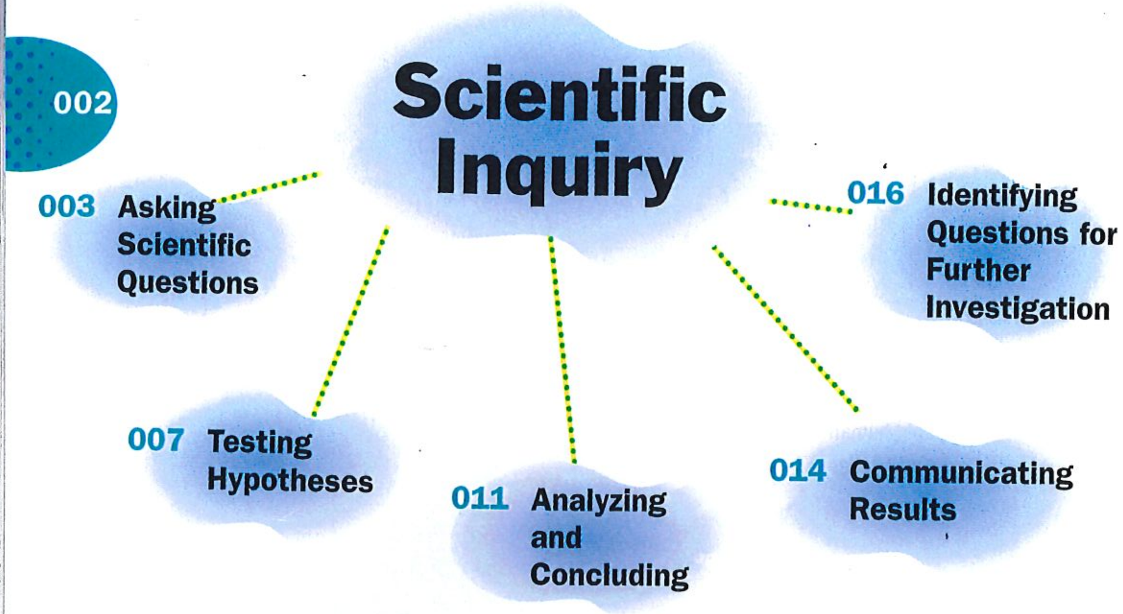
002 Scientific Inquiry



Scientific Inquiry is a fancy way of describing how scientists go about finding answers to questions about the natural world. Scientific inquiry begins when you ask questions. It continues as you look for answers to these questions.

The goal of scientific inquiry is to understand and explain the natural world. Scientific inquiry draws from two main sources when attempting to answer questions: scientific observations and scientific ideas.

Word Watch!

The word *inquiry* comes from the Latin verb *inquirere* meaning "to seek."

SCILINKS NSTA Keyword: Scientific Inquiry
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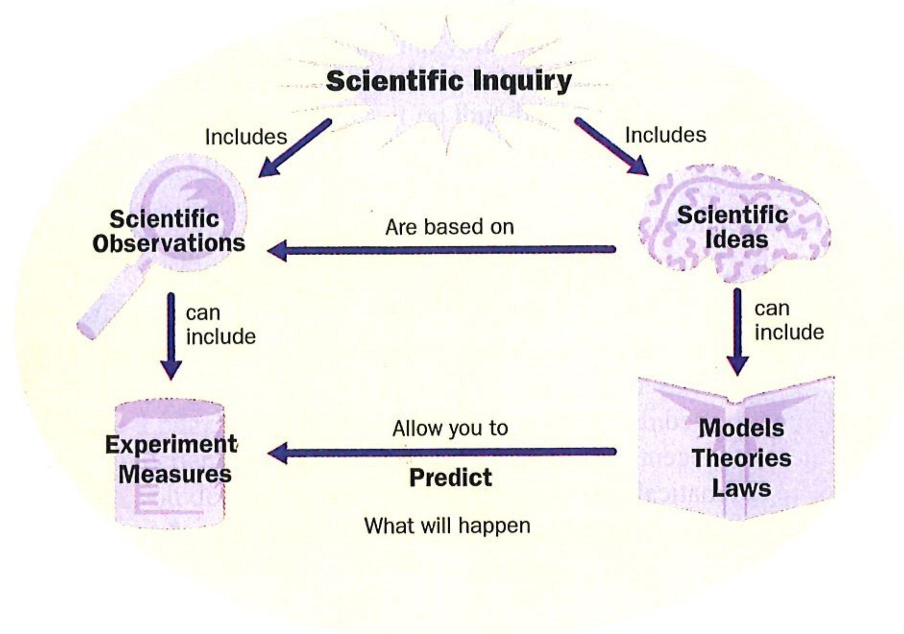
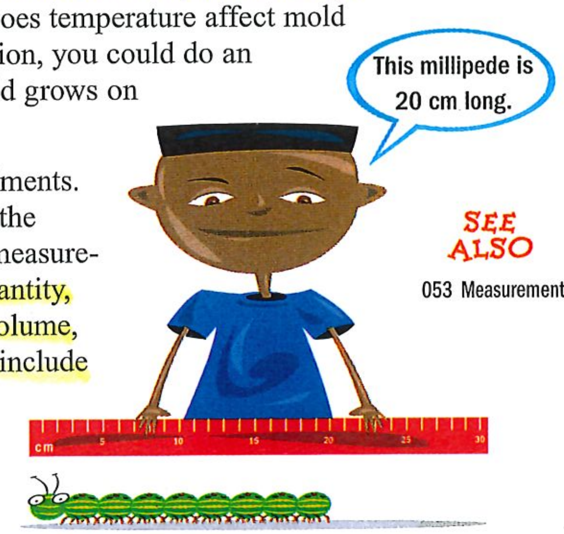


Scientific observations involve using your senses to describe the natural world. For example, you may open a package of bread and see patches of green or black fuzz. You may also note that the bread has a strange odor. These observations tell you that mold has started to grow on the bread.

SEE ALSO
008 Designing an Experiment

Observations are often made during experiments. An **experiment** is a test or trial that produces evidence you can use to help answer a question. For example, you may wonder: Does temperature affect mold growth on bread? To answer this question, you could do an experiment to compare how much mold grows on bread stored at different temperatures.

Not all observations come from experiments. Sometimes you get information about the world just by observing it and taking measurements. A **measurement** describes a quantity, such as time, length, distance, mass, volume, or temperature. Measurements always include a number and a unit.

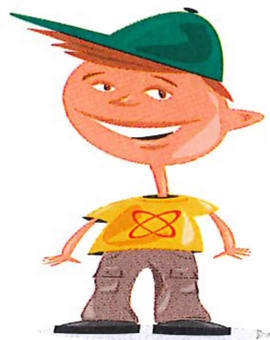


SEE ALSO
053 Measurement

MORE ▶

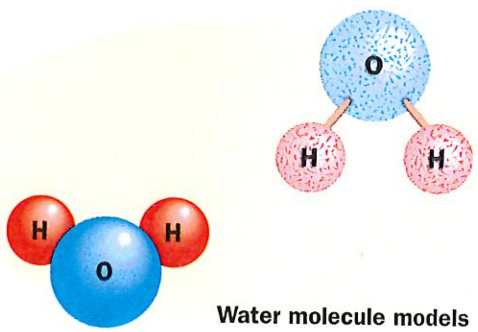
Scientific ideas are developed using evidence gathered from scientific observations. In turn, these ideas can be used to help you understand and explain what you observe in the natural world. Models, theories, and laws are all types of scientific ideas.

Scientific ideas can never be "proven." They can only be supported or unsupported by scientific observations. The more observations you and others gather that agree with an idea, the more support the idea gains.



SEE ALSO
006 Forming a Hypothesis
013 Drawing Conclusions

A **scientific model** is a simplified representation of a part of the natural world that explains what that part looks like or how it works. Models are often used to represent things that cannot be observed directly, like individual water molecules or the center of Earth. Drawings, objects, mathematical equations, and computer simulations can all be models.



Water molecule models

If observations do not support a scientific theory, the theory must be changed. Observations should never be changed to match scientific theories!

SEE ALSO
276 Gravity

A **theory** is a set of ideas that tie together many observations. For example, the theory that the universe is expanding is based on many observations showing that objects in space are moving farther and farther away from one another. Theories are based on ideas that have been tested and shown to be true over time.

A **law** describes how some part of nature acts under certain conditions. For example, the law of universal gravitation explains how the force of gravity affects all objects in the universe. Like theories, laws are based on ideas that have been tested by observations and experimentation. Both theories and laws are used to explain nature.

A **prediction** is a statement of what you think will happen under certain conditions based on what you know from observations or research. For instance, if you observed that mold grew on bread stored in a warm place but not on bread stored in a cold place, you might predict that storing bread in the refrigerator would keep mold from growing, or at least slow it down. You might make the same prediction if you read that more types of mold are found in warm areas of Earth than in cold areas. In either case, you use your prior knowledge to predict what you might observe in an experiment.

Working in science is like working with puzzles. There is no single way to do science, just as there is no single way to solve a puzzle. The methods you use to answer a question depend partly on what the question is. How do you decide the best way to find an answer to a particular question? You use a combination of reasoning, common sense, imagination, intuition, and guesswork—just like when you try to solve a puzzle. This is how most work in science is done.

Did You Know?

Albert Einstein described science this way: "The whole of science is nothing more than a refinement of everyday thinking."

You will find it helpful to become familiar with each of the following procedures when performing a scientific investigation. Remember that you will not use all of these steps for every investigation.

Scientific Investigation

- Ask a question
- Do research
- Form a hypothesis
- Design an experiment
- Gather data
- Analyze data and draw conclusions
- Communicate results
- Identify questions for further investigation

003

Asking Scientific Questions

Your work in science will likely include doing experiments. You may design your own experiment, or do an experiment that is assigned to you. Either way, your experiment should be based on a scientific question that you want to answer.

004

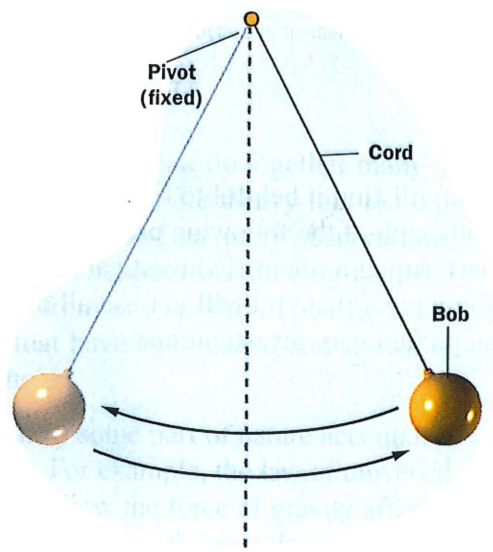
Asking a Question

All scientific investigations begin with a question. At what temperature does glass melt? What effect does weathering have on rocks? What are the stages of an insect's life cycle?

Suppose you are interested in devices used to measure time. You come across a pendulum clock and wonder: "How does a pendulum work?"

You can find out how a pendulum works by reading about pendulums. Or, you can do an experiment to see for yourself. But first you need a testable question.

Parts of a Pendulum



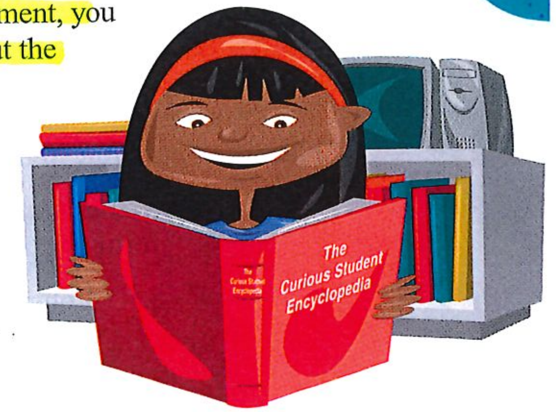
Experiments can only answer testable questions. For example, an experiment cannot answer the question, "How does a pendulum work?" Here are some testable questions about pendulums:

- Does the time it takes a pendulum to swing back and forth depend on the length of the pendulum cord?
- Does the time it takes a pendulum to swing back and forth depend on how heavy the bob is?
- Does the time it takes a pendulum to swing back and forth depend on how wide the pendulum swings?

SEE ALSO
414 Asking Questions

005

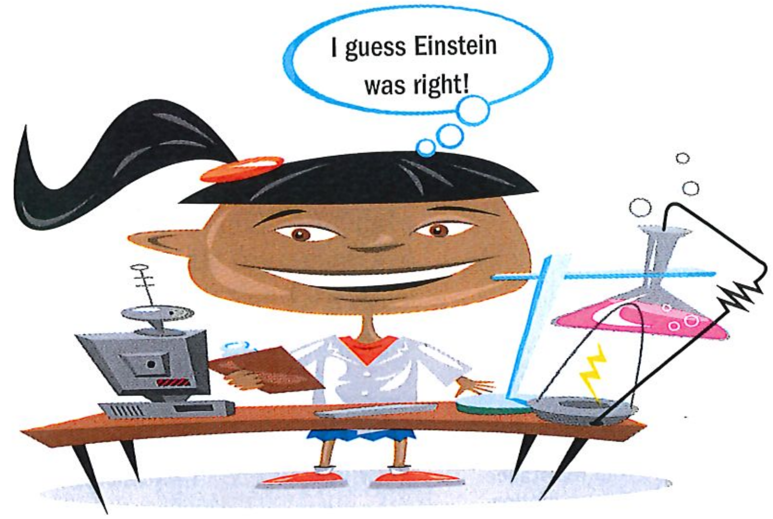
Doing Research



Before you design and carry out any experiment, you should find out what is already known about the topic you are investigating.

Suppose you want to do an experiment with pendulums. First, you should find out what is known about pendulums—what the parts of a pendulum are, how pendulums are built, and if there are different kinds of pendulums. The more you learn about your subject, the better your chances of designing a good experiment!

As you do research, you may discover that other people have already done experiments on a topic that interests you. You may decide to do a similar experiment to see if you get the same results. Repeating an experiment that's already been done may not sound very exciting to you, but the results can be just as valuable. You see, the more times we repeat an experiment and get the same results, the more certain we can be of those results.



Or, you may plan an original experiment—one that has never been done. In this case, you can use information you found about similar or related experiments to develop your own experiment.

SEE ALSO
420 Researching Information

006

Forming a Hypothesis

A **hypothesis** is an idea that can be tested by an experiment. All experiments should have a hypothesis. The hypothesis might be a positive statement ("All objects fall at the same speed"), or a negative statement ("Plants will not grow in the dark").

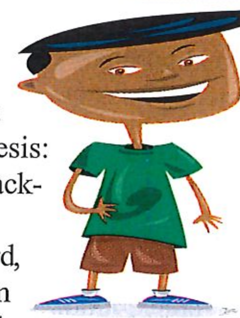
Many hypotheses turn out to be wrong. However, even wrong hypotheses are useful because they help you rule out some ideas.

Let's look at an example of how you might form a hypothesis.

Word Watch!

The plural of *hypothesis* is *hypotheses.*

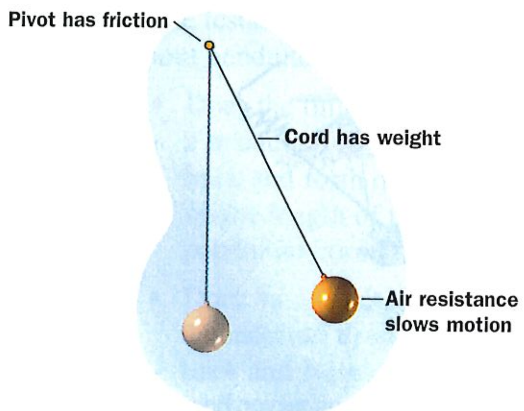
Consider an experiment with a pendulum. After doing research and thinking about pendulums, you might propose this hypothesis: The time it takes for one back-and-forth swing (period) of a pendulum depends on the length of pendulum cord, but not on the weight of the bob, or the angle from which the bob is released. Your experiment should be designed to test this hypothesis.



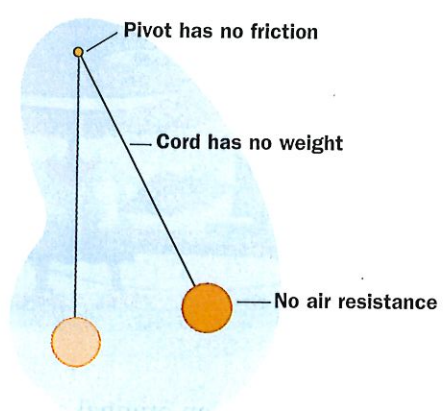
SEE ALSO
002 Scientific Inquiry
013 Drawing Conclusions
279 Friction

Sometimes a hypothesis includes a model. A **scientific model** is a simplified version of some part of nature. In thinking about a pendulum, you might assume that the cord has no weight and that the pivot has no friction. This is your model of a pendulum.

Real Pendulum



Model Pendulum



Testing Hypotheses

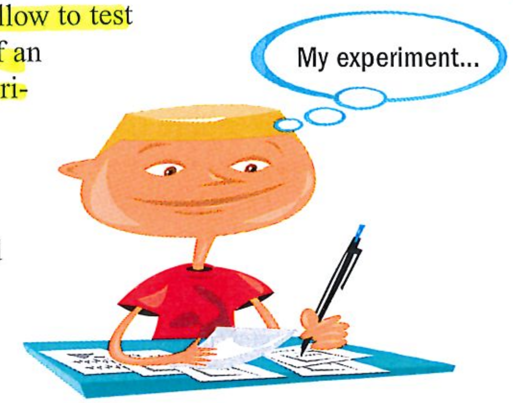
007

Once you have done research and formed a hypothesis, you are ready to design and carry out an investigation to find the answer to your question.

008

Designing an Experiment

An **experiment** is a set of steps you follow to test a hypothesis. In order for the results of an experiment to be meaningful, the experiment must be carefully designed.



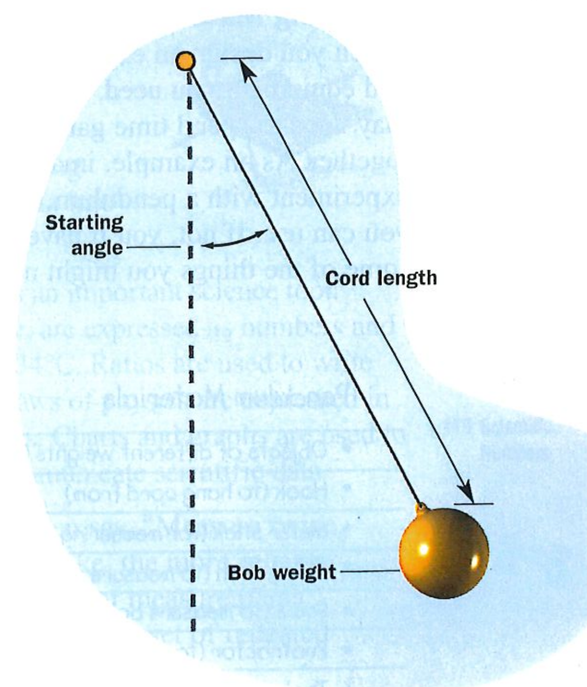
Start out by writing down how your experiment will be set up. Once you have a plan, collect your materials and start your experiment.

Identifying Variables

Variables are factors that can affect the results of an experiment. Before you begin any experiment, you must identify variables that can affect your results. You then need to decide which variables to control and which to vary.

Suppose you do an experiment with a pendulum. Your variables might be cord length, bob weight, and starting angle. Your experiment might test which variable affects how long it takes the bob to swing back and forth.

Variables Affecting Pendulum Period



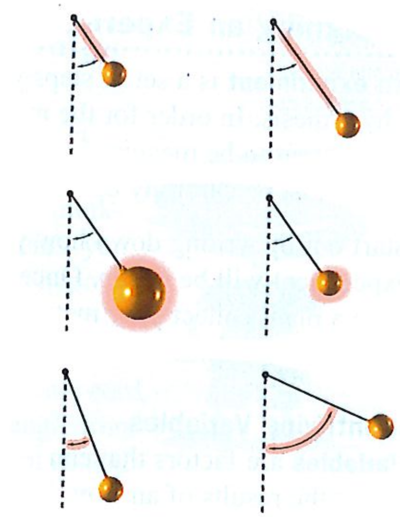
Establishing Controls

The factors you keep constant, or hold fixed, in an experiment are called **controls.** A control is held fixed so that it doesn't affect the outcome of the experiment.

MORE ▶

How can you find which variable—cord length, bob weight, or starting angle—affects how long it takes a pendulum to swing back and forth? You separately test the effect of each variable on the pendulum's period. You do this by keeping two variables the same while changing the third. To test all three variables, you would perform the following three tests:

1. Vary cord length, but keep bob weight and starting angle fixed.
2. Vary bob weight, but keep cord length and starting angle fixed.
3. Vary starting angle, but keep cord length and bob weight fixed.



SEE ALSO 411 Managing Your Time

Gathering Materials and Equipment

When you design an experiment, you must figure out what materials and equipment you need. Sometimes, this is easy. Other times, you may need to spend time gathering materials and then putting them together. As an example, imagine that you want to carry out an experiment with a pendulum. You may have a ready-made pendulum you can use. If not, you'll have to build your own. Here's a list of some of the things you might need to build a pendulum.

Pendulum Materials

- Objects of different weights (for use as pendulum bobs)
- Hook (to hang cord from)
- Meter stick (for measuring cord length)
- Stopwatch (to measure period)
- Scale (to measure bob weight)
- Protractor (to measure starting angle)
- Tools: hammer, nails, pliers, wood block, dowel, etc. (to build pendulum)

Plan how you will build your pendulum. Anticipate any problems your pendulum might have. For example, you need to make sure the bob won't fall off the cord. How will you attach the bob to the cord?

Gathering Data

Information you gather during an experiment is called **data.** Sometimes data include numbers (10 plant leaves) or measurements (0.12 cm). Other times they include simple observations (the mineral did not scratch the glass). As you search for answers to scientific questions, you will gather data in many different ways.

Word Watch!
Data is the plural of *datum.*

Using Tools and Technology Tools and technology can be used to help you gather and organize data. You can use a telescope to view objects in the sky, while microscopes let you look at things too small to see with the unaided eye. You can use a balance to find an object's mass or a meter stick to find its length.

SEE ALSO 389 Recording Data Electronically

Computers, calculators, graphing calculators, and data probes are other useful tools. Hand-held calculators can be used to make quick and accurate calculations. Computers can be used to do research, store data, and make graphs, tables, and charts. A graphing calculator can be used to convert raw data into a graph.

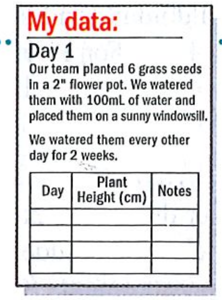
Using Math Mathematics is an important science tool. Measurements, for example, are expressed as numbers and units, such as 40 grams or 34°C. Ratios are used to write chemical formulas. Many laws of physics are expressed in the language of mathematics. Charts and graphs are used to display, understand, and communicate scientific data.

SEE ALSO 375 Scientific Numbers

Repeating Measurements Carpenters often say, "Measure twice, cut once." The more measurements you make, the more reliable your results. When possible, you should repeat measurements several times, and then average the results. Each set of repeated measurements is called a **trial.**

010 Recording Data

After you design an experiment, you are ready to carry it out. As you do so, it is important to record your data in a sensible, orderly way. If you scribble notes all over the place, you might forget what your data mean.



Good data sheet

Bad data sheet

SEE ALSO
375 Scientific Numbers
053 Measurement

General observations can be recorded like diary entries in a science journal. For observations that include numbers or measurements, however, tables are the best way to organize the data.

Imagine you conduct an experiment with a pendulum. You measure the pendulum's period (the time it takes for one back-and-forth swing of the bob) as you change the cord length (while keeping the bob weight and starting angle fixed). You might set up your data table as follows:

SEE ALSO
386 Organizing Data Tables

Period vs. Cord Length

	Time (sec)			
Cord Length (cm)	Trial 1	Trial 2	Trial 3	Average
10	0.5	0.6	0.6	0.6
20	1.0	1.0	0.8	0.9
30	0.9	1.1	1.0	1.0
40	1.1	1.3	1.4	1.3
50	1.4	1.4	1.5	1.4
60	1.7	1.6	1.6	1.6
70	1.8	1.5	1.9	1.7
80	1.6	1.9	2.0	1.8
90	1.9	1.8	1.9	1.9
100	2.0	2.1	2.0	2.0

You could use similar tables to record your data for bob weight vs. period and starting angle vs. period.

Analyzing and Concluding

Data collected from an experiment must be analyzed in order to be meaningful. Analyzed data can then be used to help you draw a conclusion about what you learned in your scientific investigation.

Analyzing Data

After you do an experiment, you need to decide what your data mean. This process is called analyzing your data. How you analyze your data depends on your experiment. For example, you may need to make calculations or graph your data.

SEE ALSO
390 Kinds of Graphs
395 Making a Line Grapl

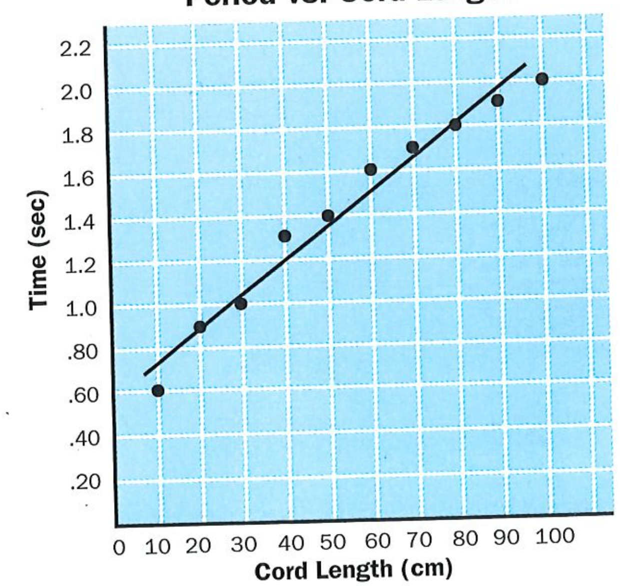
Suppose you did an experiment to find out how cord length, bob weight, and starting angle affect how long it takes a pendulum to swing back and forth. It would make sense to graph these data. In this case, you would draw three graphs: period vs. cord length, period vs. bob weight, and period vs. starting angle.

You should make each graph easy for someone else to read and understand by including a title, labeling the axes, showing your data points, and drawing the best line that fits those points.

Looking at this graph should help you understand how cord length affects swing time. The great thing about a graph is that it gives you a picture of your data, allowing you to uncover patterns you might not otherwise notice.

When you analyze your data carefully, you might discover things you didn' expect. For example, you might not only observe that period increases wit cord length; you may als be able to figure out exactly how it increases.

Period vs. Cord Length



013

Drawing Conclusions

Always question your data and conclusions. Ask yourself if errors in measurement or other factors may have affected your results. If so, redesign your experiment and try it again. This shows you're thinking like a scientist.

Conclusions are explanations that are based on evidence from observations. The main question to be answered in any experiment is: "Do my observations support my hypothesis?" Let's ask this question for a pendulum experiment in which your hypothesis was this: The period of a pendulum—the time it takes for one back-and-forth swing—depends on the length of the cord, but not on the weight of the bob, or the angle from which the bob is released.

Suppose your graphs show that the pendulum's period increases as its cord length increases, but that the period does not change greatly as bob weight or starting angle changes. In this case, your results support your hypothesis. If your results did not support your hypothesis, you would have to rethink your idea.

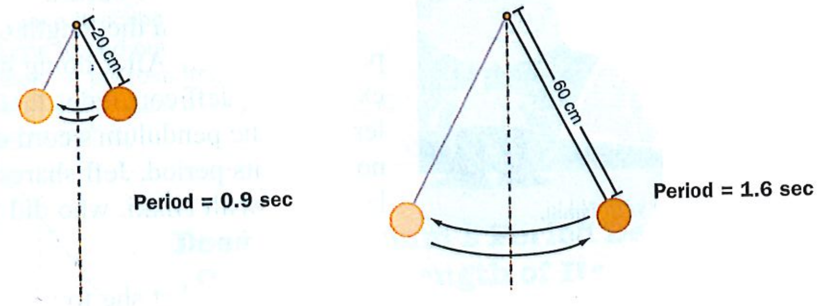
Making Inferences You will often make inferences to reach a conclusion or judgment based on your data. An **inference** is an explanation of information that is based on facts, but not direct observation. Imagine you are in a movie theater. When you leave, you see that the ground is wet. You conclude that it rained while you were in the theater. This conclusion is an example of an inference. You reached your conclusion based on the fact that the ground is wet, even though you did not observe it raining.

Scientific Models

Sometimes it is helpful to develop a model to explain what you found out in an experiment. **Scientific models**—which can be physical objects, detailed drawings, or equations—explain how a system works. For example, a cell model made out of clay, string, and beads can be used to show how chemicals flow in and out of the cell through small openings in the cell membrane. You can use a map to show the living and nonliving parts of a backyard ecosystem.

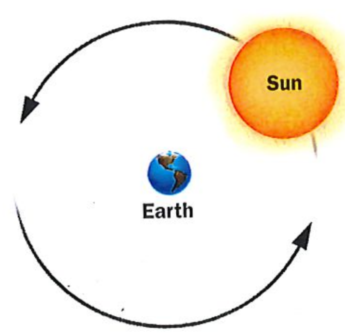
SEE ALSO
002 Scientific Inquiry
006 Forming a Hypothesis
077 Animal Cell
078 Plant Cell
129 Ecosystems

In the case of a pendulum experiment looking at the effect of cord length on period (the time it takes the bob to swing back and forth one time), a simplified model can be used to show the relationship that exists.

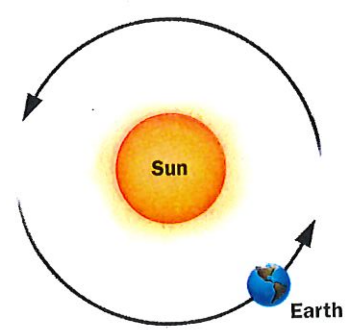


As cord length increases, so does period.

As scientists conduct more experiments, they gain new information about relationships that exist in nature. This information can be used to update and improve existing models. For example, hundreds of years ago, people believed that the sun revolved around Earth. But through careful observation and experimentation, scientists later discovered that Earth actually revolves around the sun, and not vice versa. Thus a new model of the solar system was developed.

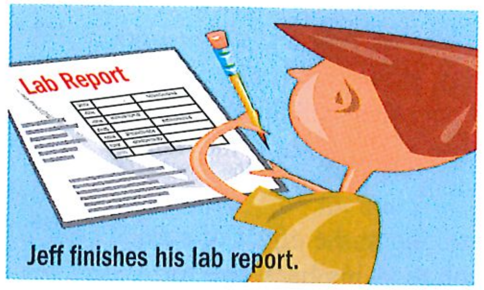


Old Solar System Model



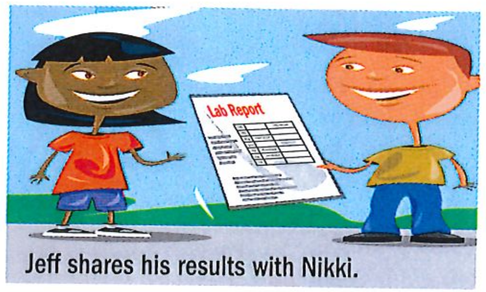
New Solar System Model

Communicating Results



Jeff finishes his lab report.

Both as you are doing an experiment and afterward, you should communicate your questions, ideas, and results with others. This allows them to evaluate and understand your experiment. Let's look at an example:



Jeff shares his results with Nikki.

Suppose Jeff does an experiment to test the following hypothesis: The period of a pendulum (the time it takes for one back-and-forth swing) depends on the length of the pendulum's cord. After doing his experiment, Jeff concludes that the length of the pendulum's cord does not affect its period. Jeff shares his lab report with Nikki, who did the same experiment.

Nikki compares her results to Jeff's.

Nikki tells Jeff that she found that swing time does depend on cord length. Nikki reads through Jeff's lab report. She checks his procedure, his data, and his analysis. She suspects that Jeff may have incorrectly measured his cord lengths, and discusses her findings with him.

Jeff does his experiment again and finds that swing time does depend on cord length. Jeff may not have found out there was a problem with his experiment if he hadn't shared his results with Nikki.

Communicating your results with others gives you a chance to see if any mistakes were made in experimental design, calculations, or analysis. In this way, the quality of everyone's work is improved. Sharing results may also give you new ideas for other topics to investigate.

Writing a Lab Report

It is important to share your ideas and findings in science with others. Communication allows you to learn from work done by others and gives others a chance to learn from your work. It may also provide you with new ideas for study. You can share your lab results by talking with other people. You can also write a report. A **lab report** is a written summary of how you did your work and the results you obtained. This report should be clear enough so whoever reads it can repeat your experiment.

Let's look at the parts of a lab report using an experiment with a pendulum as an example.

Purpose
The purpose describes what you were trying to find out in your experiment. A purpose may also include an explanation of why you did your experiment.

Title
The title briefly tells the reader your investigation topic.

Does a Pendulum's Period Depend Only On the Length of Its Cord?

Purpose: To determine what factors (cord length, bob weight, or starting angle) affect the period of a pendulum (the time it takes a pendulum to make one back-and-forth swing).

Hypothesis: The period of a pendulum (the time it takes for one back-and-forth swing) is affected by cord length, but not by bob weight or starting angle.

Hypothesis
State your hypothesis here. In your pendulum experiment, the hypothesis was that cord length affects the pendulum's period, while bob weight and starting angle do not. In a lab report, you should always tell the reader what hypothesis you were trying to test.

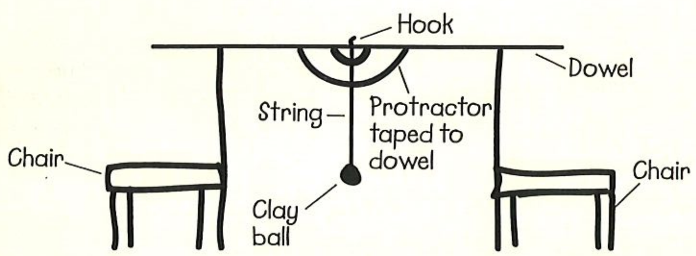
SEE ALSO
006 Forming a Hypothesis

MORE ▶

Materials and Equipment
This section lists all the materials needed for your experiment. It should also explain how the materials are put together. Drawings or sketches can also show the reader how materials are set up.

SEE ALSO
008 Designing an Experiment

Materials and Equipment: wooden dowel, two chairs, masking tape, hook, string, scissors, clay (used for bobs), meter stick, spring scale, protractor, stopwatch, hammer, pliers



Procedure:

1. The pendulum was built using the materials and setup shown in the Materials and Equipment section of this report.

2. Ten different lengths of cord were cut, from 10 cm to 100 cm. A meter stick was used to measure the cord lengths.

3. The 10 cm cord was attached to the ball of clay. The cord was set in motion using a starting angle of 25°. A stopwatch was used to measure the period of one swing and the time was recorded. This process was repeated three times. The average of the three swing times was then calculated.

4. Step 3 was repeated for each of the other cord lengths.

5. Bob weight was tested next...

Procedure
The procedure is a step-by-step description of how you carried out your experiment. The procedure should allow the reader to reproduce your results in a new experiment.

Data
All the data collected during the experiment is shown here. This allows the reader to determine if your data make sense.

Data:

Steps 3 and 4 of the procedure produced the following data:

Table 1: Period vs. Cord Length

Cord Length (cm)	Trial 1 (sec)	Trial 2 (sec)	Trial 3 (sec)	Average (sec)
10	0.5	0.6	0.6	0.6
20	1.0	1.0	0.8	0.9

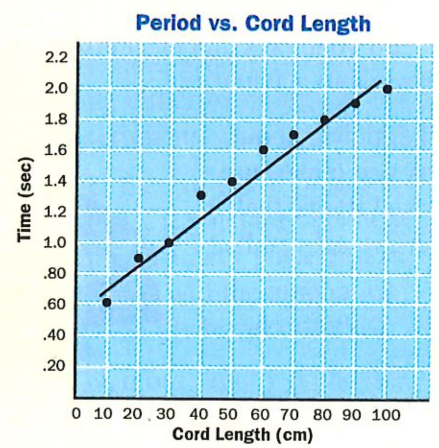
Analysis of Data
The analysis section explains how you analyze, or make sense of, your data. This section might include graphs and calculations. It should tell why you analyzed your data as you did.

SEE ALSO
009 Gathering Data
010 Recording Data
012 Analyzing Data

Analysis of Data:

Data collected for period vs. cord length, bob weight, and starting angle were graphed.

The cord length graph is shown here:



The bob weight graph is shown here:

Conclusions Based on Data
Here you summarize what you learned from your experiment. Restate your hypothesis, tell if it was supported or not, and explain your conclusion.

SEE ALSO
013 Drawing Conclusions

Conclusions Based on Data:

The data collected (see graphs) showed that bob weight and starting angle did not have a significant effect on the period of the pendulum. The data also showed that cord length did have an effect on pendulum period. Thus, the data support this hypothesis: The period of a pendulum (the time it takes for one back-and-forth swing) is affected by cord length, but not by bob weight or starting angle.

The data also show...

Include any other conclusions you reach while doing your experiment. For example, if you find a mathematical equation that describes the motion of a pendulum, include that data. Include any observations that may be useful to someone reading your report.

Your conclusion section should also discuss limitations of your experiment—and all experiments have limitations. Here are some issues to consider.

SEE ALSO
006 Forming a Hypothesis

- Did you think of all the factors that could affect your results? For example, can you be sure that cord length was the only variable affecting the pendulum's period? How do you know the change in period was not also affected by air resistance or by friction in the pendulum's pivot?
- Do you have to redo your experiment in order to take these factors into account?

Always have some skepticism about your work. This helps you make sure you have not overlooked things that may affect your experimental results.