Section 2
Scientific Methods

Key Concept Scientists use scientific methods to answer questions and to solve problems.

What You Will Learn

- Scientific methods are based on six steps, which may be followed in different ways based on the kind of question being asked.
- Scientific investigations begin with a question and proceed by forming a hypothesis and then testing it.
- Scientists use a variety of methods to analyze and report their data.

Why It Matters

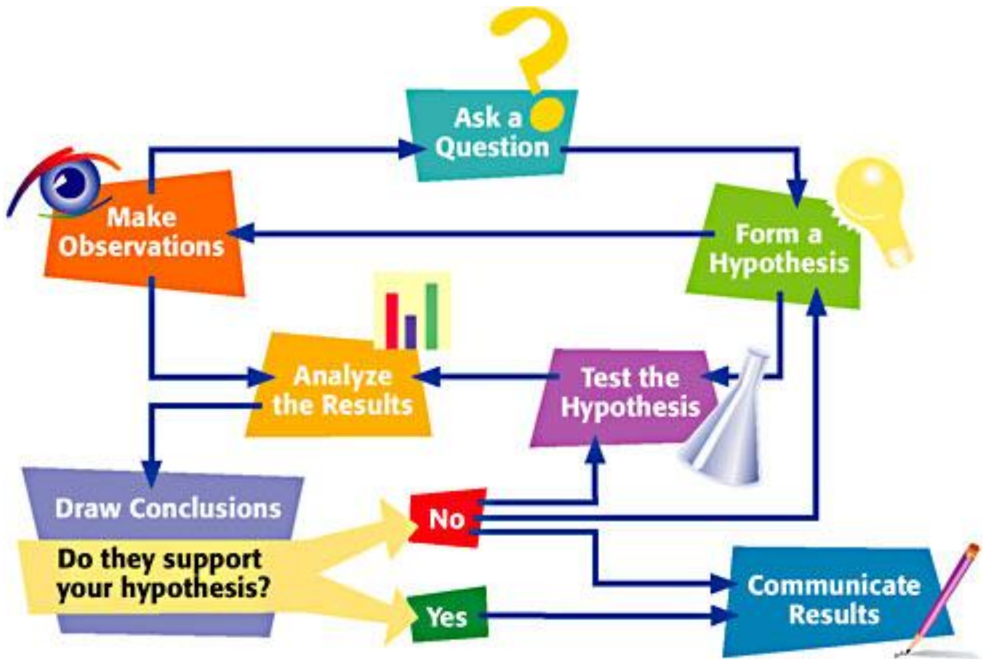
Scientific methods provide a framework for conducting careful investigations and understanding the natural world.

Two scientists from the Massachusetts Institute of Technology (MIT) thought that studying penguins was a great way to improve ships! James Czarnowski (zahr NOW SKEE) and Michael Triantafyllou (tree AHN ti FEE loo) used scientific methods to develop *Proteus* (PROH tee uhs), the penguin boat. Can you imagine how and why they did that? In the next few pages, you will learn how these scientists used scientific methods to answer their questions. Scientific methods require knowledge and creativity. And they are very useful in answering some difficult questions.

What Are Scientific Methods?

Scientific methods are the ways in which scientists answer questions and solve problems. As scientists look for answers, they often use the same steps. But there is more than one way to use the steps. Look at **Figure 1.** This figure is an outline of the six steps on which scientific methods are based. Scientists may use all of the steps or just some of the steps during an investigation. They may even repeat some of the steps or do the steps in a different order. How they choose to use the steps depends on what works best to answer their question.

Figure 1 Steps of Scientific Methods



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Asking a Question

Asking a question helps focus the purpose of an investigation. Scientists often ask a question after making many observations. **Observation** is any use of the senses to gather information. Noting that the sky is blue or that a cotton ball feels soft is an observation. Measurements are observations that are made with tools. Observations can be made (and should be accurately recorded) at any point during an investigation.

Standards Check In science, what is the purpose of asking questions?

A Real-World Question

Czarnowski and Triantafyllou, shown in **Figure 2,** are engineers—scientists who put scientific knowledge to practical use. Czarnowski was a graduate student at the Massachusetts Institute of Technology. He and Triantafyllou, his professor, worked together to observe boat propulsion (proh PUHL shuhn) systems. Then, they investigated how to make these systems work better. A propulsion system is what makes a boat move. Most boats have propellers to move them through the water.

Figure 2 James Czarnowski (left) and Michael Triantafyllou (right) made observations about how boats work in order to develop Proteus.

Czarnowski and Triantafyllou began their investigation by studying the efficiency (e FISH uhn see) of boat propulsion systems. *Efficiency* compares energy output (the energy used to move the boat forward) with energy input (the energy supplied by the boat's engine). From their observations, Czarnowski and Triantafyllou learned that boat propellers are not very efficient.

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The Importance of Boat Efficiency

Most boats that have propellers are only about 70% efficient. Boat efficiency is important because it saves many resources. Making only a small fraction of U.S. boats and ships just 10% more efficient would save millions of liters of fuel per year. Based on their observations and all of this information, Czarnowski and Triantafyllou were ready to ask a question: How can boat propulsion systems be made more efficient? This is a good example of a question that can start a scientific investigation because it is a question that can be answered by observation.

Forming a Hypothesis

Once you've asked your question and made observations, you are ready to form a hypothesis. A **hypothesis** is a possible explanation or answer to a question. You can use what you already know and what you have observed to form a hypothesis.

A good hypothesis is testable. In other words, information can be gathered or an experiment can be designed to test the hypothesis. A hypothesis that is not testable isn't necessarily wrong. But there is no way to show whether the hypothesis is right or wrong.

A Possible Answer from Nature

Czarnowski and Triantafyllou wanted to base their hypothesis on an example from nature. Czarnowski had made observations of penguins swimming. He observed how quickly and easily the penguins moved through the water. **Figure 3** shows how penguins propel themselves. Czarnowski also observed that penguins, like boats, have rigid bodies. These observations led to a hypothesis: A propulsion system that imitates the way that a penguin swims will be more efficient than a propulsion system that uses propellers.

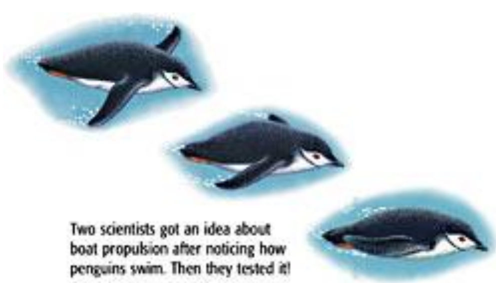

Figure 3 Penguins use their flippers to "fly" underwater. As they pull their flippers toward their bodies, they push against the water, which propels them forward.

Making Predictions

Before scientists test a hypothesis, they often predict what they think will happen when they test the hypothesis. Scientists usually state predictions in an if-then statement. The engineers at MIT might have made the following prediction: *If* two flippers are attached to a boat, *then* the boat will be more efficient than a boat powered by propellers.

Testing the Hypothesis

After you form a hypothesis, you must test it. You must find out if it is a reasonable answer to your question. Testing helps you find out if your hypothesis is pointing you in the right direction or if it is way off the mark. If your hypothesis is way off the mark, you may have to change it.

Controlled Experiments

A controlled experiment is a good way to test a hypothesis. A *controlled experiment* compares the results from a control group with the results from experimental groups. All factors remain the same except for one. The factors that are kept the same between the groups are called *controlled parameters.* These factors are held constant. The one factor that changes between the groups is called a *variable parameter.* The results will show the effect of the variable parameter.

Czarnowski and Triantafyllou thought the best way to test their hypothesis was to build a device to test. So, they built *Proteus,* the penguin boat, shown in **Figure 4.** It had flippers like a penguin so that the scientists could test their hypothesis.

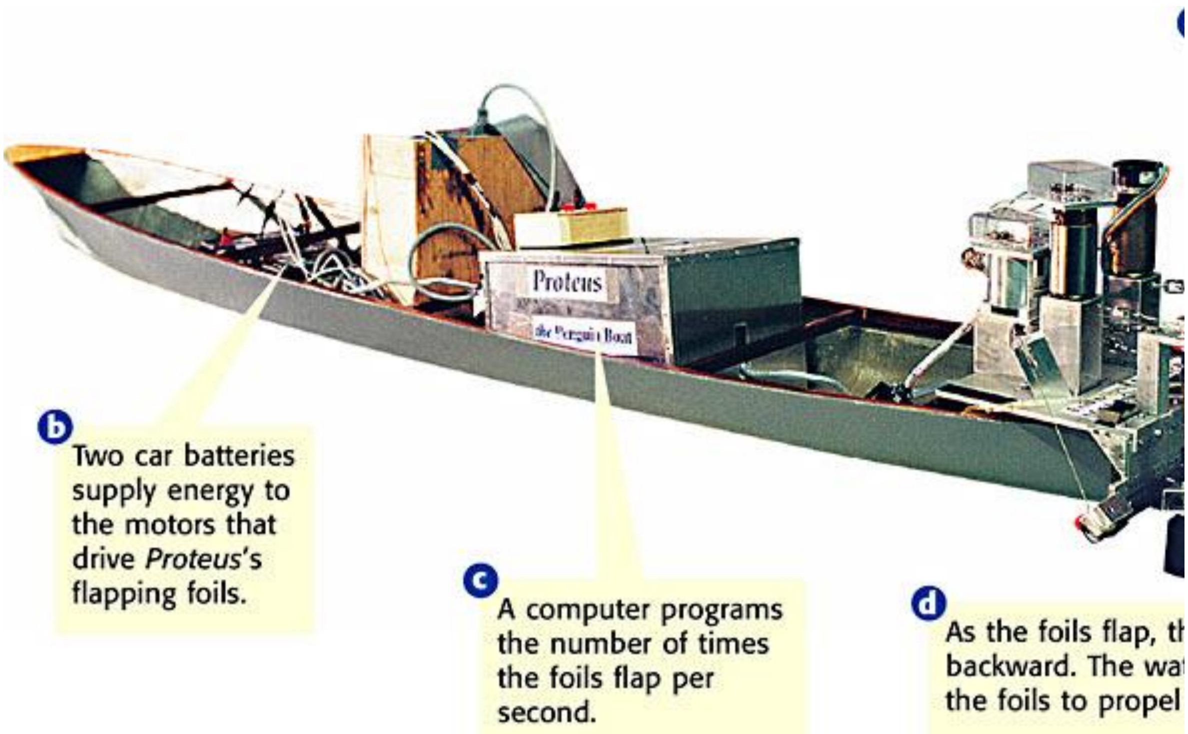

Figure 4 Proteus, a 3.4 m long and 50 cm wide specially built boat model, was used to test the "flippers" hypothesis.

Standards Check What is the difference between the controlled and the variable parameters in an experiment?

Testing *Proteus*

Czarnowski and Triantafyllou took *Proteus* out into the open water of the Charles River in Boston, shown in **Figure 5,** when they were ready to collect data. **Data** are any pieces of information gotten through experimentation. For each test, data such as the flapping rate, the energy used by the motors, and the speed achieved by the boat were carefully recorded. But the only parameter the scientists changed was the flapping rate. That way, they could tell what effect the flapping rate had on *Proteus's* efficiency. The efficiency was the ratio of output energy to input energy. The input energy was determined by how much energy was used. The output energy was determined from the speed that *Proteus* reached.

Figure 5 Proteus, the "penguin boat," was tested in the Charles River in Boston.

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Analyzing the Results

After you collect your data, you must analyze them. Organizing data into tables and graphs makes relationships between information easier to see. Analyzing and organizing data from repeated tests can help you tell if your data were accurate. It can also help you evaluate your data's reproducibility. Data are reproducible when you get similar data from many tests.

Analyzing *Proteus*

Czarnowski and Triantafyllou used the data for input energy and output energy to calculate *Proteus's* efficiency for different flapping rates. These data are graphed in **Figure 6.** The scientists compared *Proteus's* highest level of efficiency with the average efficiency of a propeller-driven boat. As you can see, the data support the scientists' hypothesis that penguin propulsion is more efficient than propeller propulsion.

Figure 6 Graphs of the Test Results

This line graph shows that *Proteus* was most efficient when its foils were flapping about 1.7 times per second.

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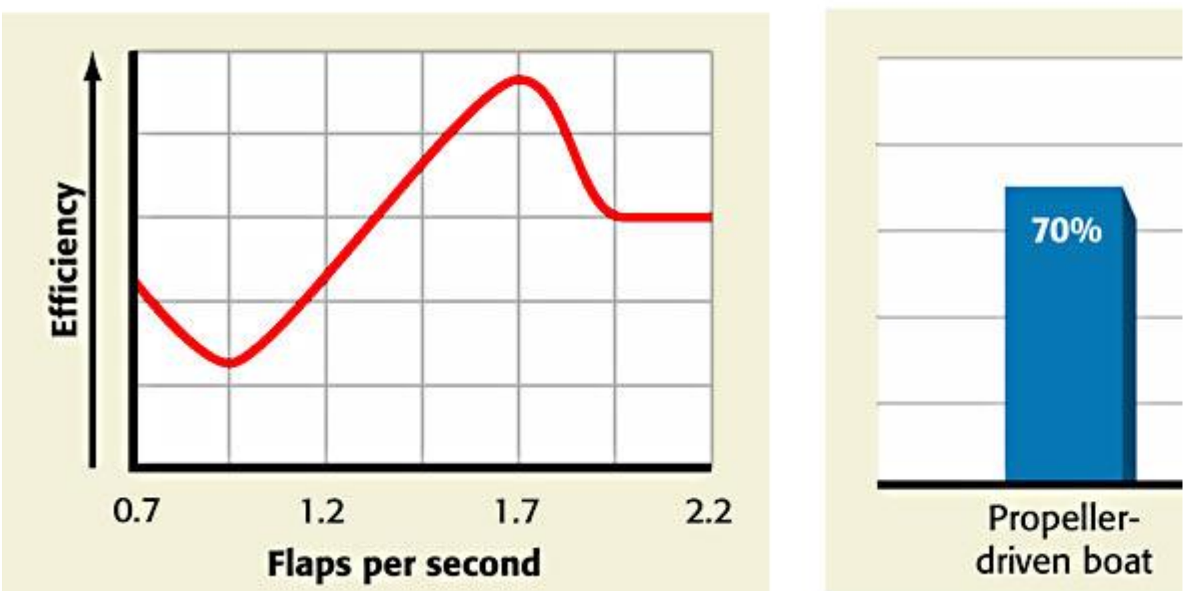

Standards Check What is a good way to evaluate the accuracy and reproducibility of data?

Drawing Conclusions

At the end of an investigation, you must draw a conclusion. You might conclude that your results support your hypothesis. Or you could conclude that your results do *not* support your hypothesis. If so, you could change the procedure, gather more information, or ask new questions. Whether or not your hypothesis was supported, the results are always important.

The *Proteus* Conclusion

Czarnowski and Triantafyllou found that the penguin propulsion system was more efficient than a propeller propulsion system. They concluded that their hypothesis was supported.

The scientists were able to reach this conclusion because of repeated tests of variable and controlled parameters. Valid—that is, trustworthy—conclusions require that your data are reproducible. In other words, you can demonstrate the same relationship many times. This helps make sure the data of your experiment were not accidental. Reaching a valid conclusion usually leads to more questions that can be investigated, as **Figure 7** shows. In this way, the process of scientific progress continues!

Figure 7 A penguin propulsion system may one day be used on large ships. Would it work? The research continues!

Standards Check Why is it important to establish the reproducibility of data?

Communicating Results

One of the most important steps in any investigation is communicating your results. You can write a scientific paper, make a presentation, or create a Web site. Telling others what you learned keeps science going. Other scientists can then conduct their own tests based on your results.

Czarnowski and Triantafyllou published their results in academic papers, science magazines, and newspapers. They also displayed the results of their project on the Internet. Sharing your results allows other scientists to continue your work or to verify your results by doing their own experiments.

Section Summary

- Scientific methods are the ways in which scientists answer questions and solve problems.
- Asking a question usually results from making an observation. Questioning is often the first step in using scientific methods.
- A hypothesis is a possible explanation or answer to a question. A good hypothesis is testable by an experiment.
- After performing an experiment, you should analyze your results. Analyzing is usually done by using calculations, tables, and graphs.
- After analyzing your results, you should draw conclusions about whether your hypothesis is supported.
- Communicating your results allows others to check or continue your work. You can communicate through reports, posters, and the Internet.