# The Process of Science...and its Interaction with Non-Scientific Ideas

A Guide for Teachers, Students, and the Public

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# The Process of Science
## and its Interaction with Non-Scientific Ideas



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The Very Large Array, near Socorro, New Mexico, consists of 27 radio antennas in a Y-shaped configuration.

The Mosaic wide field optical imager, attached to the 0.9-meter telescope at Kitt Peak National Observatory, is one example of technology being used to extend our senses.

Mars Rover. Artist's concept of Rover on Mars.

*All truth passes through three stages.*
*First it is ridiculed.*
*Second it is violently opposed.*
*Third, it is accepted as being self-evident.*
*— Arthur Shopenhauer (1788-1860)*

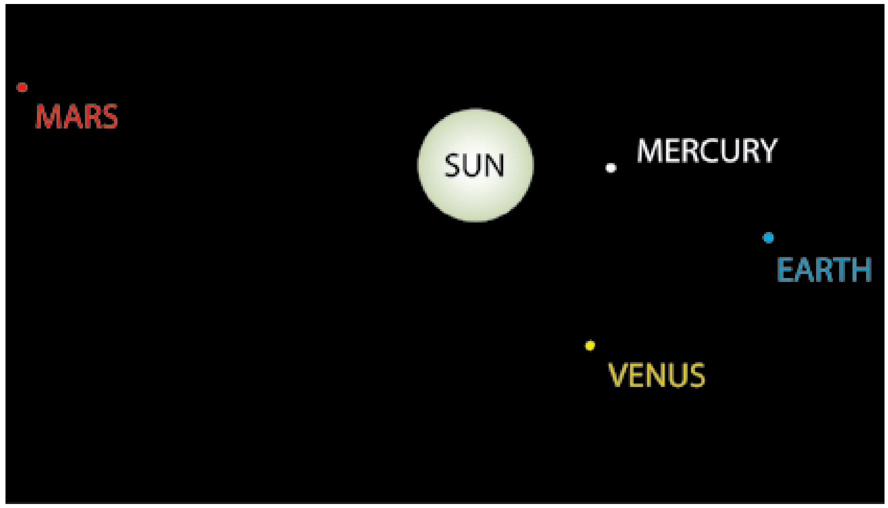
# What is science?

## Science is...

**Science is the study of the workings of the material universe.** Scientists try to discover facts about the universe and to find out how those facts are related. Those relationships are expressed as theories or laws of nature. The object or phenomenon that is the target of a scientific study must be perceivable by the senses or measurable with scientific instruments. Thus, supernatural phenomena, which would not be detectable by our senses (or scientific instruments), are not part of science. Scientists use a variety of tools to verify that an object is real and not imagined or a mirage. Instruments are used to record images and sounds, to identify atoms and molecules, and to determine an object's physical properties — its temperature, density, size, shape, and state of motion. The use of scientific devices to make these measurements helps to remove some of the subjective uncertainties that would otherwise cast doubt on new findings. Ultimately, however, scientific investigations begin with observations of objects or events in the physical universe.

The requirement for objective detection and measurement means that religious or spiritual aspects of our world are beyond the scope of scientific investigation. They are not rejected by scientists; indeed many scientists are deeply religious. But, because of the stringent protocol and constraints of scientific investigations, religion is not part of their scientific work.

**Science is a process for acquiring knowledge.** This does not mean that there is a definite series of steps that scientists follow, the way a cook would follow a recipe. There are many possible strategies in scientific investigations, just as there are many ways to win a soccer game. Scientists build on previous work and current knowledge, which is one reason why open communication among scientists is so important. Experience has shown that events


**Left:** During a lunar eclipse the curved shadow of the earth provides good evidence that the earth is pretty much round and not flat or any other shape. **Right:** Our knowledge of the laws of nature enables scientists to predict the positions of the planets far into the future. Here are the positions of the inner planets on June 7, 2015, as viewed from over the sun's north pole. (The distances in this image are to scale, but the sizes of the sun and planets are not.)

in the universe can be described by physical theories and laws. Laws of nature describe how objects and events are related. Scientists do not state laws of nature based on speculation about how the world should work or how they would prefer that it work. Rather, the laws of nature are determined by what is observed — the way the world is, not how we would like it to be.

Scientists observe the universe, they formulate questions and perform experiments or make additional observations to try to answer those questions. In trying to explain some observed event, they may offer a hypothesis — a tentative explanation of the observed phenomenon. A scientific hypothesis must make predictions that can be tested by experiment or observation. For example, suppose someone suggests that the phases of the moon are caused by the earth's shadow on the moon. One prediction of this hypothesis might be that at certain times every month, we should see the moon with just a little bit of the earth's shadow on it, looking like the illustration on the top left. Notice how the terminator — the borderline between the lighted and dark parts of the moon — is curved.

However, observations show that the moon doesn't look like that every month, and so we can reject that hypothesis. (Only during a lunar eclipse — a couple times per year -- does the moon look like this. The terminator of a gibbous moon is curved in the opposite direction from what's shown in the photo above.) Note that a non-scientific explanation, such as that the moon's phases are caused by the changing appearance of the Greek goddess Selene, would not be considered a scientific hypothesis because this idea does not make any testable predictions.

With more and more supporting evidence, a hypothesis may become accepted as very likely true and is distinguished by the term **theory**. It is important to understand that scientists do not use the word theory as the general public does. To most people, a theory is an idea

It is an amazing tribute to both the simplicity of the universe and the success of the scientific enterprise that scientists have been able to describe so much of nature using only a very small number of scientific laws.

that is highly speculative, perhaps a complete guess. But when scientists dignify an idea by the term theory, they are saying that they are quite confident that it is correct. Indeed, many scientific ideas that are referred to as theories are also facts. For example, airplane pilots learn about the "theory of flight." We use the word theory but there's no question about whether airplanes can really fly.

**Science is a collection of facts.** Scientific knowledge encompasses an enormous amount of information about the physical universe. One nice feature of science is that we don't need to be able to explain *why* something works in order to understand *how* it works. Newton could formulate the law of gravity without understanding why gravity works the way it does. Without understanding anything about why gravity works, we can use the law of gravity to accurately calculate and predict the motion of baseballs and missiles on the earth, planets around the sun, and stars moving in distant galaxies.

Facts are not the heart and soul of what makes this endeavor science. More than anything else, science is a self-correcting process for acquiring knowledge, with many mechanisms for detecting errors. It has other important features as well.

**Science is organizing principles and laws.** Besides discovering the objects in the universe — from atoms to galaxies — scientists have also found that these objects interact only in specific ways that can be described by laws. A physical law can be expressed mathematically, such as Newton's law of gravity, $F=Gm_1m_2/r^2$, or conceptually, such as the law of conservation of mass. It is an amazing testament to the simplicity of the physical universe and the success of the scientific enterprise that scientists are able to describe so much of nature using only a very small number of scientific laws. The essence of science is organizing what we know — facts and correlations — into a few guiding principles (laws or theories) like biological evolution or general relativity. This can successfully occur since science is self-correcting and results in well-established scientific conclusions having tremendous credence.

**Science is a culture.** Members of the scientific community have developed a culture that engenders trust and sharing of information. Science is a human activity and therefore, just like any other human activity, involves social interaction, a variety of personalities, and distinctive ways of thinking and working that have resulted in tremendous advances in science and technology. Because of the importance of communication, science is a highly social activity. Today's scientific discussions provide fertile ground for new ideas that will evolve into tomorrow's theories. Scientists bounce ideas off one another and, when interests coincide, may decide to collaborate on a project. New results are not only discussed informally (for example, via e-mail or when chatting at a meeting), but are also formally presented at conferences and, for greatest credibility, published in refereed journals*. Conferences provide the opportunity for the presenting scientist to hear additional ideas or evidence that could support or refute the new results. After additional refinement, researchers usually submit the results for publication, at which time additional reviews and criticism are provided, and the referee(s) verify that there is sufficient supporting evidence to justify communication of the results to the scientific community.

Referees don't verify the original data that led to the scientific conclusions. Other scientists will do that when they repeat the observations or experiment. Referees make sure that accepted scientific procedures were followed and that, if the data are correct, then the conclusions are justified.

**Science is an object of study by sociologists and philosophers.** In recent decades, there have been a number of new academic disciplines devoted to the study of science and scientists. These subjects include the sociology of science, the philosophy of science, the history of science, and the general discipline of "Science Studies." These disciplines are concerned with exactly how it is that scientists acquire new knowledge. They consider the social, political and intellectual factors that shape the practice of science. And they may also consider the difference in the sequence of steps scientists use to acquire new information and the sequence of steps presented in publications for their colleagues, students, and the public.

**Science is a profession, but not just any profession.** People don't enter a scientific career to become rich. What motivates scientists is a passion for learning about some aspect of the universe. The delight that comes from making discoveries explains, in large part, why fraud is so rare in science. (Because it is so rare, any case of scientific fraud always produces huge headlines.) Science is a profession that requires honesty and truth. Indeed, without those qualities, there could not be the tremendous progress in science that we observe.

An additional result of scientists' integrity is that the scientific community can be trusted to present a picture of the universe as close to reality as possible. Scientists trust each

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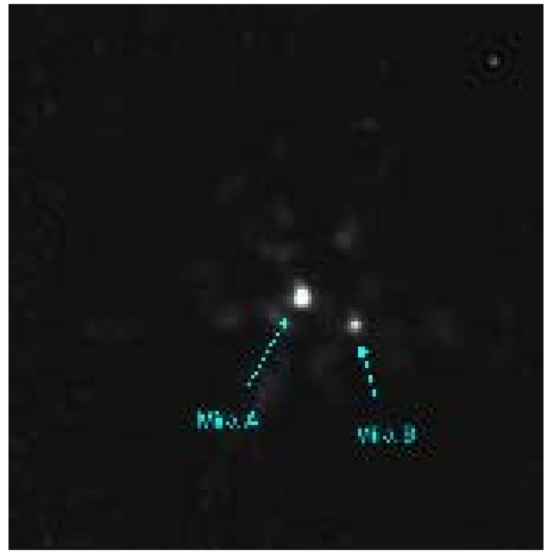
* A referred journal is a journal in which the editors first look at the paper and decide if it might be suitable for the journal. If it look suitable, it is then sent out to one or more (often anonymous) "referees"—other scientists who try to provide an objective review to determine if standard scientific methods have been used and whether the conclusions are likely to be correct. The paper will be published only if the referee(s)—in addition to the editor—approve the paper.



The author experienced the thrill of discovery -- he was the first person to obtain images of the Stingray Nebula (left) and the companion to the star Mira (known as Mira B, right).

other to be honest and unbiased (and you can, too). But we don't need to rely solely on trust, because other scientists will certainly repeat the research and verify that is correct. In this way, any mistakes are caught fairly quickly. (One example was the announcement of "cold fusion" in 1989, which was met with skepticism from the scientific community. People tried to reproduce those results, and scientists quickly reached a consensus that the results were not correct.)

Curiosity about the world can motivate someone to become a scientist. But success in science requires other qualities, such as persistence and creativity. Rewards include a job and a fascinating profession. Best of all is the thrill of discovery — finding something that absolutely *no one* knew about before you discovered it!. As a scientist, you could be the first person in the world to discover something new!

**Science is a symbol of credibility.** People frequently tack "science" onto the name of an area of interest when they wish to add an air of authority. For example, the school subject that used to be called "home economics" is now sometimes called "domestic science." Similarly, the topic known as "creation science," is, in fact, not a science at all. Real scientific subjects don't even have the word "science" as part of their name, e.g., physics, astronomy, chemistry, biology, geology. These have been around for centuries, and the etymology of their names indicates that they are sciences. The real way to tell is whether they use modern scientific techniques, including repeated testing and peer review that lead to significant advances when new information is acquired, and then to practical applications and/or new technologies.

## The Hallmark of Science: Testing and Verifying

The foundation of science is empirical testing — actually looking at what is happening rather than simply speculating. Stripped of all its symbolism and sociological baggage, science remains at its core a way to learn about nature. Scientists do not (or should not) accept ideas as being correct unless supported by objective observations and a great deal of compelling evidence. The testability of an idea is one criterion that separates science from non-science.

## Importance of Understanding the Scientific Process

Individual scientific facts are interesting, but without an understanding of how those facts were discovered, and how we know they are correct, it would be impossible to distinguish well-founded laws from merely speculative ideas that are most likely wrong. As it is, Americans waste billions of dollars on products and services that are known not to work. (See the section on pseudoscience on page 21.) While the promoters of these products and services are very enthusiastic, the results can range from merely wasting time and money to personal tragedy (for example, when ineffective “remedies” are substituted for needed medical treatment). It is therefore critical to understand how real science works, so that we can identify the cheap imitations.


People are often fooled by products that do not live up to the advertised claims. One clue that a product won’t work is if it claims to take care of too many different problems, such as a medical “cure-all.”

## Science is Part of the Larger Context of Society and the Natural World.

Science is everywhere in our daily life. For example, a painting contains science in both the content and the media. Consider the detailed drawings of Leonardo Da Vinci. One way that science is apparent in these drawings is in the detailed understanding of human anatomy that he came to have through his scientific investigations. A second way that science appears here, as it always does in art, is in connection with the paper, canvas and inks, which are the result of extensive scientific experimentation and analysis. A third way that science enters into the arts is in the academic study of those fields. There are studies of human perception of art and music as legitimate scientific subjects. Science is also fundamental to music in several ways, from the physics that explains the source of the sounds and the combinations of sounds that are harmonic, to the science that goes into the construction of musical instruments. The subject matter of the music can also be scientific (e.g., Haydn's *Il Mondo della Luna*, a comic opera involving an amateur astronomer who is tricked into believing that he is on the Moon.)

Science is everywhere -- outside where we see all the flora, fauna, stars, and planets, and inside where we benefit from applied sciences through the technology in our homes -- refrigerators, televisions, air conditioners, and computers, all with scientific underpinnings. These technologies are not science per se, but applications of scientific results. The successful functioning of these technologies demonstrates the effectiveness of modern scientific methods.

At various times in history, most religions encouraged scientific work as a way to mark religious events or to better appreciate the works of God (or a god). Indeed, there is an astronomical observatory at the Vatican. Sometimes science provides us with a greatly increased understanding of the universe that contradicts traditional religious ideas. This is discussed in the section on Opposition to Science (pages 28 to 37) Many people find that the increased understanding and recent spectacular views of the universe that science has provided have bolstered their religious beliefs.

This drawing by Leonardo da Vinci shows not only the kind of detailed knowledge that can come with scientific investigation, but also demonstrates Leonardo's artistic skills and their application to his scientific work.

Science is everywhere in our daily lives.

# What do scientists do?

Many students are taught that scientists use a five-step "scientific method" in their work. Real science is much more varied than that and involves many other steps. Here are just some of the activities that scientists carry out in the course of their work.

Model

DESIGN AN EXPERIMENT

Read papers

Ask questions

Observe the world

Solve mysteries

Hypothesize

Graph

Build instruments

Summarize results

Get surprised, and discover something new

Evaluate the evidence

Measure

Report findings

Compute

Locate funding sources

Establish theories

Experiment

Estimate

Draw conclusions

Consider and compare alternative ideas

Calculate uncertainty or levels of confidence

Formulate goals

Collaborate

Plan investigations

Explore

Build on previous scientific work

Gather evidence

Collaborate with other scientists

## Characteristics of Scientific Ideas

- **Observability:** The event under study, or evidence of a phenomenon, can be observed with the human senses or with tools that serve as extensions of the senses like microscopes, telescopes, Geiger counters, etc.

- **Consistency:** The results of repeated observations and/or experiments are the same when performed by other competent investigators.

- **Natural explanation:** Our understanding of phenomena relies on natural causes. Supernatural explanations are outside of the realm of science, since they cannot be observed or tested.

- **Predictability:** A scientific explanation can be used to make specific predictions. Each prediction can be tested to determine whether it supports the proposed explanation.

- **Testability:** The proposed explanation must be testable through controlled experimentation or observation.

- **Repeatability:** If an idea is correct, its predictions will not only be verified, but will also be repeatable. For example, if we think we understand the effects of gravity, we should be able to repeat any test of it and always get the same results if we have the same experimental conditions. Scientists' reluctance to accept new ideas -- sometimes called skepticism -- stems from the requirement for repeated and consistent results. Until such robust evidence is obtained, there will not be a consensus in the scientific community.

- **Falsifiability:** A scientific idea must always be stated in such a way that the predictions derived from it can potentially be shown to be false.

## Characteristics of Scientists' Work

- **Standard methods:** Procedures for research must be accepted by the scientific community, and results must be peer-reviewed. Although different branches of science use different techniques, they agree that the methods used must be generally accepted by the scientific community.An example of differences in methods is that physics is experimental, while astronomy is observational. There is no definite sequence of steps for undertaking a scientific investigation, but there is an expectation that proposed ideas will be testable by observations or experiments, and that the results will be repeatable.

- **Peer review:** The results of scientific work are submitted in the form of papers or articles to the scientific community for review. Findings are critically examined by qualified scientific experts in the field who act as referees, approving new results for publication only if there is compelling evidence that the data support the conclusions. New ideas are accepted gradually by the scientific community, because of the rigor and skepticism that help guard against the adoption of ideas that are incorrect (or unsupported by evidence).

- **Logical reasoning:** Conclusions drawn from experimental, observational, or theoretical work must be reasonable given the data presented and methods used. Sometimes results from new data will contradict previous ideas, and scientists are then compelled to change their thinking. This is not a bad thing; this is precisely how science progresses. Notice how different this is from a court of law, where an attorney must continue to defend the client, even despite overwhelming evidence against the client. When the attorney maintains a position on the client's behalf in the face of conflicting evidence, we assume that the attorney is just doing his/her job. But in the rare case when a scientist refuses to change his/her mind in the face of overwhelming evidence to the contrary, the scientific community questions his/her worth (and sanity) as a scientist.

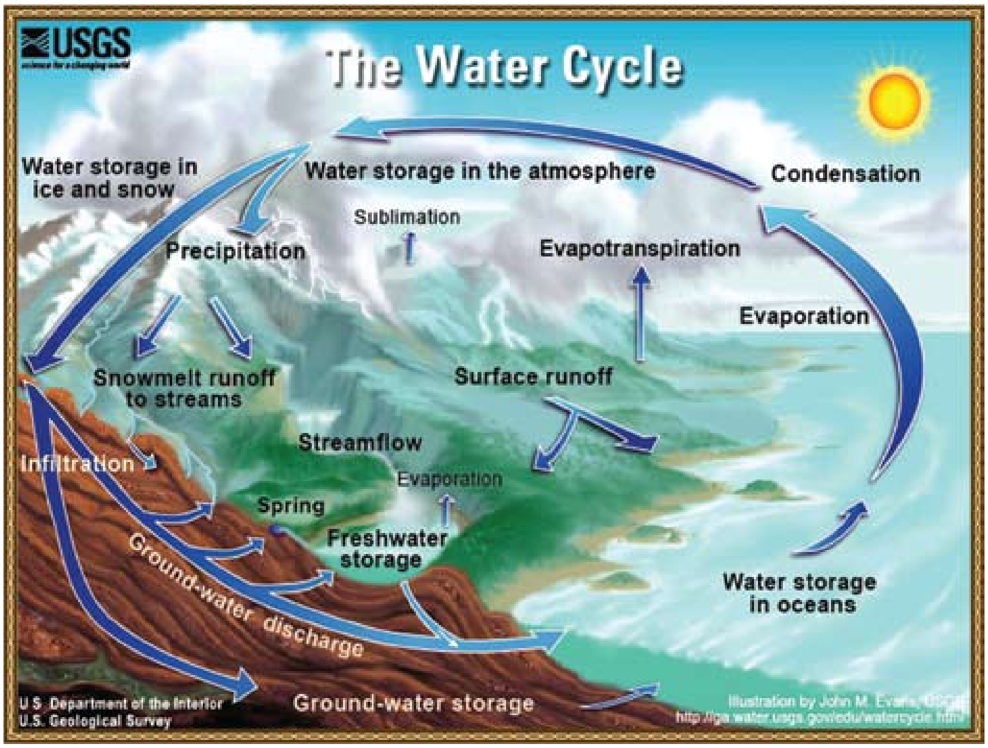
- **Use of models:** A scientific model helps scientists understand how some aspect of nature appears or operates. A model can be a simplified representation of something more complex, or it can be a manageable-size replica of something too large or too small to easily grasp, either physically or mentally. Models can be physical (like a globe of the earth), mathematical (an equation or a computer simulation), or conceptual (like a description of the water cycle or a flow chart depicting how scientists undertake research). Models are corrected, expanded, and revised so that they are improved and more useful.

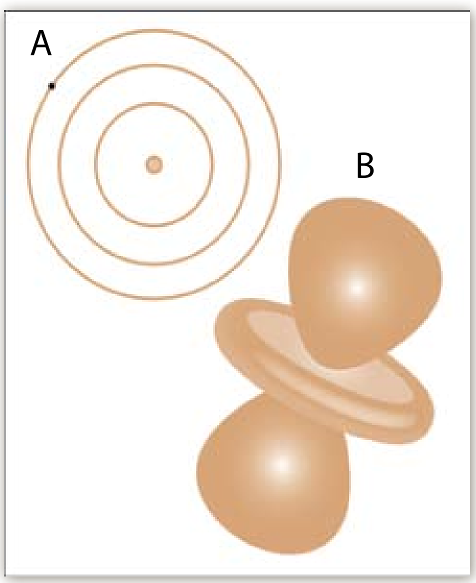
- **Acceptable data analysis:** Data have been analyzed using accepted quantitative or statistical methods.

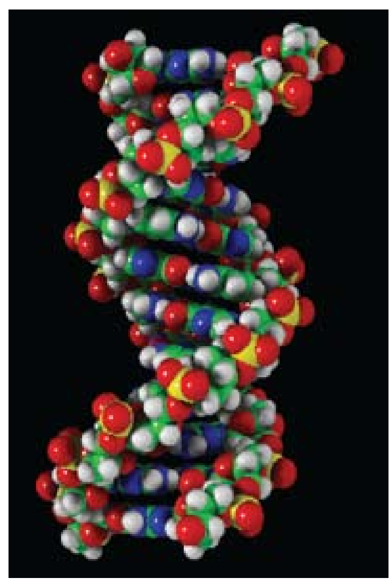
- **Relevance of data:** Data and findings are considered in their proper scientific context.

- **Appropriate references:** Assumptions, analytical techniques, and conclusions are referenced to relevant, credible, and respected scientific literature.

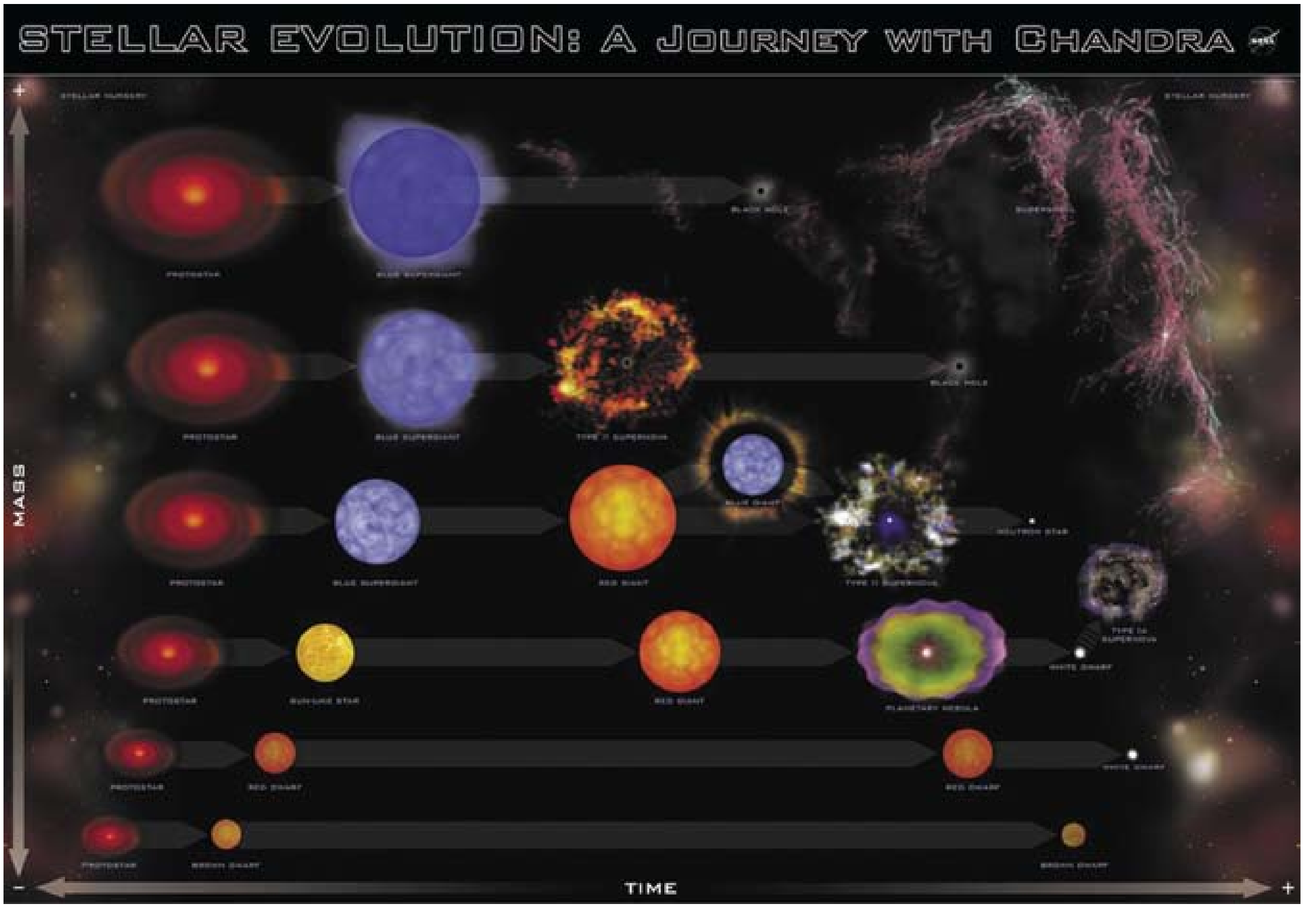
- **Communication of results:** Scientific work is widely disseminated to the scientific community at conferences and in peer-reviewed publications.



Scientists use different kinds of models. **Top:** Conceptual model of the water cycle. **Lower Left:** Early 20th century model of an atom (Bohr Model) visualized electrons as little balls orbiting an atomic nucleus with precise locations. With the advent of quantum mechanics, we now know that electrons are not found in definite locations in the atom. They are better represented as "clouds of probability", as illustrated by figure B. **Lower Right:** This is a physical model of part of a DNA molecule.



This poster, from the Chandra X-ray Observatory, depicts the main stages of stellar evolution for stars of different masses.

## Interplay between theory and observation/experimentation

Not only do multiple observations or experiments provide evidence for a scientific idea, but when the observations agree with theory, we can be confident that we are on the right track. Examples:

- **Stellar Evolution:** By observing stars in all stages from formation to demise, astronomers put together a reasonable scenario about how stars might form and evolve. Theorists calculated, using known physical laws (and with the help of computers), what stages stars should go through after they form*. The theoretical results and the observationally determined scenario agree, which means that we've most probably got it right.

* The seminal paper on the creation of the chemical elements was "Synthesis of the Elements in Stars," published in 1957 by E. M. Burbidge, G. R. Burbidge, W. A. Fowler, and F. Hoyle. This paper exemplified how scientific research is an iterative process, with observation and experiment providing new insights and constraints for the theory, and the theoretical work demanding new experiments and observations for verification.

## Only with very substantial supporting evidence will the scientific community embrace new information.

- **The Big Bang:** Measurements of distances and speeds of galaxies show that the universe is expanding. This means that in the past galaxies must have been closer together than they are today. Because we know distances and speed, we can calculate when the expansion started. That event is called the Big Bang. One prediction based on a Big Bang beginning of the universe is that there should be leftover radiation from that early expansion, observable with radio telescopes. In 1964 that radiation was detected and observed to include all the predicted characteristics. This discovery, combined with other evidence also predicted from Big Bang, makes it clear that there really was a Big Bang, and so that is the consensus among scientists today.

- **Dark Energy:** Observations of supernovae (exploding stars) showed that the universe's expansion was slower in the past, and that the expansion has been accelerating. This was a surprise since gravity should make the expansion of the universe gradually slow down. Something is creating a repulsive force making the expansion speed up and, although we don't yet know exactly what it is, astronomers refer to it as "dark energy."

  Albert Einstein, in developing his theory of relativity, thought there must be some repulsive force, since without it the universe would have to be either expanding or contracting. At the time (in the early 20th century), it was thought that the universe was static. Einstein did not initially know that the universe is expanding. When he later learned of observations showing that the universe is expanding, he removed the repulsive force from his theory. But, now that new observations reveal that the expansion of the universe is actually accelerating, scientists realize that a repulsive force is indeed needed to correctly describe the expansion of the universe. Here again, we see how the interplay between observations and theory allowed our understanding to advance.

- **Global Climate Models:** Studies in climatology make use of both theory and observations to understand the mechanisms that control the global environment. After understanding the basic processes, as well as their potential influence on climate change, these processes are incorporated into atmospheric and ocean models. The models are used to make predictions, which are then compared to actual observations. Any discrepancies result in modification and refinement of the theory and greater understanding of the processes that affect our climate. One prediction is that the average temperature will continue to rise, leading to various effects, such as increased ocean temperatures.

- **Ocean Temperatures and Storms:** Both theory and observations support a modest increase in storm intensity with warming sea surface temperatures. All else being equal, for every 1 degree C increase in sea surface temperature, there is a 5% increase in the maximum surface wind speed. In fact, tropical sea surface temperatures warmed about 0.5 degrees C during the 20th century and, sure enough, the total power dissipated by tropical cyclones has risen with the average tropical sea surface temperature over the past 30 years.

  The number of Category 4 and 5 hurricanes has increased by 80 percent worldwide during the past 35 years. Hurricanes in these two highest storm categories, with winds of 135 miles per hour or greater, now account for roughly 35 percent of all hurricanes, up from around 20 percent in the 1970s.

- **Heavier-Than-Air Flight:** The development of airplanes involved an extensive amount of theoretical work combined with experimentation. The first experimenter who actually analyzed the various forces that contributed to flight was the Englishman George Cayley. At the end of the eighteenth century, Cayley identified and defined the forces of flight and sketched out an airplane that had the major parts of a modern airplane. He defined the principles of mechanical flight and realized, for instance, that it was necessary to apply a forward force greater than air resistance.

  The Wright brothers used a combination of theory and experiment to get their first airplane to fly. After one of their gliders crashed in 1901, they went back home to work out new calculations of the lift and drag on airplane wings. They also built a wind tunnel to answer some remaining questions regarding the best shape and location of the wings. Repeated experiments combined with critical thinking made it possible for humans to fly!

The beginning of the Wright brothers' first flight, on December 17, 1903.

## Science can be surprising

Because no one can predict the directions in which science will develop, no single person, committee, religious group or government can dictate which ideas should be pursued. The history of science has sometimes shown that what was previously thought impossible, is not. For example, before the Wright brothers flew their first airplane, many people thought that heavier-than-air flight was impossible. Only by pursuing various lines of research can we know what directions will be most fruitful.

# Scientific Ethics

## Honesty

Different professions have different (written or unwritten) codes of conduct. For a scientist, ethical conduct may mean something different than it does to a lawyer or to a minister. As with all professions, scientists are expected to exercise professional conduct consistent with moral judgment. Fabrication, falsification, and plagiarism are considered academic misconduct, no matter what the field. Honesty is paramount for several reasons. It is, of course, demanded by basic ethical considerations; it is important for a scientist's professional reputation; and it is essential for the successful progress of science and the advancement of our understanding of the universe.

Scientists are required to accurately report all results — not just those results that support the scientist's expectations or desires. Notice how this differs from the work of a trial lawyer who may choose not to bring up points that might be damaging to the case. A scientist is expected to address all relevant evidence, pro or con, to most effectively determine why things are the way they are. Sometimes most of the data support a researcher's conclusion, but there may be a small amount of discrepant data that does not. It would be dishonest for the researcher to ignore the inconsistent data, even if it is a very small percentage of all the evidence. The scientist should note the discrepancies, which would then aid others in taking the research further and determining whether there is a flaw with the strange data (perhaps due to a problem with the experimental apparatus) or with the inferred conclusions.

As an example, consider the case of Johannes Kepler who initially believed that the planets move in circular orbits around the sun. He tried to find a circular orbit for Mars that would match Tycho Brahe's observational data.

After years of calculation, Kepler found an orbit that matched most of Tycho's observations of Mars to within 1/30 of a degree, but there were two cases where the calculated orbit differed from Tycho's observations by 4/30 (or 2/15) of a degree. Kepler must have been tempted to ignore these two observations and assume that Tycho had been in error. (An angle of 2/15 of a degree is only ¼ the apparent diameter of the full moon.) But Kepler trusted Tycho's observations, and the small 2/15-degree


This postage stamp, issued by Ajman (part of the federation of the United Arab Emirates), commemorates Johannes Kepler's discoveries about the orbits of the planets.

discrepancies led Kepler to give up the idea of circular orbits and find that the orbits are ellipses.

Rejecting the idea that the planets' orbits had to be perfect circles went against firmly entrenched beliefs. Kepler said that it shook his deep religious faith. Given that only two of Tycho's observations disagreed with a perfectly circular orbit — and only by 2/15 of a degree, one can speculate whether other people would have made Kepler's choice to abandon perfect circles. The scientific importance of relying on objective data rather than preconceived beliefs cannot be underestimated. History has shown the folly of rejecting science in favor of political, religious, or other ideological beliefs. Indeed, in any disagreement between scientific views and religious views about the natural world, scientific views have always prevailed. Famous is the case of Galileo's run-in with the Church or when the Indiana House of Representatives in 1897 passed a bill that specified the value of pi, stating that "the ratio of the diameter and circumference is as five-fourths to four." This implies that the ratio of the diameter to the circumference of a circle (which is 1/pi) is 5/4 divided by 4, which is 5/16. Pi, (or as written by scientists and mathematicians, □), the ratio of the circumference to the diameter, would be the reciprocal of this, or 16/5 = 3.2. The actual value of pi is approximately 3.14. One cannot determine the nature of the universe by legislating it or by decreeing it based on faith.

Scientists are aware that there is always some uncertainty in any measurement, and consequently it is expected that they will quantify the uncertainty and indicate the level of precision with which the results are known. Any possible sources of error need to be mentioned, which is an aid both to other scientists checking for possible mistakes and to the original researcher who tries to avoid making such errors.

Not only must the results be truthfully reported, but scientists must also accurately describe the methods used to arrive at the conclusions. This facilitates important checks in the scientific process whereby other scientists can decide whether the methods used were appropriate and also makes it possible for them to repeat the experiment and verify that the original results were correct.

## Objectivity and Skepticism

Scientists want to understand natural phenomena, and that will most easily be achieved if bias can be avoided. Bias exists if a conclusion is based on considerations other than tangible evidence and sound theory. Scientists must make sure their own values or desires do not affect the collection or interpretation of the data. Consequently, objectivity is extremely important. Scientists work very hard at preventing preconceptions from influencing the results, although it cannot always be avoided. That's why, for example, new medicines are tested in double-blind studies in which neither the researcher nor the subjects know who is receiving the treatment.

Scientific objectivity is always at risk when decisions about science are made for non-scientific reasons. For example, if a state's Board of Education removes questions on a particular topic from its assessment exams simply because Board members feel the topic is inconsistent with their political, religious, or social values, then it is a safe bet that the best, current science will not be taught in that state.

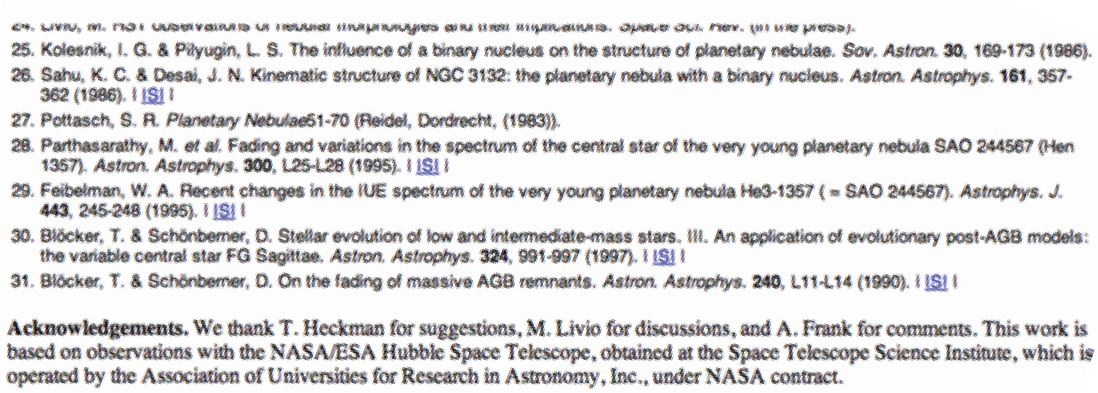
Knowing how easy it is to be mistaken, scientists are very cautious about accepting new ideas. Only with very substantial supporting evidence will the scientific community embrace new information. This skepticism guards against bias and unsubstantiated claims that are made only to support a dogmatic conviction. This skepticism is evident whenever claims are made without tangible evidence to support it, such as the claims of "cold fusion" or "intelligent design." On the positive side, this skepticism means that when the scientific community finally accepts an idea, we can be confident that it is correct. For example, it took many years and many kinds of evidence to know with certainty that the earth is billions of years old. (For more information on this, see *The Ancient Universe: How Astronomers Know the Vast Scale of Cosmic Time,* http://education.aas.org/publications/ancientuniverse.html)

## Societal Implications

While maintaining the highest level of integrity in pursuit of the advancement of science, scientists also have responsibilities to society. Sometimes new scientific information can have huge effects on the populace through resulting new technologies. An obvious example is the development of nuclear weapons that emerged following research on atomic nuclei. Scientists must therefore be prepared to address the social and economic issues that arise from their scientific work. Committees are often assembled to study the situation and reach a consensus on how to proceed. One case where this occurred was when biologists first had to deal with genetic engineering issues. Scientists might agree to a temporary moratorium on a particular kind of research while they set up a regulatory mechanism to ensure its safety.

## Credit and Citation

Honesty and fairness require that everyone give credit where it is due. This is especially important when credit for work done plays such an important role in career advancement, as it does in science. The author of a scientific paper can acknowledge others' work in three places: the list of authors, the acknowledgments, and the list of references. Scientists who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**Acknowledgements.** We thank T. Heckman for suggestions, M. Livio for discussions, and A. Frank for comments. This work is based on observations with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract.

The references in a scientific paper not only help readers find related work, but also give credit to those who provided the foundation for the new results. The acknowledgements give further credit to those who provided special assistance.

do not give proper credit for others' work soon find themselves excluded from the scientific community. Thus, published scientific papers must not only be clearly written and verifiable, but they must be honest in both the content and the credit to other scientists who contributed to the field.

## Service to the Scientific Community

Since checking each other's results is such an important part of the scientific process, all scientists can expect to eventually be called upon to perform the community service of helping to verify other scientists' claims and discoveries. The scientific community considers it just as valuable as making a new discovery, if not more so, to find out that another scientist erred in reaching a conclusion.

Because scientists frequently check one another's conclusions (sometimes out of eagerness to catch others' mistakes), faulty results are generally uncovered quickly. Furthermore, the large amount of evidence needed to convince scientists of new ideas makes it very unlikely that a wrong conclusion will attain wide acceptance among scientists for very long.

## Publication

Science is a social activity and depends on frequent communication among scientists for its progress enabling them to build upon previous work and avoid duplication of effort. Because of this, important social conventions have developed. One is to not keep scientific information

**Claim of Achieving Fusion in Jar Gains Support in 2 Experiments**

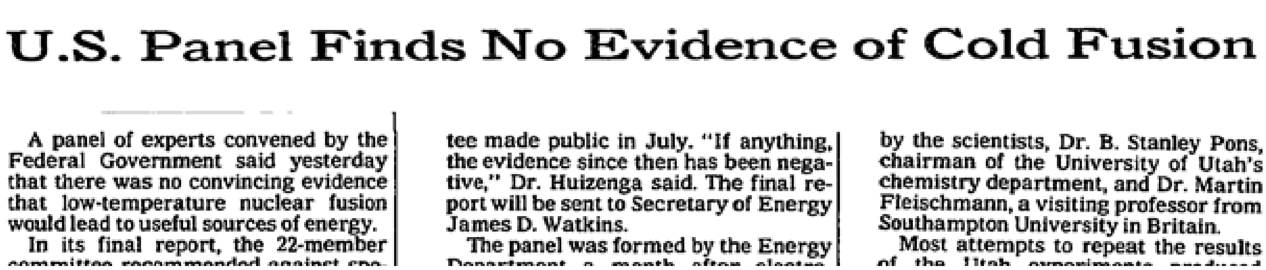
By MALCOLM W. BROWNE

Special to The New York Times

COLLEGE STATION, Tex., April 10 — A recent claim by scientists in Utah that they had achieved nuclear fusion in a jar of water gained important sup-

significant results first reported on March 23 by B. Stanley Pons of the University of Utah and Martin Fleischmann, a collaborator from the University of Southampton in Britain

Without peer review and duplication of results by other scientists, new findings are less likely to be correct. In this case, the New York Times first reported (left) on April 11, 1989, evidence of cold fusion, but then later (below), on November 4, 1989, reported that after attempted replication of results, there was "no convincing evidence that low-temperature nuclear fusion would lead to useful sources of energy."



**U.S. Panel Finds No Evidence of Cold Fusion**

A panel of experts convened by the Federal Government said yesterday that there was no convincing evidence that low-temperature nuclear fusion would lead to useful sources of energy.

In its final report, the 22-member

tee made public in July. "If anything, the evidence since then has been negative," Dr. Huizenga said. The final report will be sent to Secretary of Energy James D. Watkins.

The panel was formed by the Energy

by the scientists, Dr. B. Stanley Pons, chairman of the University of Utah's chemistry department, and Dr. Martin Fleischmann, a visiting professor from Southampton University in Britain.

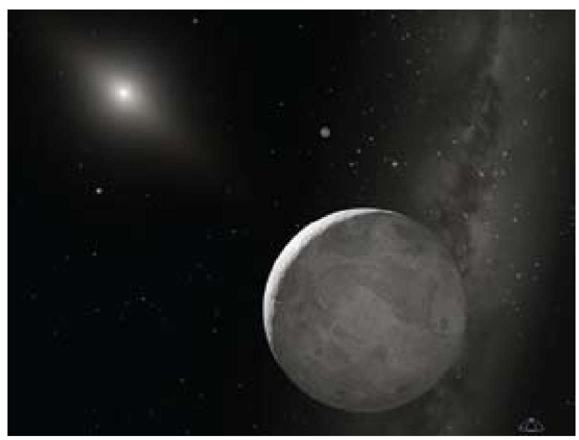
Most attempts to repeat the results

secret. But if a scientist shares new information, how does (s)he prevent other scientists from claiming the new work as their own? The answer is by publishing the new results. Besides establishing authorship for the new work, publishing scientific papers contributes to the process of science by allowing others to use new information, and, through peer review, provides a mechanism to ensure that the new information is likely to be correct.

Problems can occur if new research results are disseminated to the public prior to peer review. If that happens, there is an increased risk that the new information will not be correct. Scientists are therefore urged to wait until their peers have had a chance to scrutinize the results before releasing them to the press.

## Conflicts of interest

Sometimes the values and interests of different groups will be in conflict, and some conflicts of interest can seriously jeopardize the usual norms of scientific integrity. For example, if a researcher has a financial interest in a particular company, then there is an unacceptably high risk for bias in scientific decisions that affect the future of that company. In addition, a scientist might receive a proposal or manuscript to review that involves work related to but outdistancing that being done by the reviewer. These situations usually require that a scientist withdraw from the reviewing task.



This is an artist's concept of what Eris, the largest known dwarf planet, might look like.

Another tricky situation can occur if a scientist finds someone else's unpublished data. The scientist is obligated to not steal the data or use it to scoop the other person. One case where this may have occurred involved the discovery of the object initially called "2003 UB313," now known as Eris.

Eris was discovered by astronomers Mike Brown (Caltech), Chad Trujillo (Gemini Observatory), and David Rabinowitz (Yale University). Before they had announced their discovery, other astronomers found the location of the object in telescope observing logs available on the World Wide Web. Less than two days later, the astronomers in Spain announced the discovery of the object (the announcement was sent from the same computer that had been used to access the telescope observing logs). The Spanish astronomers are not faulted for looking at or using publicly available data. Rather, their violation of scientific ethics involved not acknowledging and citing the source of their information.

Cutting-edge research areas often provide opportunities for breaches of ethics, since advances in these "hot" topics can result in immediate recognition and celebrity. An example occurred when Hwang Woo-suk and his colleagues claimed that they had cloned human embryos and extracted stem cells from these clones. (Stem cells can produce various types of tissues, including liver, skin, heart, and brain cells). This was considered a major breakthrough, since stem cells could be used to replace diseased tissue without risk of organ rejection. However, an independent investigation concluded there were never any cloned embryonic stem cells. Besides not achieving the advertised breakthrough, the incident resulted in many other scientists misdirecting their efforts, trying to reproduce the achievement. Stem cell research may have been set back by years.

While the profit motive can create a conflict of interest, this type of conflict is actually quite rare in science. Scientific advances rarely result in great fortune, and fraudulent assertions in science are eventually discovered as other scientists try to reproduce the results. Most institutions and agencies have policies in place concerning conflicts of interest, which are generally effective for protecting the integrity of the scientific process.

In short, scientific ethics involves proceeding in a manner that maintains the highest level of integrity, including honest consideration of the evidence, avoiding bias, giving appropriate credit, and working in ways that most effectively advance our understanding of the universe.

# Opposition to Science

## Various causes for opposition

Opposition to scientific methods or results occurs when people …

…are not familiar with the evidence.
Example: Reports of the Wright brothers' first flights were not believed until enough people had seen the flights first-hand.

…believe there to be contradictory evidence.
Example: Some people thought there were limitations in physical laws that would prevent supersonic flight.

…have an ideological objection, on either philosophical or religious grounds.
Example: Some religious leaders embraced the discovery of the Big Bang as confirming the biblical creation story while others opposed the idea on religious grounds.

…misunderstand what scientists are saying.
Example: Some people mistakenly believe that the idea of biological evolution involves rejection of God, or that science promotes atheism.

## Pseudoscience

The term pseudoscience refers to a belief in false or extremely improbable ideas that might sound scientific but do not have supporting evidence, involve faulty logic, and are in open defiance of scientific consensus.

Promoters of pseudoscience frequently refer to obsolete or faulty experiments that agree with their beliefs, while later and better results tend to be ignored.

Example: When someone presents "evidence" that the earth cannot be billions of years old, or that biological evolution has not occurred, they make two mistakes: (1) not considering alternative explanations of that evidence and (2) ignoring the preponderance of evidence that tells us that the earth really is billions of years old and that evolution has occurred and still does occur.

Practitioners of pseudoscience are loath to submit their ideas to testing and falsification by independent investigators, and they generally do not submit their papers to mainstream science journals where their submission would undergo peer review.

Intelligent Design is a pseudoscience because its promoters present it as science, but do not follow standard scientific procedures of producing supporting evidence, testing hypotheses, and respecting the conclusions of independent peer reviews. Perhaps more importantly, Intelligent Design has no predictive power. Its inability to make testable predictions means that it does not qualify as part of science.

Promoters of pseudoscience (and many other non-scientific subjects) do not have the same level of skepticism that scientists do. Scientists will not accept new ideas without strong, repeatable, and compelling evidence. Therefore, scientists critically question one another about new results and change their minds when there is contradictory evidence. Pseudoscience advocates are not critical of one another, and as a result, the pseudoscience does not evolve to accommodate new information. Different types of pseudoscience can be categorized as supernatural, sensationalist, autocratic, or junk science.

- **Supernatural pseudoscience** includes magical ideas to explain, validate, or predict what people subjectively experience. It includes extrasensory perception (ESP), various kinds of psychic phenomena, numerology, palmistry, "New Age" ideas (preferring intuition to rationality, union with non-human or dead human spirits, reincarnation, etc.), astrology (not to be confused with astronomy), and medical quackery, such as magnet therapy, homeopathy, and psychic surgery.

- **Sensationalist pseudoscience** is often found in tabloid newspapers because of the superficial excitement it creates. It includes ideas that have mass appeal, such as UFOs (Unidentified Flying Objects), Big Foot, the Loch Ness monster, and various conspiracies.

- **Autocratic pseudoscience** comes from authoritarian edicts and includes such ideas as creationism (of the type that denies current, well-established science; see Appendix A for an explanation of the varieties of creationism) and the purported mystical significance of the number 666. Another example of autocratic pseudoscience was the mid-twentieth century Soviet governments' rejection of genetic research and modern agricultural techniques in favor of obsolete methods that set back Soviet agricultural research by decades.

- **Junk science** includes ideas that have been soundly rejected by a large body of research and scientific consensus, but which its proponents still endorse as legitimate science. Examples include denial of the dangers of smoking and the rejection of expert witness standards. Also in this category is the Fox television program, which aired on February 15, 2001, entitled, *Conspiracy Theory: Did We Land on the Moon?* Twelve astronauts really did land on the moon; see Appendix B for a list of ways that we know the moon landings were real. Intelligent Design is in the "junk" category because of its lack of scientific consensus, and in "autocratic pseudoscience" category as a form of creationism, the teaching of which some school boards and religious fundamentalist groups have tried to mandate.

## Anti-science

**Why it Exists**

Anti-science refers to active attacks on science by people whose belief structure will be undermined by critical thinking. They might lose prestige or power if ideas they advocate are revealed to be flawed. They would then also stand to lose funding. The most vociferous anti-science arguments come from people who perceive a conflict between scientific findings and deeply held religious or ideological beliefs. Some feel that they must do what they can to defend their position regardless of what's actually correct, or simply don't understand the

Alleged photos of unidentified flying objects like the one of a "UFO" (top) contribute to the popular misconception that UFOs are alien spacecraft. In this case, the "UFO" was made out of a Frisbee, a tennis ball, and some duct tape. It was tossed into the air right before the photo was taken. It is easy to make a "UFO." Many UFO hoaxes have been created this way.

> In science, there is a physical reality that anyone can potentially discover, and people can eventually agree what that reality is.

process of science and why it is so successful. Some proponents of pseudoscience also promote anti-science to try to defend their pseudoscientific ideas against criticism. It is very surprising to hear about attacks on well-established facts, such as the shape of the earth — and yet there exists a Flat Earth Society.

**Objective Reality**

The anti-science movement isn't an attack on just a particular scientific idea or on scientists themselves, but on science as a reasonable way to reach objective truth. Objective reality means that not only is there a universe to explore, but that we can accumulate knowledge toward a better understanding and build upon prior knowledge. Eventually people should be able to discover what there is in the universe and how the contents of the universe are interrelated. For example, if Sir Isaac Newton had not formulated the law of gravity, someone else eventually would have. If the Wright brothers had not achieved controlled, powered, sustained flight, someone else would have, as there were many people actively racing to achieve mechanical flgiht. One reason for this attitude is that people don't recognize that there is an objective truth based on the reality of how the universe works. For some others, reality means little more than how they feel about things.

**Multiple Discoverers**

The existence of an objective reality can result in different people coming up with the same conclusion or making the same discovery. For instance, Isaac Newton and Gottfried Leibnitz both independently invented the branch of mathematics now known as calculus; in the 18th century, Joseph Priestley and Carl Wilhelm Scheele independently discovered the chemical element oxygen; in 1846, astronomers John Couch Adams and Urbain Leverrier each predicted the position of a new planet which turned out to be Neptune. Charles Darwin and Alfred Wallace simultaneously formulated the theory of natural selection. Nowadays, scientific research is often undertaken in teams and multiple teams might be working on the same research. So if one scientist or one team of scientists doesn't achieve a particular accomplishment, it's a safe bet that someone else will.

**More Subjective Disciplines**

But the same is not necessarily the case in non-scientific areas like the arts or humanities. For instance, if Leonardo Da Vinci had not painted the Mona Lisa, there would never be a Mona Lisa in the Louvre. Artistic works (such as music or painting) and spiritual thoughts elicit different responses from each person and do not necessarily result in agreement. One type of anti-science sentiment results from people misunderstanding this point and incorrectly assuming that science is just as subjective as other disciplines.

**Categories and Causes of Anti-Science**

There are two categories of anti-science attitudes. One is from those who blame science for undesirable results of technology such as the bombing of Hiroshima. This involves the misconception that there is something inherently bad in the process of science. In fact, science is inherently neither good nor bad; it simply a way to acquire new information. The other category of anti-science attitudes comes from those who question science as an intellectual activity. Anti-science attitudes result from misconceptions, such as:

- ***Science is often wrong***. Frequent changes in health advice as written in the newspapers contribute to the public's suspicion of science. Why do we hear about changes in medical recommendations more often than we hear of errors in our understanding of the fundamentals of physical science? Apparently the standards of evidence are higher in the physical sciences. If a health claim passes a test at the 95% confidence level, then one out of 20 times it will be wrong. Basic information in physics and astronomy is known with much greater certainty; often greater than the 99.9% confidence level (or better than one part per thousand).

- ***Science pollutes.*** This comes from either the failure to distinguish between scientific knowledge and the technology that it enables, or the failure to distinguish between the scientific origin of potentially dangerous technology and the political decisions of how to use it. An example of the first case can be seen in how science led to the internal combustion engine (so we can drive cars, fly planes, etc.). But that technology produces toxic exhaust fumes. It is consumers who decide whether it is worth using a new technology despite its drawbacks. An example of the second case is nuclear power. Electricity can be produced by nuclear power plants, but, nuclear power tecnnology can also be applied in designing and building weapons.

- ***Science is just another subjective belief system***. This misconception could explain how, in 1897, the Indiana House of Representatives managed to pass a bill redefining the area of a circle and the value of pi.

- ***Science's days are numbered;*** its best days behind it, and its last great discoveries already made. Back in the 19th century, the English physicist Lord Kelvin claimed that all of the important scientific discoveries had already been made, and that any new knowledge would only come as fine tuning in physics. That view, which has been falsified every time, has been repeated many times since, even in recent years: "We've come to 'the end of science', writer John Horgan declared, saying that all the really important discoveries have already been made" (*Newsweek*, January 19, 1998). If this were true, scientists would now be just filling in details and making more precise measurements. But, in fact, fundamental new discoveries continue to be made, such as "Dark Energy."

- ***Science and technology are out of control.*** For example Jacques Ellul's, *The Technological Society*, suggested that technology had escaped the bonds of human control and was now an independent force. We also see this sentiment expressed in tabloid headlines that talk about scientists "playing God." Is a physician "playing God" when (s)he saves a patient's life with an antibiotic? Genetic engineering could also be a concern if there are not sufficient checks and safeguards. When someone says that science is "out of control," that may simply indicate that certain scientific methods or conclusions are not compatible with the speaker's political or religious views.

- ***The scientific world-view robs the world of mystery and beauty***. (Walt Whitman seems to have had this in mind when he wrote, *When I Heard the Learn'd Astronomer.*) Scientists tend to be puzzled by that sentiment, as their emotions are stirred by exactly the same feeling of wonder that compels the poet or the artist to gaze up at the stars. Expressing that wonder with a pen or a paintbrush is not necessarily superior to doing so with a telescope and admiring that beauty in even more detail and greater depth.

## Is it science?

If you're not sure whether an idea is scientific, ask these questions:

- Can this idea be used to make predictions about what will happen under particular circumstances or at a specific time in the future?
- Are the predictions testable?
- Have the predictions been tested?
- What evidence would it take to prove the idea wrong?
- Do conclusions in this area undergo peer review in a mainstream scientific journal?

## Separation of science and religion

Religious topics deal with issues such as ethics, morality, and how to lead a virtuous life. Generally, scientific topics are not relevant to religious concerns. While there is no formal interaction between science and religion, sometimes social and personal beliefs can influence scientists' work. For example, Einstein's statement "God does not play dice" reflects his discomfort with the apparent randomness inherent in quantum mechanics. He couldn't believe that quantum mechanics was correct because it was not an aesthetic solution that agreed with his belief in an orderly universe.

No conflict between science and religion would occur if people regarded the two realms as covering mutually exclusive areas. Conflict occurs when specific scientific findings are perceived to be in conflict with religious doctrine (e.g., the Church vs. Galileo) or when the free exchange of ideas is restricted (e.g., placing Copernicus's *De Revolutionibus* on the Index of Prohibited Books).

> As religious leaders, we share a deep faith in the God who created heaven and earth and all that is in them, and take with utmost seriousness the Biblical witness to this God who is our Creator. However, we find no incompatibility between the God of creation and a theory of evolution which uses universally verifiable data to explain the probable process by which life developed into its present form.
>
> — from a 1981 letter signed by 78 Kentucky ministers and religious leaders

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# Activities for Teaching About the Nature of Science

I. "Teaching About Evolution and the Nature of Science" (National Academy Press, 1998) contains eight activities for teaching about the nature of science. These are available online (www.nap.edu/readingroom/books/evolution98/) and the two most closely related to the nature of science are summarized below.

ACTIVITY 1: Introducing Inquiry and the Nature of Science

This activity introduces basic procedures involved in inquiry and concepts describing the nature of science. In the first portion of the activity the teacher uses a numbered cube to involve students in asking a question—what is on the bottom?—and the students propose an explanation based on their observations. Then the teacher presents the students with a second cube and asks them to use the available evidence to propose an explanation for what is on the bottom of this cube. Finally, students design a cube that they exchange and use for an evaluation. This activity provides students with opportunities to learn the abilities and understandings aligned with science as inquiry and the nature of science as described in the National Science Education Standards. Designed for grades 5 through 12, the activity requires a total of four class periods to complete. Lower grade levels might only complete the first cube and the evaluation where students design a problem based on the cube activity.

ACTIVITY 2: The Formulation of Explanations: An Invitation to Inquiry on Natural Selection

This activity uses the concept of natural selection to introduce the idea of formulating and testing scientific hypotheses. Through a focused discussion approach, the teacher provides information and allows students time to think, interact with peers, and propose explanations for observations described by the teacher. The teacher then provides more information, and the students continue their discussion based on the new information. This activity will help students in grades 5 through 8 develop several abilities related to scientific inquiry and formulate understandings about the nature of science as presented in the National Science Education Standards.

II. Another good source of activities can be found at the evolution Web site at the University of California, Berkeley (http://evolution.berkeley.edu/activities.htm). The following are the two activities pertaining to the nature of science.

Not "Just a Theory"

Evolution is often challenged by those who oppose its teaching or do not understand it. One of these challenges is that evolution is just a theory. This activity addresses this misconception. Grades 9-12

The Great Fossil Find

Students are taken on an imaginary fossil hunt through which they uncover evidence, pose hypotheses, and modify these hypotheses as new evidence is uncovered. Grades 5-12

# Photo Credits

**Cover Page:** Orion Nebula, credit: NASA, ESA, M. Robberto (Space Telescope Science Institute/ESA) and the Hubble Space Telescope Orion Treasury Project Team http://hubblesite.org/newscenter/archive/releases/2006/01/image/a/.

**Page IV**

**Top:** Very Large Array, image courtesy of NRAO/AUI. **Middle:** Mosaic wide field optical imager mounted on the KPNO 0.9-meter telescope, credit: NOAO/AURA/NSF, www.noao.edu/image_gallery/html/im0690.html. **Bottom:** Mars Rover, image courtesy of NASA/JPL-CalTech.

**Page 2 - Left:** Lunar Eclipse, detail from: http://science.nasa.gov/spaceweather/eclipses/27oct04f/Moussette2.JPG. **Right:** Planet Positions in 2015, Courtesy NASA/JPL-Caltech.

**Page 5 - Left**: Stingray Nebula, Matt Bobrowsky (Space Telescope Science Institute) and NASA. **Right:** Mira A and Mira B, Matt Bobrowsky and NASA.

**Page 6 -** Snake Oil, image credit RadishWorks.Com., www.turbosquid.com/FullPreview/Index.cfm/ID/183892/Action/FullPreview.

**Page 7 - Bottom:** Studies of the Anatomy of the Shoulder, c. 1510 Leonardo Da Vinci, courtesy of The Royal Collection, © 2007, Her Majesty Queen Elizabeth II.

**Left to right:** Plasma TV; Open Refrigerator, credit: US Consumer Product Safety Commission, www.cpsc.gov/cpscpub/prerel/prhtml05/05279b.jpg; Using a Cell Phone, Missouri Department of Education, photo taken by Gayla Hays; PC operating a NOAA 2875-MHz vertically pointing precipitation radar during the North American Monsoon Experiment in June to September 2004, photo by Christopher R. Williams, www.etl.noaa.gov/programs/2004/name/precip/photos/computer2875.jpg.

**Page 7 -** DNA Model, photo credit: Joseph Lauher - SUNY Stony Brook, www.chem.sunysb.edu/msl/DNA.HTML

**Page 8** - What do Scientists Do? Permission granted by Matt Bobrowsky to the American Astronomical Society, http://polaris.umuc.edu/~mbobrow2/What-do-scientists-do.htm.

**Page 11 - Top:** Water Cycle Drawn by John Evan, USGS graphic artist at the US Geological Survey, http://ga.water.usgs.gov/edu/watercycleprint.html. **Right:** Bohr Model of the Atom and Hydrogen d orbital, drawn by S. Deustua.

**Page 12 -** Reproduction of Stellar Evolution Poster, credit: Chandra X-ray Center NASA/CXC/SAO, http://chandra.harvard.edu/edu/formal/stellar_ev/.

**Page 14 -** Wright Brothers' Flight, Credit the Library of Congress, www.centennialofflight.gov/essay/Wright_Bros/First_Powered_Flight/WR6G15.htm.

**Page 15** - Postage stamp issued by Ajman (part of the federation of United Arab Emirates), http://jeff560.tripod.com/kepler02.jpg.

**Page 17** - References and acknowledgements from a scientific paper. Credit: NASA, ESA, (Space Telescope Science Institute/ESA) and the Hubble Space Telescope.

**Page 18** - Images of two *New York Times* articles, *The New York Times*, November 4, 1989, Sec. 1, p. 9 and *The New York Times.*

**Page 19 –** Eris, credit: NASA, ESA, (Space Telescope Science Institute/ESA), http://imgsrc.hubblesite.org/hu/db/2006/16/images/a/formats/xlarge_web.jpg

**Page 23** - How to make UFOs photos, www.ufohoax.cjb.net/.

# Appendix A: Varieties of Creationism

Despite many people's tendency to think of all creationists as one group and all evolutionists as another, "creationism" actually refers to a wide range of beliefs. Since the differences between types of creationism are not minor, the following list will be useful in identifying and understanding the viewpoints of creationist students. Most creationist beliefs are actually mutually exclusive, and many creationists disagree as much with each other as they do with evolutionists. In order from most creationist to most evolutionist (following "What is Creationism?" by M. Isaac):

**A.1. Flat-Earthers** believe that the earth is flat based on a literal reading of the Bible, such as references to the "four corners of the earth" and the "circle of the earth."

**A.2. Geocentrists** accept a spherical earth but don't agree that the sun is the center of the Solar System or that the Earth moves. The basis for their belief isa literal reading of the Bible (e.g., Psalm 96:10: "He has fixed the earth firm, immovable ...").

**A.3. Young-Earth Creationists** maintain a literal interpretation of the Bible. They believe that all life was created in six literal 24-hour days and that the earth is less than 10,000 years old. They will, however, acknowledge that the solar system is heliocentric and that the earth is spherical. Young Earth Creationism is one of the more influential varieties of creationism today.

**A.4. Young Earth, But Appears Old -** The idea that the earth is really young, but was made to appear old (also known as the Omphalos argument), was first described in a book by H.P. Gosse in 1857. This view is not uncommon today.

**A.5. Old-Earth Creationists** accept the evidence that the earth is billions of years old, but also believe that life was an act of creation by God.

**A.6. Gap Creationism** provides a way of reconciling the Bible with an ancient Earth. The idea is that there was a long period of time — a long gap — between the first two verses of Genesis. Thus, there was time for the universe and earth to have been created even before the biblical six days of creation.

**A.7. Day-Age Creationists** assume that each of the biblical six days of creation actually represents extremely long periods of time. Thus, they can accept an old age for the earth and the universe, while still maintaining the order of events described in Genesis 1.

Both Gap and Day-Age Creationism have a common theme, in that they allow for extremely long time periods for the creation of the Earth. However, they would be unlikely to accept the nebular model of the formation of the solar system, since it is not described in Genesis.

**A.8. Progressive Creationists** accept most modern scientific conclusions (but view the Big Bang as an act of creation by God); however, they do not accept much of modern biology. They believe that God created "kinds" of organisms sequentially in the order seen in the fossil record, but also believe that the more recent kinds were simply recently created by God, and not genetically related to older kinds. Note that the term "progressive" is used because of their belief in progressive acts of creation that produced the sequence of species seen in the fossil record.

**A.9. Intelligent Design Creationists** take the view that life is so complex that it could have only resulted from the work of God (the designer). Intelligent Design ideas are expressed in very technical language, using a large amount of microbiology terms.

**A.10. Evolutionary Creationists** argue that God guides evolutionary (and all other natural) processes at every step. Evolutionary Creationists can therefore accept modern science; they just take the view that it is all the work of God.

**A.11. Theistic Evolutionists** is the view that evolution is the process by which God decided life has to develop. Theistic Evolutionists basically accept modern science, assuming that God intervenes only occasionally for certain supernatural acts, such as the creation of the human soul. Pope John Paul II maintained this view, which is also found in some Protestant teachings.

**A.12. Methodological Materialistic Evolutionists** accept modern science, can believe in God, but maintain that God does not actively interfere with evolution or other natural processes.

**A.13. Philosophical Materialistic Evolutionists** take the position that the supernatural does not exist. In their view, evolution and all other aspects of nature exist without the interference, or even the presence, of God.

# Appendix B: Why We Know the Moon Landings Were Real

On February 15, 2001 the FOX television network aired a program titled "Conspiracy Theory: Did We Land on the Moon?" This program showed alleged evidence that NASA faked the moon landings. Although this hoax theory has been around for several years, this was the first time it was presented to such a wide audience.

Following are some of the ways we know the Moon landings were real. Principal sources for these are Bad Astronomy by Phil Plait and Robert Braeunig's website at www.braeunig.us/space/hoax.htm.

**Question:** The black sky should be full of stars, yet none are visible in any of the Apollo photographs.
**Explanation:** This is because stars are faint. The Apollo photos were taken using fast exposures, because the Astronauts were taking pictures of brightly lit objects on the surface of the Moon. The fast exposures simply did not allow enough starlight into the camera to record an image on the film. For the same reason, images of the Earth taken from orbit also lack stars. The stars are there; they just don't appear in the pictures. The astronauts could have recorded star images in their photos by increasing exposures, but they were not there to take star pictures. The purpose of the photos was to record the astronauts' activities on the surface of the Moon.

**Question**: Some of the Apollo video shows the American flag fluttering. How can the flag flutter when there is no wind on the airless Moon?
**Explanation:** The astronaut is rotating or jostling the pole, which makes the flag move. Also, the flag is suspended from an extendable, horizontal rod attached to the pole. In Apollo 11, the astronauts could not get the horizontal rod fully extended, so the flag was not stretched out.

**Question**: A large amount of dust was generated during the landings, yet no dust can be seen on the Lunar Module footpads.
**Explanation:** This thinking draws on our common experience from Earth but, as we all know, the Moon is not the Earth. If wind picks up dust on Earth we get billowing clouds that tend to settle all over everything. This occurs because the Earth has an atmosphere. The Moon has no atmosphere so any dust that was blown by engine exhaust would follow a simple ballistic trajectory and fall immediately back to the surface. The dust would be blown outward away from the LM, thus the lack of dust on the footpads is exactly what we would expect to see. (From www.braeunig.us/space/hoax.htm.)

If you are interested in further information regarding this topic, Robert Braeunig's website at www.braeunig.us/space/hoax.htm is quite comprehensive. The following list of references and sources is taken directly from the bibliography on this website.


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For Apollo images and other archived data

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Apollo Image Atlas, Lunar & Planetary Institute: www.lpi.usra.edu/resources/apollo/catalog/70mm/