Background for the Teacher

Inquiry

The *National Science Education Standards* emphasize: "Inquiry into authentic questions generated from student experiences is the central strategy for teaching science. Teachers focus inquiry predominantly on real phenomena, in classrooms, outdoors, or in laboratory settings, where students are given investigations or guided toward fashioning investigations that are demanding but within their capabilities." A large number of state standards also emphasize the role of inquiry—of student ability to engage in scientific investigation and to deepen their understanding of the nature of science. The *Oobleck* unit fits these recommendations perfectly.

What is inquiry? Among many excellent examples and descriptions in the standards, the following summary stands out:

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.
>
> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries.

It's also important to emphasize, as the *National Standards* do, that there is no single "scientific method." In the past, many students (including most of us who now teaching science!) learned about "*The* Scientific Method." While described in slightly different ways by different teachers over time, students have generally been taught that there is a rigid, linear, step-by-step process that scientists use to find out about the natural world. This misrepresents science. (See pages 121 and 144 of the *National Science Education Standards.)*

In fact, scientists use a variety of scientific methods (note the plural). These scientific methods, perhaps better described as scientific inquiry methods, provide a repertoire of strategies that can be brought to bear in a logical progression to find out more about a situation. Many people are surprised to learn that scientists don't just conduct controlled experiments (a comparison between two situations that are alike in all ways but one), but also, when appropriate, conduct systematic observations (observing a situation with planned conditions over time) or combine a variety of other approaches, depending on the circumstances.

Although the classic scientific method sequence (beginning with question, hypothesis, experimental design, etc.) does represent a summary of key phases of a scientific investigation, it is not uncommon for a scientist to go back and forth between two phases (or inquiry methods) before proceeding to the next. So, for instance, a scientist rarely arrives at a question without having had the opportunity to first explore and observe the subject of study. Often a scientist will refine a preliminary question by again exploring with materials. Likewise, meaningful hypotheses come from having had some firsthand experience interacting with the situation. In addition, designing an experiment is nearly always preceded by running some pilot studies, in order to try out and refine procedures, identify variables, devise ways to control variables, and come up with ways to measure the test variable.

What was once called, "The Scientific Method," is now called the inquiry process. The process of inquiry is a flexible and dynamic process that includes more than just conducting controlled experiments.

Helping Students Move Beyond Natural Inquiry

Children inquire naturally. They are in fact experts at the process of exploration and rarely need guidance in inquiring in this free form way. However, moving to more systematic ways of inquiring, such as conducting a systematic observation or a controlled experiment, is something that needs to be learned and usually requires a fair amount of guidance. The *National Standards* call for students to be given opportunities to engage in partial inquiry (also called guided inquiry) in which they develop abilities and understanding of selected aspects of the inquiry process. The standards also say that students should be provided with opportunities to engage in full inquiry (also called open-ended inquiry) in which students choose a question, design an investigation, gather evidence, formulate an answer to the original question, and communicate the investigative process and results.

Encouraging students to conduct open-ended inquiry is uncommon in most classrooms. When students are given the opportunity, they are typically thrown into the situation with little more than a worksheet describing, "The Scientific Method" and perhaps some practice in setting up controlled experiments. This is not enough. Students need to know that there are more ways to investigate than just controlled experiments. They need practice in choosing and refining investigable questions, selecting an appropriate pathway to answer their question, in identifying possible variables, and quantifying outcome variables. They need practice in putting all the aspects of inquiry together. Without this guidance and practice, students often choose questions that can't be answered experimentally. They likewise may choose inappropriate ways to answer questions, have no way to quantify their evidence, and draw conclusions unrelated to the evidence. The result is often frustrating to students and teachers alike. Most often, students' abilities to inquire don't enable them to be more systematic or productive—and to move beyond exploration (which, as we've said, they already do quite well without instruction). And there are some who believe that forcing students through a rigid and linear process even impairs their natural born ability to inquire!

What Kind of Mixture Is Oobleck?

Oobleck is a suspension of cornstarch in water. A suspension is a type of mixture, as are solutions, colloids, and precipitates. In a mixture, two or more substances are combined. In a solution, a solid dissolves into a liquid. The atoms, molecules or ions become evenly dispersed in the liquid. In a suspension the ingredients keep their own properties and usually can be separated fairly easily.

Colloids and suspensions are both types of mixtures in which a solid is mixed into a liquid without dissolving. What distinguishes the two is that the particles in a colloid are smaller than those in a suspension. In a colloid the particles also tend to remain suspended (like milk), whereas those in a suspension tend to settle out. When Oobleck is kept moist and allowed to sit for a long time, the cornstarch will begin to separate from the water on its own. In a precipitate a solid forms in a solution due to a chemical reaction. This solid does not dissolve in the particular liquid.

A **mixture** is a combination of two or more substances. Solutions, colloids, suspensions, and precipitates are types of mixtures. In a **solution,** the atoms, molecules, or ions of a substance are evenly dispersed in a liquid, or **dissolved.** In a **colloid,** very tiny particles of a substance are dispersed in another substance—but not dissolved. The particles in a colloid are smaller than those in a suspension. Milk is a colloid of tiny solids in a liquid. Smoke is a colloid of tiny solids in a gas. Mist is a colloid of tiny particles of liquid in a gas. In a **suspension,** tiny particles, larger than those in a colloid are dispersed in another substance, but not dissolved. These particles can usually be separated from the liquid fairly easily. Oobleck is a suspension of cornstarch in water. Sand mixed in water is also a suspension. In a **precipitate** a solid forms in a solution due to a chemical reaction. This solid does not dissolve in the particular liquid.

The distinction between Newtonion ond non-Newtonion fluids is less importont thon the opportunity for students to improve their scientific thinking obilities ond understondings through their own investigotions of this stronge substonce. More odvonced students moy find it of interest, or discover the distinction during independent web research. A full exominotion of o ronge of theories scientists hove offered for the internal workings of non-Newtonian fluids would require o deeper understanding of chemistry ond physics, and even then there is no single ogreed-upon explonotion!

In eorlier editions, we over-emphosized the foctor of temperature in this context. The cruciol distinguishing factor is shear force, which chonges the viscosity of non-Newtonion fluids, but not Newtonion ones. It is of course the case thot both temperature and pressure offect the viscosity of liquids, ond that in everydoy life we notice how mony fluids thicken when cooled ond become less viscous when heoted, but the non-Newtonian distinction relotes only to sheor force.

For on excellent, occessible discussion of non-Newtonian fluids, see the "outrageous Ooze" activity of the Exploratorium, on the Internet at: http://www.exploratorium.edu/science_explorer/ooze.html

What Are Non-Newtonian Fluids?

One of the most fascinating things about Oobleck is precisely the ambiguity that students explore when they consider whether Oobleck is a liquid or a solid. Substances that flow, such as liquids and gases, are called fluids. Oobleck is a fluid, but a fluid of an uncommon sort. Its usul nature relates to its viscosity and how its viscosity changes. Viscosity is a measure of how strongly layers of fluid resist flowing past each other when under stress, or shear forces. Words such as "thickness" or "gooiness" are often synonyms for viscosity.

Newtonian fluids, such as water, gasoline, and mineral oil, are those whose viscosity does not change as a result of a shear force exerted upon it. When you agitate a liquid by hitting it or moving your fingers through it, you are applying a shear force. Isaac Newton observed that for many fluids the flow increases in a regular way when the shear forces increase, indicating that the viscosity is a constant even when shear forces or fluid velocities change. In other words, no matter how hard you hit water or how quickly you move your fingers through it, it will have the same viscosity. Fluids that behave this way are called Newtonian fluids, and they include all gases and many liquids. Fluids that don't behave this way are called non-Newtonian fluids.

There are some non-Newtonian fluids that actually become *less* viscous when subject to shear forces. If you hit a deep pool of one of these fluids or quickly move your fingers through it, it will become less viscous. Although these are more unusual than Newtonian fluids there are some common examples, such as blood, shampoo, fruit juice concentrates, mayonnaise, gelatin, liquid cement, paint and ketchup. Common practical experience with this phenomena is when people shake a container to get one of these non-Newtonian fluids to flow more easily.

Even rarer are another type of non-Newtonian fluids, like Oobleck, that become *more* viscous when subject to shear forces. Your students discovered this as they noticed more resistance when they increased the shear force by hitting it hard or moving their fingers through it quickly. These fluids make transitions from liquid to a solid-like state that defy expectations of how a substance ought to behave. Quicksand also becomes more viscous with agitation, which is why trying to move quickly if stuck in quicksand would make it more difficult to move. To confuse matters more, most of these fluids will also become *less* viscous if only a low shear rate is applied

There are also non-Newtonian fluids known as plastic fluids. These are fluids that won't flow until a certain shear stress is applied. Some examples are toothpaste, hand cream, grease, and some ketchups. Toothpaste will not flow without pressure, but once the right amount of pressure is applied, it flows easily.

Time dependent non-Newtonian fluids either become less viscous with time (like yogurt or paint in a sealed container), or more viscous with time (like gypsum paste).

What Makes Oobleck Behave As It Does?

Why Oobleck has such properties remains somewhat of a mystery. Some scientists have approached this question on a particle level and some at a molecular level. Here are three of their explanations:

1. Sand in Water Model

In this model, the starch particles in Oobleck are compared to sand and water in a plastic squeeze bottle. The grains of sand are packed closely together, with a little water in between. The surface tension of the water does not allow all of the spaces between the grains to be filled. Squeezing the bottle gently forces the grains of sand to slide against each other, increasing the spacing between some of the grains, and allowing more water to fill the spaces. The more gently you squeeze, the more time there is for the water to fill the spaces between the grains and provide lubrication so they will slide against each other, and flow. But when the bottle is squeezed quickly, there is not enough water between the spaces to start with, and friction between the grains of sand resists the flow.

Although the grains of starch in Oobleck are much smaller than grains of sand, starch molecules are relatively large, as molecules go. Therefore, a mixture of water and cornstarch may act very much like a mixture of sand and water. This is one explanation for why Oobleck flows like a fluid, yet when suddenly compressed offers the resistance we associate with a solid.

For a brief and excellent discussion of shear force and an experiment in space designed to learn more about the properties of liquids, see this NASA website, entitled "Shear Mystery: at: http://science.nasa.gov/headlines/y2002/07jun_elastic_fluids.htm?friend

For a discussion of different kinds of non-Newtonian fluids, with viscosity graphs, and more on this general scientific topic of flow in matter, or rheology, see: http://www.sju.edu/~phabdas/physics/rheo.html

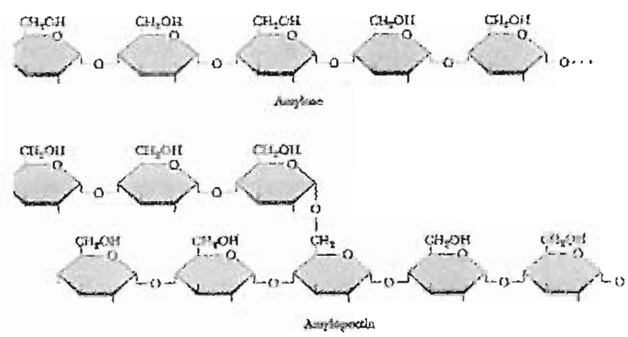
The sand-and-water process described here is directly comparable to the liquefaction of sediment that can take place during earthquakes. See, for example, www.tulane.edu/~sanelson/images/liquefaction.gif

Two articles in The Physics Teacher *report some interesting findings about how a bowl of dried beans can act as a liquid and related issues. See "On the Difference Between Fluids and Dried Beans" by Rolf Winter (February 1990) and "Liquid beans" by Robert Prigo (volume 26, 1988). There is considerable scientific literature and fascinating findings on sand (see for example, a New York Times article of September 7, 1996—"From Grains of Sand: A World of Order").*

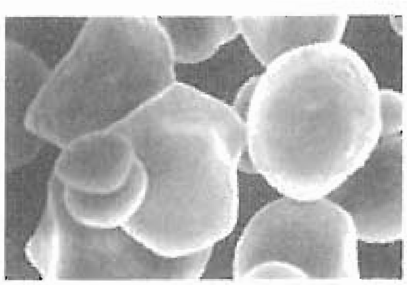
2. Long Chains Model
This model bases the behavior of Oobleck on chemical structure. Cornstarch is made of long chains called polymers. This model speculates that when a mixture of cornstarch and water is compressed, the chains are stretched in a direction that is at right angles to the direction of compression. The molecules become "tangled," are unable to slide easily against each other, and offer the resistance we associate with a solid.

3. Electrical Charge Model
This model suggests that the particles in Oobleck acquire an electrical charge as they rub together. The faster they are rubbed, the more electrical attraction is created between the particles, causing an increase in the viscosity of the mixture.

There are many places on the web, especially food-related sites, where the chemical structure of starch is explained. Here are two of the most helpful: http://www.jic.ac.uk/STAFF/cliff-hedley/Starch.html and http://www.cem.msu.edu/~reusch/VirtualText/carbhyd.htm



Most animals, including humans, depend on plant starches for food. Starch is a polymer of glucose, found in roots, rhizomes, seeds, stems, tubers, and corms of plants, as microscopic granules with characteristic shapes and sizes. The structure usually consists of two materials—amylose and amylopectin. Amylose, whose molecules are linear chains, makes up about 25%. Amylopectin, which makes up about 75%, is a much higher molecular weight substance, whose molecules are branched networks.



These are among the ways scientists have attempted to explain the unusual properties of Oobleck and similar substances. An excellent discussion is provided by Jearl Walker in two articles in "The Amateur Scientist" section of *Scientific American* and there is quite a bit of scientific literature on related subjects, including an article by Albert Einstein. If you're interested in reading more on this subject, here are a few references.

Billmeyer, Fred W. *Textbook of Polymer Science,* 3rd edition, John Wiley and Sons, New York, 1984.

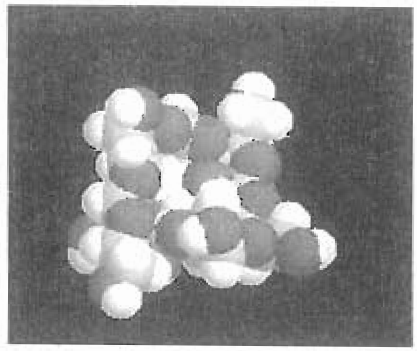
Einstein, A. (1905) "On the Motion of Small Particles Suspended in Liquids at Rest Required by the Molecular-Kinetic Theory of Heat." *Annalen der Physik 17,* 549-560. Einstein, A. (1905) "A New Determination of Molecular Dimensions." *Annalen der Physik 17,* 549-560. These papers, published two weeks apart, are often considered as one because their subjects are related. Both are extensions of Einstein's doctoral dissertation. They are among the papers he published in 1905—afterwards called the "miracle year" given what he accomplished—at the age of 26. Together the papers introduced many of his most famous ideas, including relativity and $e = mc^2$. In his work on molecular dimensions and small particles, Einstein sought to explain Brownian motion, the zigzag motion of microscopic particles in suspension, as in a colloid. He suggested it was caused by the random motion of molecules of the suspension medium as they bounced against the suspended particles. Using a statistical method, he showed he could estimate the number and size of molecules in a cubic centimeter of liquid. This made an important contribution to proving that molecules *actually do exist,* which was not generally accepted at the time. For more on this see the Gary Moring reference on the next page.

Katz, David A. *Chemistry in the Toy Store,* 2nd edition, 1983. Available from Department of Chemistry, Community College of Philadelphia, 1700 Spring Garden Street, Philadelphia, PA 19107.

Kerr, Paul F. Quick Clay, *Scientific American,* volume 209, number 5, pages 132-142, November, 1963.

Moring, Gary F. *The Complete Idiot's Guide to Understanding Einstein,* Indianapolis, Alpha Books, Macmillan USA, 2000, pages 140–161.)

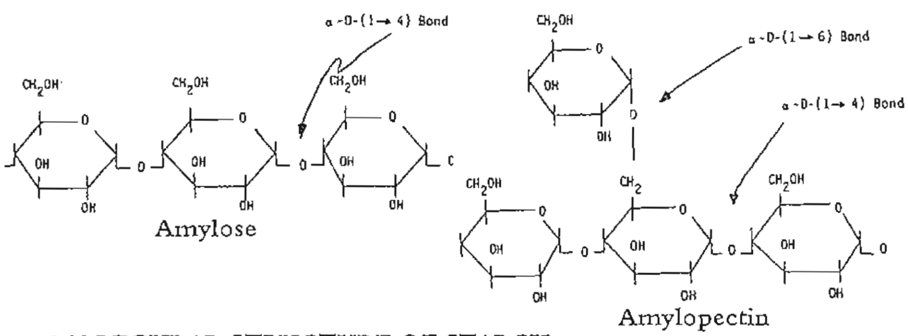
Walker, Jearl. The Amateur Scientist, *Scientific American,* volume 239, number 5, pages 186-198, November, 1978, and volume 246, number 1, pages 174-180, January 1982.



Model of Starch Molecule

States of Matter

Matter is all substances that take up space and have mass. Solids, liquids and gases are terms used to group matter according to definite mass, volume, and shape. They are states (or phases) of matter. **Solids** have definite mass, volume and shape. The particles in a solid vibrate, but do not move too much. They are packed closely together often in regular patterns. **Liquids** have definite mass and volume, but not shape. The particles in a liquid slide past each other and vibrate. They are packed closely but without regular patterns. **Gases** have definite mass, but not volume or shape. The particles in a gas vibrate and move very quickly, are well separated and are not in regular patterns. Substances can change between these states. This normally is caused by the increase or decrease of the energy of the particles brought on by heating or cooling. These changes in state are physical changes, as opposed to chemical changes. There are other states of matter, including: plasma—which exists throughout the Universe in stars and on Earth under some conditions, such as fluorescent bulbs and lightning, and Bose-Einstein condensate—which only forms at temperatures near absolute zero.



MOLECULAR STRUCTURE OF STARCH

Amylose is a linear polymer of short 1,4 linked glucose chains. The amylose fraction is usually about 25–30% of the starch molecules found in corn and has a molecular weight of about 250,000. Amylopectin is about 70–75% of the starch found in the corn kernel and has a molecular weight of about 50–500 million. It is a branched polymer of the basic repeating units of 1,4 linked glucose with branches of 1,6 linked glucose. The branching occurs irregularly, about one per 25 glucose units.

From http://www.ccmr.cornell.edu/education/ask/index.html?quid=14 The molecules that make up cornstarch are very different from the small water molecules. They consist of long chains of repeating units called sugars. Sucrose or table sugar has two such repeating units per molecule, whereas starch has many, many, more. In pure cornstarch, the sugar chains stick strongly and cannot move past one another, thus starch is a solid. However, if we add water to starch, the water gets between the starch chains, separates them and allows the chains to slide past one another; the mixture behaves as a liquid. If we apply pressure to the starch mixture, the water is squeezed out from between the chains and they are able to grab one another. Sliding is prevented and the material behaves as a solid. If we release the pressure, the water can enter between the chains to allow sliding once more. This behavior is not limited to the molecular scale. A similar phenomena occurs when you run on wet sand at the beach. If you run fast and generate pressure quickly the sand feels hard as water is squeezed out and the sand particles cling to each other. If you step slowly to apply the pressure gradually, the sand particles have time to move past one another—your foot sinks!

Scientific Facts, Laws, and Theories

These three terms describe important aspects of the nature of science, but are often misunderstood. Each has a meaning in common usage that is different from its meaning in the scientific community, and this can cause confusion. These are the definitions as written by the National Academy of Sciences.

For more information, there's an excellent website on states of matter at: http://www.chem.purdue.edu/gchelp/atoms/states.html

Fact: In science, an observation that has been repeatedly confirmed and for all practical purposes is accepted as "true." Truth in science, however, is never final, and what is accepted as a fact today may be modified or even discarded tomorrow.

Law: A descriptive generalization about how some aspect of the natural world behaves under stated circumstances.

Theory: In science, a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses.

The contention that evolution should be taught as a "theory, not as a fact" confuses the common use of these words with the scientific use. In science, theories do not turn into facts through the accumulation of evidence. Rather, theories are the end points of science. They are understandings that develop from extensive observation, experimentation, evidence and creative reflection. They incorporate a large body of scientific facts, laws, tested hypotheses, and logical inferences. In this sense, evolution is one of the strongest and most useful scientific theories we have.

**Adapted from* Teaching About Evolution and the Nature of Science *by the National Academy of Sciences (Washington, D.C.: National Academy Press, 1998).*

The History of Mars Exploration

Mars—the red planet—has fascinated humans throughout the ages. For hundreds of years, observations were limited by the vast distance separating Earth from Mars. About once every two years, at its closest regular approach (called opposition), Mars passes within about 55 million kilometers of Earth and that is when Earth-based telescopes have been able to capture the best photographs. More recently, the Hubble Space Telescope has provided excellent views from its orbit around Earth.

Mars has been the object of many theories and questions. Claims that the "canals" on Mars were built by intelligent beings aroused controversy early in the 20th century. Did life exist on Mars in the past or present? Was there water on Mars—if so, in what form? What was the Martian atmosphere composed of? Could Mars tell us more about the evolution of Earth and the Solar System? Mars not only fascinated scientists from many disciplines, but also the general public. There was a huge reaction to "War of the Worlds," the radio broadcast by Orson Welles of the H. G. Wells book that dramatized a fictitious invasion from Mars. Earth-based observations of Mars paved the way for spacecraft exploration of the planet. Fueled by the curiosities of both the scientific community and the public, on November 28, 1964 Mariner 4 was launched and 228 days later it became the first spacecraft to visit the red planet.

The Mariner Mars Missions

Mariner 4 was able to obtain and transmit close range images of Mars. After its launch and a journey of hundreds of millions of kilometers, Mariner 4 passed within 9,844 kilometers of Mars on July 14, 1965. It took four days to transmit the image information to Earth and the spacecraft returned useful data until December 20, 1967. Mariner 6 and Mariner 7 were identical spacecraft launched on February 24, 1969 and March 27, 1969 and their missions were the flyby study of Mars. The probes passed closest to Mars on July 30 and August 4 of the same year.

Mariner 9 was to have an identical companion, Mariner 8, but on May 8, 1971, 365 seconds after launch, Mariner 8 fell into the Atlantic. Mariner 9 was the first of NASA's Mars orbiters. The spacecraft was launched on May 30, 1971 and arrived in Mars orbit on November 14, 1971. After 349 days in Mars orbit, 7,329 images (including images of Mars' two moons, Phobos and Deimos) had been relayed back to Earth. The images, covering about 80% of the planet, revealed ancient river beds, craters, massive extinct volcanoes, canyons, layered polar deposits, evidence of wind-driven deposition and erosion of sediments, weather fronts, dust storms, and more. With evidence of flow features, and therefore the possibility of a time when water was in liquid form on the surface of Mars, the question of the existence of life intensified. Many new questions had been raised that a lander would be better suited to answer. The new information from Mariner 9 served as the foundation for the Viking program.

Viking Mission to Mars

Previous editions of this GEMS guide included a poster of the Viking mission and students compared their work to that of Viking mission scientists. With the landing and extensive work of the two Mars Rovers, we've updated that class session, but if you have the poster you could use it as well.

NASA's Viking Mission to Mars involved two spacecraft, Viking 1 and Viking 2, each with an orbiter and a lander. The primary objectives were to obtain high resolution images of the Martian surface, characterize the structure and composition of the atmosphere and surface, and search for evidence of life. Viking 1 was launched on August 20, 1975 and arrived at Mars on June 19, 1976. On July 20, 1976 the Viking 1 Lander separated from the Orbiter and touched down. Viking 2 was launched September 9, 1975 and entered Mars orbit on August 7, 1976. The Viking 2 Lander touched down on September 3, 1976. The Orbiters imaged the entire surface of Mars. The Viking Landers transmitted images of the surface, took surface samples and analyzed them for composition and signs of life, studied atmospheric composition and meteorology, and used seismometers. The Viking 2 Lander ended communications on April 11, 1980, and the Viking 1 Lander on November 13, 1982, after transmitting over 1,400 images of the two sites. Many of the Viking Orbiter and Lander images are available from the National Space Science Data Center (NSSDC), online or on CD-ROM, and as photographs (http://nssdc.gsfc.nasa.gov/). Seasonal dust storms, pressure changes, and transport of atmospheric gases between the polar caps were observed. A biology experiment produced no evidence of life at either landing site.

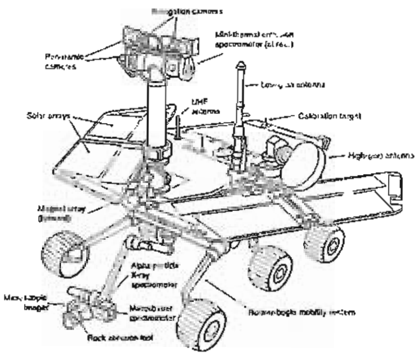
Mars Pathfinder Mission

The Mars Pathfinder mission consisted of a stationary lander and a surface rover. Its goal was to demonstrate the feasibility of relatively low-cost landings on and exploration of the Martian surface. This goal was achieved by tests of communications between the rover and lander, and the lander and Earth, tests of the imaging devices and sensors, and tests of the maneuverability and systems of the rover on the surface. Mars Pathfinder was launched on December 4, 1996. The spacecraft entered the Martian atmosphere on July 4, 1997 without going into orbit. The cruise stage was jettisoned 30 minutes before atmospheric entry. The lander took atmospheric measurements as it descended. The entry vehicle's heat shield slowed the craft. An 11 meter (36 feet) diameter parachute was deployed, slowing the craft further. The heat shield was released after parachute deployment, and the bridle, a 20 meter long braided Kevlar tether, deployed below the spacecraft. The lander separated from the backshell and slid down to the bottom of the bridle. About 10 seconds before landing four air bags inflated forming a protective "ball" around the lander. The three solid rockets, mounted in the backshell fired to slow the descent, and the bridle was cut 21.5 m above the ground, releasing the airbag-encased lander. The lander dropped to the ground and struck on July 4, 1997 and bounced about 12 meters (40 feet) into the air, bouncing at least another 15 times and rolling before coming to rest about 2.5 minutes after impact and about 1 km from the initial impact site. The Mars Pathfinder returned more than 16,000 images from the lander and 550 images from the small rover, named Sojourner, as well as more than 15 chemical analyses of rocks and extensive data on winds and other weather factors.

Mars Global Surveyor

The Mars Global Surveyor (MGS) mission entered orbit and began its mapping mission in 1999, with data acquired until April 2002. The spacecraft will also be used as a data relay for later U.S. and international missions. Mars Global Surveyor is the first spacecraft in a series of missions to be launched in a planned decade-long exploration of Mars by NASA. Launches will be orbiters, landers, rovers, and probes to Mars.

The Mars Exploration Rovers



NASA's twin robot "geologists," the Mars Exploration Rovers, launched toward Mars on June 10 and July 7, 2003, and landed on Mars January 3 and January 24, 2004 PST (January 4 and January 25 UTC). The primary scientific goal was to search for and characterize a wide range of rocks and soils that hold clues to past water activity. The spacecraft were targeted to sites on opposite sides of Mars that appear to have been affected by liquid water in the past. The landing sites were at Gusev Crater, a possible former lake in a giant crater, and Meridiani Planum, where mineral deposits (hematite) suggest a wet past.

After the airbag-protected landing craft settled onto the surface and opened, the rovers rolled out to take panoramic images. These gave information to select promising geological targets that will tell part of the story of water in Mars' past. Then, the Rovers were guided to those locations to perform on-site scientific investigations. Their mission was planned for 90 days, but the rovers continued to operate and provide information into 2008, when this guide was revised.

Future Mars missions are planned, including long-term planning for missions with astronauts aboard. There have been many other missions to Mars in the past, in addition to those summarized here. Some have been successful; some have failed; some have been partly successful. In addition to the United States, Mars missions have also involved the (former) Soviet Union, Japan, and Europe. For a list of all Mars missions, see: http://mars.jpl.nasa.gov/missions/log/

Scientific instruments carried by the rovers include: a panoramic camera for determining the mineralogy, texture, and structure of the local terrain; a miniature thermal emission spectrometer for identifying promising rocks and soils for closer examination and to provide temperature profiles of the Martian atmosphere; magnets for collecting magnetic dust particles; a microscopic imager (MI): for obtaining close-up, high-resolution images of rocks and soils; a rock abrasion tool for removing dusty and weathered rock surfaces and exposing fresh material; and a number of other instruments.

Each rover is sort of the mechanical equivalent of a geologist walking the surface of Mars. The mast-mounted cameras are 1.5 meters (5 feet) high and provide 360-degree, stereoscopic, humanlike views of the terrain. The robotic arm can move in much the same way as a human arm with an elbow and wrist, and places instruments directly up against rock and soil targets of interest. In the mechanical "fist" of the arm is a microscopic camera that serves the same purpose as a geologist's hand-held magnifying lens. The Rock Abrasion Tool serves as the geologist's rock hammer to expose the insides of rocks.

Before landing, the goal for each rover was to drive up to 40 meters (about 44 yards) in a single day, for a total of up to one 1 kilometer (about three-quarters of a mile). Both goals have been far exceeded! For much more on the Mars Rovers, encourage your students to visit: http://marsrovers.jpl.nasa.gov/home/