SCIENTIFIC INQUIRY

Nobel Prize-winning chemist Sir Cyril Norman Hinshelwood described science as "an imaginative adventure of the mind seeking truth in a world of mystery." The different ways that scientists explore or seek truth in the world can be collectively described as scientific inquiry. The most traditional model for conducting scientific inquiry is known as the scientific method.

THE SCIENTIFIC METHOD

The scientific method is used by scientists to conduct experiments and research and record their findings. These recordings allow others to interpret and build upon their work. Because there is more than one way to explore science, different books, websites, and documents describe the scientific method in various ways. Some sources describe the scientific method in four steps. Others describe it in five steps. No matter how it is presented, the scientific method generally includes the same basic concepts, which are described in the following pages. It is important to remember that when conducting scientific inquiry, scientists may go through the process in different ways. For example, sometimes you may make a new observation after conducting research.

OBSERVATION

Scientists generally begin by making an observation. They explore and collect information with their senses (smell, sight, sound, touch, and taste) and ask a question that they would like to answer. This question will guide scientists in conducting research and experiments.

***Example:** Observation*

- When I turn on a flashlight using the on/off switch, light comes out of one end.

***Example:** Question*

- What makes light come out of a flashlight when I turn it on?

RESEARCH

Once scientists ask a question, they generally do research. Scientists have been asking questions for thousands of years, so there is a good chance that someone has made the same observation and asked a similar question. Therefore, after asking the question, scientists spend time reading papers and books on past research to prepare for their own research. Your students should do the same! When studying prior research, it is important that the information is from a credible source, meaning that the information and the source of the information are believable and trustworthy. Conducting research helps scientists better understand their observations or questions before they conduct experiments (and will help you and your students, too!).

***Example:** Research*

- Look in the flashlight's instruction manual for tips, or conduct an online search on how flashlights work using the manufacturer's website. You can even analyze information and past experiments or discoveries regarding the relationship between energy and light.

HYPOTHESIS

With a question in mind, scientists decide on what they want to test. (The question may have changed as a result of research.) Scientists will clearly state what they expect to find out during the experiment. They'll make an educated guess that could answer the question or explain the observation. This statement is called a **hypothesis**. A hypothesis guides the experiment and must be testable.

***Example:** Hypothesis*

- The batteries inside a flashlight give it energy to produce light when the flashlight is turned on.

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EXPERIMENTATION

Design and conduct an experiment that tests the hypothesis. Remember, a hypothesis is only an educated guess (a possible explanation), so it cannot be considered valid until an experiment verifies that it is valid.

Example:* *Experimental Procedure

1. Remove the batteries from the flashlight, and try to turn it on using the on/off switch.
   Result: The flashlight does not produce light.
2. Reinsert the batteries into the flashlight, and try to turn it on using the on/off switch.
   Result: The flashlight does produce light.
3. Write down these results.

In general, it is important to design an experiment to measure only one thing at a time. This way, you know your results are directly related to the one thing that you changed. If you do not design the experiment carefully, your results may be confusing and will not tell you anything about your hypothesis.

The things that change in an experiment are known as variables. In an experiment, scientists use two types of variables. The **independent variable** (manipulated variable) is the variable you are going to change in the experiment. The **dependent variable** (responding or outcome variable) is the variable you observe when the independent variable is changed. These variables are used to show how changes in the independent variable affect the dependent variable.

A constant or **control** is something that does not change throughout an experiment. Controls are used to make sure your comparisons are meaningful. Without controls you may not be able to tell why you got the results that you did. Often an experiment may have two or more different setups. An experimental setup is one part or one arrangement of materials in the overall experimental design. In a controlled experiment, one setup may not be changed in any way. This setup is considered the control. The control helps you to know what happens when you don't make any changes (when the setup is left alone). In the other setups, the independent variable is changed.

After your experiment, you can compare the data from the different setups. (For example, if testing the effects of different fertilizers on plant growth, a plant that receives no fertilizer would be the control setup. In the other setups, the type of fertilizer used changes.) Likewise, **controlled variables** are used to make sure you are only testing one thing. They are things that should not change during an experiment. Experiments often have many controlled variables.

Example:* *Designing an Experiment

- Independent variable: The use of batteries.
- Dependent variable: Whether or not light was produced.
- Controlled variables: The same flashlight was used each time. The on/off switch is moved into the same positions each time.

Another important principle of experimentation is that the experiment should be repeatable and give the same results every time. If experimental results cannot be repeated, this may be because of unwanted changes in controlled variables or errors. (Did you use two different flashlights? If so, there might be something else besides the battery that is making the difference.)

Through experimentation, scientists collect data. **Data** are pieces of information collected before, during, or after an experiment. To collect data, scientists read the measuring instruments carefully. Scientists usually record their data in notebooks, journals, or on a computer.

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ANALYSIS

Once the experiment is complete, the data is then analyzed to determine the results. In addition, performing an experiment multiple times can be helpful in determining the credibility of your data.

***Example:** Analysis*

- Record the results of the experiment in a table.
- Review the results that you have written down.

Fun Fact

Although it is not common, even well-established theories and laws can be invalidated by new data.

CONCLUSION

If the hypothesis was testable and the experiment provided clear data, scientists can make a statement telling whether or not the hypothesis was correct. This statement is known as a **conclusion**. Conclusions must always be backed up by data. Therefore, scientists rely heavily on data so they can make an accurate conclusion.

- If the data support the hypothesis, then the hypothesis is considered correct or *valid*.
- If the data do not support the hypothesis, then the hypothesis is considered incorrect or *invalid*.

***Example:** Valid Hypothesis*

- The flashlight did not produce light without batteries. The flashlight did produce light when batteries were inserted. Therefore, the hypothesis that batteries give the flashlight energy to produce light is valid, given that no changes are made to the flashlight during the experiment.

***Example:** Invalid Hypothesis*

- What if the flashlight did NOT produce light when the batteries were inserted? Then, the hypothesis would have to be modified to say something such as, "The batteries inside a flashlight give it energy to produce light when the batteries are in the correct orientation and when the flashlight is turned on." Then, another experiment would be conducted to test the new hypothesis.

An invalid hypothesis is not a bad thing! Scientists learn something from both valid and invalid hypotheses. If a hypothesis is invalid, it must be rejected or modified. This gives scientists an opportunity to look at the initial observation in a new way. They may start over with a new hypothesis and conduct a new experiment. Doing so is simply the process of scientific learning.

COMMUNICATION

Scientists generally tell others what they have learned. Communication is a very important component of scientific progress! It gives other people a chance to learn more and improve their own experiments. Many scientists' greatest breakthroughs would not have been possible without published communications from previous experimentation.

Every experiment yields new findings and conclusions. By documenting both the successes and failures of scientific inquiry in journals, speeches, or other public documents, scientists are contributing information that will serve as a basis for future research. Therefore, communication is an important step in future scientific discovery.

***Example:** Communication*

- Write your findings in an article and share it with others, or present your findings to a group of people. Your work may guide someone else's research on creating alternative energy sources to generate light, additional uses for battery power, etc.