Chapter 1: Introduction to Biology

Lesson 1.2: The Scientific Method

The goal of science is to learn and explain how nature works. We do this by observing the natural and physical world and also through research and experimentation. Science is, in part, a process of learning about the world through observation, inquiry, formulating and testing hypotheses, gathering and analyzing data, and reporting and evaluating findings. This process is sometimes referred as the scientific method. We are all part of an amazing a mysterious phenomenon called "life" that thousands of scientists everyday are trying to better explain. And it's surprisingly easy to become part of this great discovery! All you need is your natural curiosity and an understanding of how people use the process of science to learn about the world.

Lesson Objectives

• Identify the goal of science.
• Describe how scientists study the natural world; using the scientific method.
• Explain how and why scientists do experiments.
• Describe types of scientific investigations.
• Explain what a scientific theory is.

Vocabulary

- dependent variable
- evidence
- experiment
- homeostasis
- hypothesis
- independent variable
- observation
- prediction
- scientific law
- scientific theory

THE SCIENTIFIC METHOD

There are basic methods of gaining knowledge that are common to all of science. At the heart of science is the scientific investigation, which is done by following the scientific method. A scientific investigation is a plan for asking questions and testing possible answers. It generally follows the steps listed in **Figure 1.17.** See http://www.youtube.com/watch?v=zcavPAFiG14& for an overview of the scientific method.

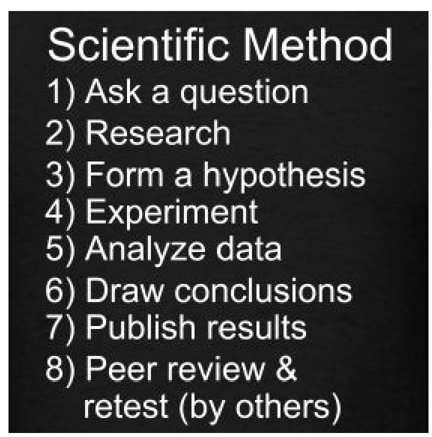

Figure 1.17: Steps of a Scientific Investigation. A scientific investigation typically has these steps.

Making Observations & Inferences

A scientific investigation typically begins with observations. You make observations all the time. Observations are made using your 5 senses. These include sight, sound, taste, touch, and smell. An inference is a guess that is made based on your observations. Let's say you take a walk in the woods and observe a moth, like the one in **Figure 1.18**, resting on a tree trunk. You observe that the moth has spots on its wings that look like eyes. You think the eye spots make the moth look like the face of an owl. You infer that the moth uses the "owl eye" to protects itself from predators.

Figure 1.18: Does this moth remind you of an owl?

Asking a Question

Observations often lead to questions. For example, you might ask yourself why the moth has eye spots that make it look like an owl's face. What reason might there be for this observation? Asking a question helps focus your investigation.

Forming a Hypothesis

The next step in a scientific investigation is forming a hypothesis. A hypothesis is a possible answer to a scientific question, but it isn't just any answer. A hypothesis must be based on scientific knowledge, and it must be logical. A hypothesis must be testable and falsifiable. Falsifiable is the ability to collect data that does not support a hypothesis. Finally, hypotheses are often stated as an "If...then" statement, because it shows *cause and effect*; if A occurs, then B will happen. Assume you know that some birds eat moths and that owls prey on other birds. From this knowledge, you make the hypothesis: If a moth has eye spots on its wings, then birds will avoid eating it.

Testing the Hypothesis - Conducting a Controlled Experiment

Next, you must gather evidence to test your prediction. Evidence is any type of data that may either agree or disagree with a prediction. So it may either support or disprove a hypothesis. The most ideal way to gather data is to conduct a controlled experiment. All good controlled experiments include the following elements: independent variables, dependent variable, constants, control group, and experimental groups. These terms will be discussed later in the section. However, a controlled experiment cannot be used in every situation; sometimes scientists simply rely on a large number of consistent observations to draw conclusions. For example, suppose you gather evidence by making more observations of moths with eye spots -- many observations under many types of conditions. If you consistently observe that birds really do avoid eating the moths, then your data (observations) support your prediction.

Drawing Conclusions

Evidence that agrees with your prediction supports your hypothesis. Does such evidence prove that your hypothesis is true? Not necessarily; a hypothesis cannot be proven conclusively to be true unless there is a very tightly controlled experiment. This is rarely possible because you can never examine all of the possible evidence, and someday evidence might be found that disproves or refutes the hypothesis. Nonetheless, the more evidence that supports a hypothesis, the more likely the hypothesis is to be true.

Communicating Results

The last step in a scientific investigation is communicating what you have learned with others. This is a very important step because it allows others to verify your methods and results. If other researchers get the same results as yours, the hypothesis becomes stronger. However, if they get different results, they may not support the hypothesis. When scientists share their results, they should describe their methods and point out any possible problems with the investigation. Finally, communicating results can be done in a variety of ways including scientific papers, blogs, news articles, conferences, etc.

For example, while you were observing moths, perhaps your presence scared birds away. This introduces an error into your investigation. You got the results you predicted (the birds avoided the moths while you were observing them), but not for the reason you hypothesized. Other researchers might be able to think of ways to avoid this error in future studies.

CONTROLLED EXPERIMENTS

A scientific investigation is a plan for asking questions and testing possible answers. A controlled experiment is a special type of scientific investigation that is performed under specific conditions, usually in a laboratory. The complexity of an experiment can range. However, no matter the complexity, all controlled experiments share important properties. An example experiment can be seen here or here.

Figure 1.19: A laboratory experiment studying plant growth. What might this experiment involve?

Variables

An experiment generally tests how one variable is affected by another. The **dependent variable** is measured throughout an experiment and is sometimes called the affected variable. In the plant experiment shown above, the dependent variable is plant growth. The variable that affects the dependent variable is called the **independent variable**. Independent variables can be controlled by the experimenter. In the plant experiment, the independent variable is fertilizer—some plants will get fertilizer, others will not.

Constants

In any experiment, other factors that might affect the dependent variable must not change; these are known as **constants**. A constant is something that remains the same throughout the experiment. These things are the same for each test. In the plant experiment, what factors do you think should be constants? (*Hint:* What other factors might affect plant growth?) You were right if you said things such as: amount of sunlight, amount of water, container type and size, etc.

Control and Experimental Groups

Experiments will often have a control and experimental groups. An **experimental group** is a group individuals/events that the independent variable is applied to during the experiment. The **control group** is a group of individuals/events that are *not* tested upon. Essentially, the control group creates a baseline to compare the data from the experimental group to. It's important to note that not all experiments have a control group.

Sample Size and Repetition

The sample in an experiment or investigation consists of the individuals or events that are studied. Typically, the an experiment's sample is much smaller than those that exist in the world. In general**, the larger the sample is, the more likely it is that the results are valid.** Similarly, the more times that an experiment is repeated and the same results obtained, the more likely the results are valid. This is why scientific experiments should always be repeated.

OTHER TYPES OF SCIENTIFIC INVESTIGATIONS

Controlled experiments are sometimes hard or even impossible to do. For example, a scientist who is studying an extinct animal cannot experiment with the animal. The scientist must rely instead on indirect evidence, such as fossils that the extinct animal left behind.

Natural Studies

When natural studies are completed, there are often factors that cannot be controlled. As such, the data or observations are less reliable because there may have been other factors that influenced the data. For example, assume you are studying how plants grow in a forest or field. You cannot control the amount of sunlight or water the plants receive, so it will be difficult to determine which factors most influence plant growth. However, the benefits of a natural study is that it shows what actually occurs in nature. Therefore, it may provide a truer picture of what happens in the real world than an experiment.

Modeling

Another way to gain scientific knowledge without a controlled experiment is by making and manipulating models. A model is a representation of part of the real world, and these can include physical models as well as computer simulations. Did you ever build a model car? Scientific models are something like model cars; which represent the real world in a smaller simpler fashion. This is why models are useful for investigating complex systems. By using a model, scientists can better understand how the actual system works. An example of a scientific model is shown in **Figure 1.20**. Do you know what systems these two models represent?

The usefulness of a model depends on how well its predictions match observations of the real world. Even when a model's predictions match real-world observations, however, it doesn't prove that the model is true or that it is the only model that works.

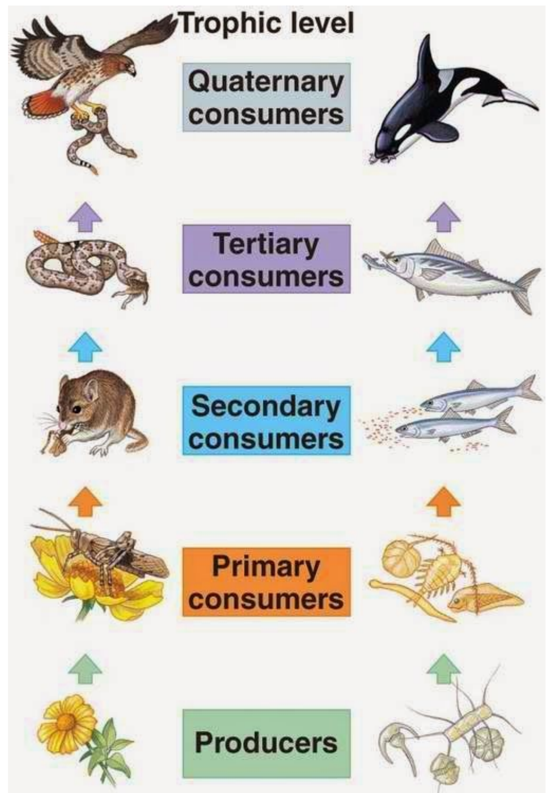

Figure 1.20: Food Chains. These two food chains represent complex systems in nature. They make the systems easier to understand. These are simple conceptual models. Models of very complex systems are often based on mathematical equations or computer simulations.

SCIENTIFIC THEORIES AND LAWS

Scientific Theories

With repeated testing, some hypotheses may eventually become scientific theories. A scientific theory is a broad explanation that is widely accepted as true. To become a theory, a hypothesis must be tested over and over again, and it must be supported by a great deal of evidence. People commonly use the word **theory** to describe a guess about how or *why* something happens. For example, you might say, ‘‘I think a woodchuck dug this hole in the ground, but it's just a theory.” Using the word *theory* in this way is different from the way it is used in science. A scientific theory is more like a fact than a guess because it is so well-supported.

One key idea behind theories is that they change. As scientist gain new information about a topic, they will adjust or change the theory. There are several well-known theories in biology, including the theory of evolution, cell theory, and gene theory. You will read about all three of these theories in the next lesson. A video explaining scientific theories can be seen here.

Scientific Laws

Scientists think of nature as a single system controlled by natural laws. By discovering natural laws, scientists strive to increase their understanding of the natural world. Laws of nature are expressed as scientific laws. A scientific **law** is a statement that describes *what* always happens under certain conditions in nature. A law will not change and always hold true.

An example of a scientific law is the law of gravity, which was discovered by Sir Isaac Newton (see **Figure 1.16**). The law of gravity states that objects always fall towards Earth because of the pull of gravity. Based on this law, Newton could explain many natural events. He could explain not only why objects such as apples always fall to the ground, but he could also explain why the moon orbits Earth. Isaac Newton discovered laws of motion as well as the law of gravity. His laws of motion allowed him to explain why objects move as they do.

Figure 1.16: Did Newton discover the law of gravity when an apple fell from a tree and hit him on the head? Probably not, but observations of nature are often the starting point for new ideas about the natural world.

APPLYING CONCEPTS: Bio-Inspiration: Nature as Muse

For hundreds of years, scientists have been using design ideas from structures in nature. Now, biologists and engineers at the University of California, Berkeley are working together to design a broad range of new products, such as life-saving milli-robots modeled on the way cockroaches run and adhesives based on the amazing design of a gecko's foot. This process starts with making observations of nature, which lead to asking questions and to the additional aspects of the scientific process. *Bio-Inspiration: Nature as Muse* can be observed here.

Lesson Summary

- The goal of science is to understand the natural world through systematic study. Scientific knowledge is based on evidence and logic.
- Scientists gain knowledge through scientific investigations. A scientific investigation is a plan for asking questions and testing possible answers.
- Scientists use experiments to test hypotheses under controlled conditions. Experiments are often done in a lab.
- Other types of scientific investigations include natural studies and modeling. They can be used when experiments are difficult to do.
- Scientific theories are broad explanations that are widely accepted as true. This is because they are supported by a great deal of evidence.

1.2 References/ Multimedia Resources

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