–9** For centuries, the workings of the human body remained a mystery. Gradually, scientists observed the body's structures and recorded their work in drawings like this. This diagram dates back to fifteenth-century Austria. **Comparing and Contrasting** *How does this drawing compare with the modern illustrations in Unit 10?*

Recording and Analyzing Results Scientists usually keep written records of their observations, or data. In the past, data were usually recorded by hand, often in notebooks or personal journals. Sometimes, drawings such as **Figure 1–9** recorded certain kinds of observations more completely and accurately than a verbal description could. Today, researchers may record their work on computers. Online storage often makes it easier for researchers to review the data at any time and, if necessary, offer a new explanation for the data. Scientists know that Redi recorded his data because copies of his work were available to later generations of scientists. His investigation showed that maggots appeared on the meat in the control jars. No maggots appeared in the jars covered with gauze.

Drawing a Conclusion Scientists use the data from an experiment to evaluate the hypothesis and draw a valid conclusion. That is, they use the evidence to determine whether the hypothesis was supported or refuted. Redi's results supported his hypothesis. He therefore concluded that the maggots were indeed produced by flies.

As scientists look for explanations for specific observations, they assume that the patterns in nature are consistent. Thus, Redi's results could be viewed not only as an explanation about maggots and flies but also as a refutation of the hypothesis of spontaneous generation.

✓CHECKPOINT ***What did Redi conclude?***

Repeating Investigations

A key assumption in science is that experimental results can be reproduced because nature behaves in a consistent manner. When one particular variable is manipulated in a given set of variables, the result should always be the same. In keeping with this assumption, scientists expect to test one another's investigations. Thus, communicating a description of an experiment is an essential part of science. Today's researchers often publish a report of their work in a scientific journal. Other scientists review the experimental procedures to make sure that the design was without flaws. They often repeat experiments to be sure that the results match those already obtained. In Redi's day, scientific journals were not common, but he communicated his conclusion in a book that included a description of his investigation and its results.

Needham's Test of Redi's Findings Some later tests of Redi's work were influenced by an unexpected discovery. About the time Redi was carrying out his experiment, Anton van Leeuwenhoek (LAY-vun-hook) of the Netherlands discovered a world of tiny moving objects in rainwater, pond water, and dust. Inferring that these objects were alive, he called them "animalcules," or tiny animals. He made drawings of his observations and shared them with other scientists. For the next 200 years or so, scientists could not agree on whether the animalcules were alive or how they came to exist.

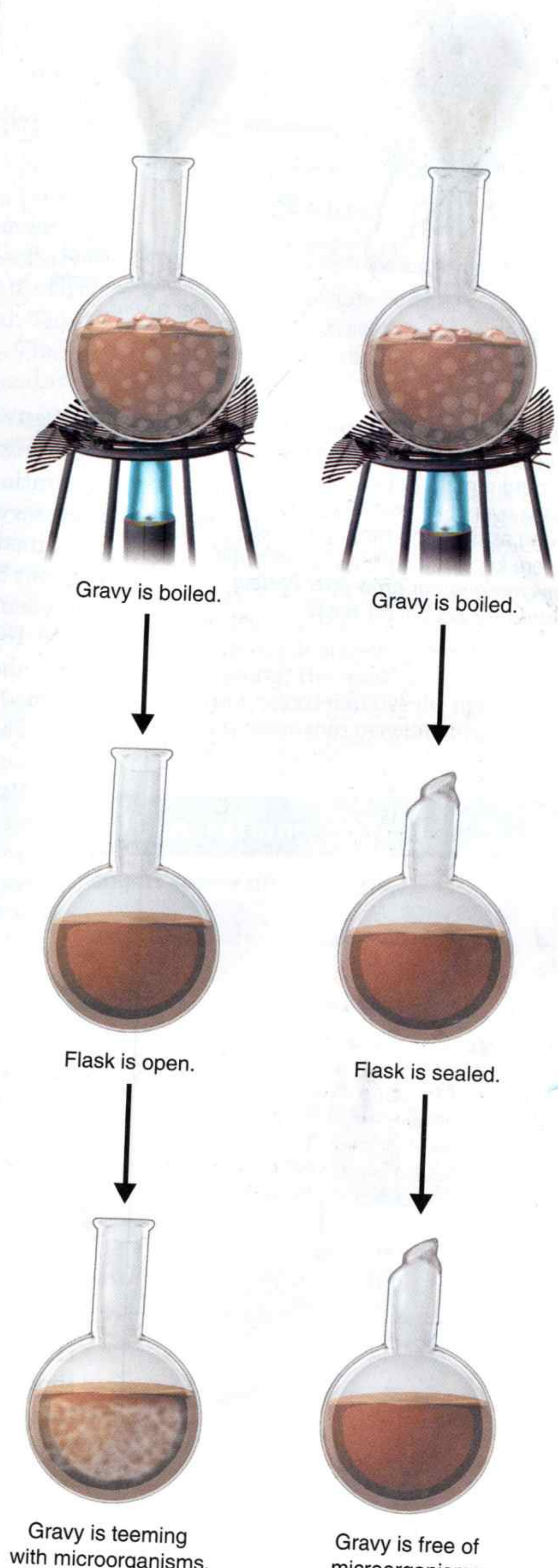
In the mid-1700s, John Needham, an English scientist, used an experiment involving animalcules to attack Redi's work. Needham claimed that spontaneous generation could occur under the right conditions. To prove his claim, he sealed a bottle of gravy and heated it. He claimed that the heat had killed any living things that might be in the gravy. After several days, he examined the contents of the bottle and found it swarming with activity. "These little animals," he inferred, "can only have come from juice of the gravy."

Spallanzani's Test of Redi's Findings

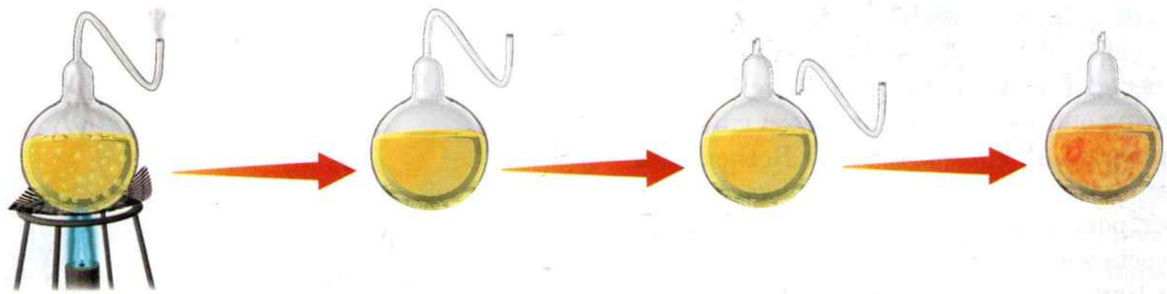
An Italian scholar, Lazzaro Spallanzani, read about Redi's and Needham's work. Spallanzani thought that Needham had not heated his samples enough and decided to improve upon Needham's experiment. **Figure 1–10** shows that Spallanzani boiled two containers of gravy, assuming that the boiling would kill any tiny living things, or microorganisms, that were present. He sealed one jar immediately and left the other jar open. After a few days, the gravy in the open jar was teeming with microorganisms. The sealed jar remained free of microorganisms.

Spallanzani concluded that nonliving gravy did not produce living things. The microorganisms in the unsealed jar were offspring of microorganisms that had entered the jar through the air. This experiment and Redi's work supported the hypothesis that new organisms are produced only by existing organisms.

CHECKPOINT ***How did Spallanzani's investigative procedures improve upon Needham's work?***



▶ **Figure 1–10** Spallanzani's experiment showed that microorganisms will not grow in boiled gravy that has been sealed but will grow in boiled gravy that is left open to the air. **Interpreting Graphics** *What variable was controlled in this experiment?*



▲ **Figure 1–11** Pasteur's experiment showed that boiled broth would remain free of microorganisms even if air was allowed in, as long as dust and other particles were kept out. **Inferring** ***Why did microorganisms grow after Pasteur broke the neck of the flask?***

Pasteur's Test of Spontaneous Generation Well into the 1800s, some scientists continued to support the spontaneous generation hypothesis. Some of them argued that air was a necessary factor in the process of generating life because air contained the "life force" needed to produce new life. They pointed out that Spallanzani's experiment was not a fair test because air had been excluded from the sealed jar.

In 1864, French scientist, Louis Pasteur, found a way to finally disprove the hypothesis of spontaneous generation. He designed a flask that had a long curved neck, as shown in **Figure 1–11.** The flask remained open to the air, but microorganisms from the air did not make their way through the neck into the flask. Pasteur boiled the flask thoroughly to kill any microorganisms it might contain. Pasteur waited an entire year. In that time, no microorganisms could be found in the flask.

About a year after the experiment began, Pasteur broke the neck of the flask, allowing air dust and other particles to enter the broth. In just one day, the flask was clouded from the growth of microorganisms. Pasteur had clearly shown that microorganisms had entered the flask with particles from the air. His work convinced other scientists that the hypothesis of spontaneous generation was not correct. In other words, Pasteur showed that all living things come from other living things. This change in thinking represented a major shift in the way scientists viewed living things.

✓CHECKPOINT ***What improvement did Pasteur make to Redi's experiment?***

The Impact of Pasteur's Work During his lifetime, Pasteur made many discoveries related to microorganisms. His research had an impact on society as well as on scientific thought. He saved the French wine industry, which was troubled by unexplained souring of wine, and the silk industry, which was endangered by a silkworm disease. Moreover, he began to uncover the very nature of infectious diseases, showing that they were the result of microorganisms entering the bodies of the victims. Pasteur is considered one of biology's most remarkable problem solvers.