The Nature of Science and the Scientific Method

THE GEOLOGICAL SOCIETY OF AMERICA

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Cover image: A basalt dike cuts through rocks of Permain age on Wasp Head, NSW Australia. Photo by Gary B. Lewis.

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Nature of Science and the Scientific Method

“The most incomprehensible thing about the world is that it is comprehensible.”
—Albert Einstein

What is Science?

Science is a methodical approach to studying the natural world. Science asks basic questions, such as how does the world work? How did the world come to be? What was the world like in the past, what is it like now, and what will it be like in the future? These questions are answered using observation, testing, and interpretation through logic.

Most scientists would not say that science leads to an understanding of the truth. Science is a determination of what is most likely to be correct at the current time with the evidence at our disposal. Scientific explanations can be inferred from confirmable data only, and observations and experiments must be reproducible and verifiable by other individuals. In other words, good science is based on information that can be measured or seen and verified by other scientists.

The scientific method, it could be said, is a way of learning or a process of using comparative critical thinking. Things that are not testable or falsifiable in some scientific or mathematical way, now or in the future, are not considered science. Falsifiability is the principle that a proposition or theory cannot be scientific if it does not admit the possibility of being shown false. Science takes the whole universe and any and all phenomena in the natural world under its purview, limited only by what is feasible to study given our current physical and fiscal limitations. Anything that cannot be observed or measured or shown to be false is not amenable to scientific investigation. Explanations that cannot be based on empirical evidence are not a part of science (National Academy of Sciences, 1998).

Layers rocks making up the walls of the Grand Canyon.

Science is, however, a human endeavor and is subject to personal prejudices, misapprehensions, and bias. Over time, however, repeated reproduction and verification of observations and experimental results can overcome these weaknesses. That is one of the strengths of the scientific process.

Scientific knowledge is based on some assumptions (after Nickels, 1998), such as

- The world is REAL; it exists apart from our sensory perception of it.
- Humans can accurately perceive and attempt to understand the physical universe.
- Natural processes are sufficient to explain or account for natural phenomena or events. In other words, scientists must explain the natural in terms of the natural (and not the supernatural, which, lacking any independent evidence, is not falsifiable and therefore not science), although humans may not currently recognize what those processes are.
- By the nature of human mental processing, rooted in previous experiences, our perceptions *may be* inaccurate or biased.
- Scientific explanations are limited. Scientific knowledge is necessarily contingent knowledge rather than absolute, and therefore must be evaluated and assessed, and is subject to modification in light of new evidence. It is impossible to know if we have thought of every possible alternative explanation or every variable, and technology may be limited.
- Scientific explanations are probabilistic. The statistical view of nature is evident implicitly or explicitly when stating scientific predictions of phenomena or explaining the likelihood of events in actual situations.

As stated in the *National Science Education Standards* for the ***Nature of Science***:

> Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models. Although all scientific ideas are tentative and subject to change and improvement in principle, for most major ideas in science, there is much experimental and observational confirmation. Those ideas are not likely to change greatly in the future. Scientists do and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations. (NSES, 1996, p. 171)

The *Standards for Science Teacher Preparation* correctly state that

> Understanding of the nature of science—the goals, values and assumptions inherent in the development and interpretation of scientific knowledge (Lederman, 1992)—has been an objective of science instruction since at least the turn of the last century. It is regarded in contemporary documents as a fundamental attribute of science literacy and a defense against unquestioning acceptance of pseudoscience and of reported research. Knowledge of the nature of science can enable individuals to make more informed decisions with respect to scientifically based issues; promote students' in-depth understandings of "traditional" science subject matter; and help them distinguish science from other ways of knowing…
>
> Research clearly shows most students and teachers do not adequately understand the nature of science. For example, most teachers and students believe that all scientific investigations adhere to an identical set of steps known as the scientific method, and that theories are simply immature laws. Even when teachers understand and support the need to include the nature of science in their instruction, they do not always do so. Instead they may rely upon the false assumption that doing inquiry leads to understanding of science. Explicit instruction is needed both to prepare teachers and to lead students to understand the nature of science. (NSTA, 2003, and references therein, p. 16)

Scientific Method

Throughout the past millennium, there has been a realization by leading thinkers that the acquisition of knowledge can be performed in such a way as to minimize inconsistent conclusions. Rene Descartes established the framework of the scientific method in 1619, and his first step is seen as a guiding principle for many in the field of science today:

> …never to accept anything for true which I did not clearly know to be such; that is to say, carefully to avoid precipitancy and prejudice, and to compromise nothing more in my judgment than what was presented to my mind so clearly and distinctly as to exclude all ground of methodic doubt. *(Discours de la Méthode,* 1637, section I, 120)

By sticking to certain accepted "rules of reasoning," scientific method helps to minimize influence on results by personal, social, or unreasonable influences. Thus, science is seen as a pathway to study phenomena in the world, based upon reproducibly testable and verifiable evidence. This pathway may take different forms; in fact, creative flexibility is essential to scientific thinking, so there is no single method that all scientists use, but each must ultimately have a conclusion that is testable and falsifiable; otherwise, it is not science.

The scientific method in actuality isn't a set sequence of procedures that must happen, although it is sometimes presented as such. Some descriptions actually list and number three to fourteen procedural steps. No matter how many steps it has or what they cover, the scientific method does contain elements that are applicable to most experimental sciences, such as physics and chemistry, and is taught to students to aid their understanding of science.

That being said, it is most important that students realize that the scientific method is a form of critical thinking that will be subjected to review and independent duplication in order to reduce the degree of uncertainty. The scientific method may include some or all of the following "steps" in one form or another: observation, defining a question or problem, research (planning, evaluating current evidence), forming a hypothesis, prediction from the hypothesis (deductive reasoning), experimentation (testing the hypothesis), evaluation and analysis, peer review and evaluation, and publication.

Observation

The first process in the scientific method involves the observation of a phenomenon, event, or "problem." The discovery of such a phenomenon may occur due to an interest on the observer's part, a suggestion or assignment, or it may be an annoyance that one wishes to resolve. The discovery may even be by chance, although it is likely the observer would be in the right frame of mind to make the observation. It is said that as a boy, Albert Einstein wanted to know what it would be like to ride a light beam, and this curious desire stuck with him throughout his education and eventually led to his incredible theories of electromagnetism.

Question

Observation leads to a question that needs to be answered to satisfy human curiosity about the observation, such as why or how this event happened or what it is like (as in the light beam). In order to develop this question, observation may involve taking measures to quantify it in order to better describe it. Scientific questions need to be answerable and lead to the formation of a hypothesis about the problem.

Hypothesis

To answer a question, a hypothesis will be formed. This is an ***educated*** guess regarding the question's answer. Educated is highlighted because no good hypothesis can be developed without research into the problem. Hypothesis development depends upon a careful characterization of the subject of the investigation. Literature on the subject must be researched, which is made all the easier these days by the Internet (although sources must be verified; preferably, a library data base should be used). Sometimes numerous working hypotheses may be used for a single subject, as long as research indicates they are all applicable. Hypotheses are generally consistent with existing knowledge and are conducive to further inquiry.

A scientific hypothesis has to be testable and also has to be falsifiable. In other words, there must be a way to try to make

The Pineal Gland and the "Melatonin Hypothesis," 1959–1974, from public file "Profiles in Science, National Library of Medicine."

the hypothesis fail. Science is often more about proving a scientific statement wrong rather than right. If it does fail, another hypothesis may be tested, usually one that has taken into consideration the fact that the last tested hypothesis failed.

One fascinating aspect is that hypotheses may fail at one time but be proven correct at a later date (usually with more advanced technology). For example, Alfred Wegener's idea that the continents have drifted apart from each other was deemed impossible because of what was known in the early 1900s about the composition of the continental crust and the oceanic crust. Geophysics indicated the brittle, lighter continents could not drift or be pushed *through* dense ocean crust. Years later, it was shown that one aspect of Wegener's idea, that the continents were once together, was most likely correct (although not as separate units but as part of a larger plate). These plates didn't, however, have to plow through ocean crust. Instead, magma appears to have arisen between them and formed new oceanic crust while the plates carrying the continents diverged on either side The exact mechanism of how the plates were pushed apart from the rising magma, or were pulled apart, allowing magma to rise between them, or a combination of both, is still not completely understood.

The hypothesis should also contain a prediction about its verifiability. For example, if the hypothesis is true, then __(1)__ should happen when __(2)__ is manipulated.

The first blank (1) is the **dependent variable** (it depends on what you are doing in the second blank) and the second blank (2) is the **independent variable** (you manipulate it to get a reaction). There should be no other variables in the experiment that may affect the dependent variable.

One thing is clear about the requirement of the testability of hypotheses: it must exclude supernatural explanations. If the supernatural is defined as events or phenomena that cannot be perceived by natural or empirical senses, then they do not follow any natural rules or regularities and so cannot be scientifically tested. It would be difficult to test the speed of angels or the density of ghosts when they are not available in the natural world for scientific testing, although certainly people have tried to determine if such entities are real and testable, and it cannot be precluded that someday technology may exist that can test certain "supernatural" phenomenon.

Experiment

Once the hypothesis has been established, it is time to test it. The process of experimentation is what sets science apart from other disciplines, and it leads to discoveries every day. An experiment is designed to prove or disprove the hypothesis. If your prediction is correct, you will not be able to reject the hypothesis.

The average layperson may think of the above kind of picture when thinking of science experiments. This may be true in some disciplines, but not all. Einstein relied on mathematics to "predict" his hypotheses on the nature of space and time in the universe. His hypotheses had specific physical predictions about space-time, which were shown to be accurate sometimes years later with developing technology.

Testing and experimentation can occur in the laboratory, in the field, on the blackboard, or the computer. Results of testing must be reproducible and verifiable. The data should be available to determine if the interpretations are unbiased and free from prejudice.

As the *National Science Education Standards* state:

> In areas where active research is being pursued and in which there is not a great deal of experimental or observational evidence and understanding, it is normal for scientists to differ with one another about the interpretation of the evidence or theory being considered. Different scientists might publish conflicting experimental results or might draw different conclusions from the same data. Ideally, scientists acknowledge such conflict and work towards finding evidence that will resolve their disagreement. (NSES, 1996, p. 171)

It is interesting that other scientists may start their own research and enter the process of one scientist's work at any stage. They might formulate their own hypothesis, or they might adopt the original hypothesis and deduce their own predictions. Often, experiments are not done by the person who made the prediction, and the characterization is based on investigations done by someone else. Published results can also serve as a hypothesis predicting the reproducibility of those results.

Evaluation

All evidence and conclusions must be analyzed to make sure bias or inadequate effort did not lead to incorrect conclusions. Qualitative and quantitative mathematical analysis may also be applied. Scientific explanations should always be made public, either in print or presented at scientific meetings. It should also be maintained that scientific explanations are tentative and subject to modification.

Again, the *National Science Education Standards* state:

> It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, theoretical models, and the explanations proposed by other scientists. Evaluation includes reviewing the experimental procedures, examining the evidence, identifying faulty reasoning, pointing out statements that go beyond the evidence, and suggesting alternative explanations for the same observations. Although scientists may disagree about explanations of phenomena, about interpretations of data, or about the value of rival theories, they do agree that questioning, response to criticism, and open communication are integral to the process of science. As scientific knowledge evolves, major disagreements are eventually resolved through such interactions between scientists. (NSES, 1996, p. 171)

Thus, evaluation is integral to the process of scientific method. One cannot overemphasize the importance of peer-review to science, and the vigor with which it is carried out. Full-blown academic battles have been wagged in scientific journals, and in truth, many scientific papers submitted to peer-reviewed journals are rejected. The evaluation process in science truly makes it necessary for scientists to be accurate, innovative, and comprehensive.

To better understand the nature of scientific laws or theories, make sure students understand the following definitions.

Definitions

Fact: 1. A confirmed or agreed-upon empirical observation or conclusion. 2. Knowledge or information based on real occurrences: *an account based on fact.* 3. a. Something demonstrated to exist or known to have existed: *Genetic engineering is now a fact. That Einstein was a real person is an undisputed fact.* b. A real occurrence; an event.

Hypothesis: An educated proposal to explain certain facts; a tentative explanation for an observation, phenomenon, or scientific problem that can be tested by further investigation.

Scientific Theory (or Law): An integrated, comprehensive explanation of many "facts," especially one that has been repeatedly tested or is widely accepted and can be used to make predictions about natural phenomena. A theory can often generate additional hypotheses and testable predictions. Theories can incorporate facts and laws and tested hypotheses.

Unfortunately, the common/non-scientific definition for theory is quite different, and is more typically thought of as a belief that can guide behavior. Some examples: *"His speech was based on the theory that people hear only what they want to know"* or *"It's just a theory."* Because of the nature of this definition, some people wrongly assume scientific theories are speculative, unsupported, or easily cast aside, which is very far from the truth. A scientific hypothesis that survives extensive experimental testing without being shown to be false becomes a scientific theory. Accepted scientific theories also produce testable predictions that are successful.

Fossil Lab at John Day Fossil Beds National Monument. Photo courtesy of National Park Service.

Theories are powerful tools (National Science Teachers Association, *The Teaching of Evolution Position Statement*):

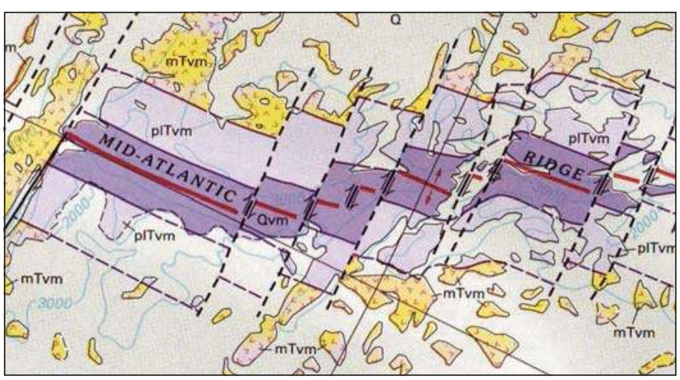
> Scientists seek to develop theories that
> - are firmly grounded in and based upon evidence;
> - are logically consistent with other well-established principles;
> - explain more than rival theories; and
> - have the potential to lead to new knowledge.

Scientific theories are falsifiable and can be reevaluated or expanded based on new evidence. This is particularly important in concepts that involve past events, which cannot be tested. Take, for example, the Big Bang Theory or the Theory of Biological Evolution as it pertains to the past; both are theories that explain all of the facts so far gathered from the past, but cannot be verified as absolute truth, since we cannot go back to test them. More and more data will be gathered on each to either support or disprove them. The key force for change in a theory is, of course, the scientific method.

A scientific law, said Karl Popper, the famous 20^{th} century philosopher, is one that can be proved wrong, like "the sun always rises in the east." According to Popper, a law of science can never be proved; it can only be used to make a prediction that can be tested, with the possibility of being proved wrong. For example, as the renowned biologist J.B.S. Haldane replied when asked what might disprove evolution, "Fossil rabbits in the pre-Cambrian." So far that has not happened, and in fact the positive evidence for the "theory" of evolution is extensive, made up of hundreds of thousands of mutually corroborating observations. These come from areas such as geology, paleontology, comparative anatomy, physiology, biochemistry, ethnology, biogeography, embryology, and molecular genetics. Like evolution, most accepted scientific theories have withstood the test of time and falsifiability to become the backbone of further scientific investigations.

Science Through the Recent Ages

The term *science* is relatively modern. Nearly all civilizations, however, have evidence of methods, concepts, or techniques that were scientific in nature. Science has its historical roots in two primary sources: the technical tradition, in which practical experiences and skills were passed down and developed from one generation to another; and the spiritual tradition, in which human aspirations and ideas were passed on and augmented (Mason, 1962). Observations of the natural world and their application to daily activities assuredly helped the human race survive from the earliest times. In western society, it was not until the Middle Ages, however, that the two converged into a more pragmatic method that produced results with both technical and philosophical implications.



The Mid-Atlantic Ridge (N is to upper left) on the 2005 Geologic Map of North America. Location near 50N, 30W.

An excellent example of the development of science and the scientific method is the demise of the geocentric view of the solar system. Although it strongly appears to the naked eye that the sun and moon go around Earth (geocentric), even ancient astral observers noted that stars moved in a different yearly pattern, and certain planets or "wanderers" had even stranger movements in the night sky. In the 16^{th} and 17^{th} centuries, observers began to make more detailed observations of the movements of the stars and planets, made increasingly complex with the aide of the newly invented telescope. Galileo improved the telescope enough to observe the phases of Venus as seen from Earth. With the application of mathematics to their precise measurements, it became obvious to astronomers like Copernicus, Kepler, and Galileo that the planets and Earth must revolve around the sun (heliocentric). It is necessary, however, to backtrack here a little and make clear that, as early as the third century B.C., the Greek astronomer Aristarchus proposed that Earth orbited the sun. Earth's spherical nature was not only well known by about 300 B.C., but good measurements of Earth's circumference had already been made by that time. Unfortunately, throughout history, knowledge from one culture has not necessarily been passed on to other cultures or generations.

New discoveries and technological advancements led to what is known as the Scientific Revolution, a period of time between Copernicus and Sir Isaac Newton during which a core transformation in "natural philosophy" (science) began in cosmology and astronomy and then shifted to physics. Most profoundly, some historians have argued, these changes in thinking brought important transformations in what came to be held as "real" and how Europeans justified their claims to knowledge.

> The learned view of things in 16th-century thought was that the world was composed of Four Qualities (Aristotle's Earth, Water, Air, and Fire). By contrast, less than two centuries later Newton's learned contemporaries believed that the world was made of atoms or corpuscles (small material bodies). By Newton's day most of learned Europe believed the Earth moved, that there was no such thing as demonic possession, that claims to knowledge … should be based on the authority of our individual experience, that is, on argument and sensory evidence. The motto of the Royal Society of London was: Nullius in Verba, roughly, Accept Nothing on the Basis of Words (or someone else's authority). (Hatch, 1991, p. 1)

One of the first to put this idea in print was Rene Descartes. Although the exact dates of the Scientific Revolution may be disputed by science historians, Newton is most commonly considered the "end" of the revolution, because his work brought the heavens and Earth together as a *universe* that operates under universal laws of motion, changing forever how scientists studied it. This new world picture, quantitative, logical, comprehensible, made science a justifiable pursuit, and the study of natural explanations for the world around us grew exponentially. Humans felt free to not be told how things happen, but to study and detect and experiment with how the world works in their own ways. Science has expanded rapidly since the Scientific Revolution (Crowe, 1991), and the scientific method is well used.

Scientific Method and Earth Sciences

The scientific method is not an exact recipe. There are many ways to apply the scientific thought process without necessarily using all the steps listed previously. Even when you encounter a simple, everyday problem, like the failure of your car to start when you turn the key in the ignition, you will likely use a thought process much like the scientific method. Your mind will jump through a succession of hypotheses that you will test until you find the hypothesis that is correct. For example, you will ask yourself, is the car out of gas (check gas gauge or remember when you last filled up), is the battery dead (do the lights work?), is there a short in the ignition apparatus (jiggle the key and the ignition), etc. You will continue thinking of hypotheses and testing them until you have found one that is correct, and if you don't, you will call in an expert who will go through the same process but with a more educated background in the possible solutions.

Earth science is the study of the physical Earth, from the outer reaches of the atmosphere to the center of the planet, including all the interrelationships between atmosphere, water, and rock. This study is necessary in order to understand the natural world around us, including natural disasters (from hurricanes to earthquakes to volcanoes) and where to find and get natural resources (including energy, minerals, and fresh water) (Punaridge.org, 1998).

As an example of using the scientific method, consider a study of faster flowing sections of ice that lie within large glaciers in the Antarctic:

1. *Research* all previous studies in the area and on the topic, collecting all data, photos, papers, satellite images, etc., if there are any.
2. *Make field observations* of the glacier being studied and the exceptional "rivers" of ice that flow faster than the ice around them.
3. *Identify physical conditions* and take measurements with all necessary technology at your disposal and over a certain prescribed time frame at the glacier.
4. *Construct a model* describing a possible method for the ice in this one section of the glacier to move faster than the ice around it, as shown by the data collected. One geologist's hypothesis was that some liquid material underlies the area of the glacier in question, providing a lubricant for the ice.

Finding fossils in Silurian rocks in Canberra, Australia.

5. *Make predictions* based on the model. The prediction would be that upon drilling to the bottom of the glacier, a wet material would be found that is not found under other areas of the glacier.
6. *Test the predictions* in the field by designing an experiment to collect the right type of data to answer the questions. In this case, samples were indeed collected from beneath specific areas of the glacier, a difficult and sometimes dangerous task. Results showed that underlying the faster-moving areas of ice was a wet mud and gravel slurry not found in other areas, perhaps from an old stream bed, that provided lubrication for the ice above it.

Using the scientific method can sometimes be complicated for geologists because Earth is their laboratory and it has many variables and is NOT a controlled environment. Controlled experiments (usually carried out in laboratories) are carefully designed to test a specific hypothesis, and they can be **repeated**. Unfortunately, many hypotheses in geology cannot be directly tested in a controlled experiment (e.g., the origin of the Grand Canyon cannot be discovered by using this approach). Geologists must collect data by mapping or collecting specimens. They must rely on circumstantial evidence, which is subject to interpretation, and therefore can be challenged.

The Theory of Plate Tectonics again is an excellent example. Alfred Wegener took some of his own studies and the work of others and realized that the continents on opposite sides of the Atlantic Ocean fit together, and not just in shape, but in geology and fossil content as well. He proposed a hypothesis that the continents had drifted apart based on this "circumstantial evidence," which was not accepted in his lifetime. It took decades for technology to advance enough for scientists to discover additional evidence to support his claim that the continents had once been together (the Atlantic Ocean floor was younger than the continents and had formed between them). As more and more evidence was produced, his hypothesis was modified and refined into a theory we now know as Plate Tectonics. This theory revolutionized the way humans look at Earth. Many

Talking Points about Science

On the Nature of Science

1. Science is a way of studying our natural environment, using a repeatable, methodical approach.
2. Science relies on evidence from the natural world, and this evidence is examined and interpreted through logic.
3. Science cannot be used, by definition, to study events or phenomena that cannot be perceived by natural or empirical senses and do not follow any natural rules or regularities.
4. Science is a human endeavor; it is based on observations, experimentation, and testing. It allows us to connect the past with the present.
5. Science provides us with a way to present ideas that can be tested, repeated, and verified.
6. Scientific claims are based on testing explanations against observations of the natural world and rejecting the ones that fail the test.
7. Scientists gather evidence (as opposed to "proof") to support or falsify hypotheses. Hypotheses and theories may be well supported by evidence but never proven.
8. A scientific theory is a well-substantiated explanation for a set of natural phenomena that has been tested and verified but is still subject to falsification. Theories are supported, modified, or replaced as new evidence appears and are central to scientific thinking.
9. There is no such thing as "*THE* Scientific Method." Scientists in different fields often approach their scientific testing in different ways.
10. Science is non-dogmatic. Science never requires ideas to be accepted on belief or faith alone.
11. "Explanations on how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not science." (NSES, 1996, p. 201)
12. The nature of science "is regarded in contemporary documents as a fundamental attribute of science literacy and a defense against unquestioning acceptance of pseudoscience and of reported research." (NSTA, 2003. p. 16)
13. Science does not prove nor disprove religious or spiritual beliefs, nor does it replace either. Science provides a method of understanding the *natural* world only.
14. Science cannot make moral or aesthetic judgments. Understanding how to clone a cat does not indicate whether cloning is an acceptable endeavor by humans. Understanding what makes eyes blue or green does not indicate which is more beautiful.

On Evolution, Creation Science, and Intelligent Design

1. Creationism, creation science, Intelligent Design (ID), or any other spiritual concept, involve events or phenomena that cannot be tested, verified, or repeated through scientific methodology and, therefore, cannot be measured using scientific practice. Because science is limited to explaining natural phenomena through the use of empirical evidence, it cannot provide religious or ultimate explanations.
2. Evolution is a theory greatly accepted by the scientific community because all available evidence supports the central conclusions of evolutionary theory, that life on Earth has evolved and that species share common ancestors and genomes.
3. Vigorous questioning of existing ideas is central to the scientific process. Solid and long-held theories such as evolution or relativity stand as important foundations of science because they have proven, so far, unassailable (but not from want of trying…).
4. Evolution is a theory that has developed since Darwin's initial concepts. It is not a static idea, but a growing concept added to by scientific observation, testing, and debate.
5. Science teachers should not advocate any religious interpretations of nature and should be nonjudgmental about the personal beliefs of students. (NSTA recommendation)
6. "Do you *believe* in evolution?" The answer might be, "*Believe* is not the appropriate term, since it implies faith not based on evidence. I *accept* the inference that Earth is very old and life has changed over billions of years because that is what the evidence tells us." Science is not about belief—it is about making inferences based on evidence, and there is overwhelming evidence for evolution from many different disciplines. (Adapted from the *Understanding Evolution* Web site.)

unexplained geologic phenomenon now make perfect sense in the light of Plate Tectonics.

Other Earth science–related discoveries that caused major conceptual changes in the way humans view their world were the discovery that Earth is spherical and not flat; that all the planets revolve around the sun, not around Earth; and that fossils give us a detailed, logical record of the evolutionary development of biological organisms on Earth. Today, incredible discoveries are being made in the field of astronomy, all based again on circumstantial evidence and observation with increasingly more powerful and varied telescopes.

Conclusion

Percy W. Bridgman, author of *Reflections of a Physicist* in 1955 and winner of the 1946 Nobel Prize in physics, perhaps most clearly states in "On Scientific Method" how the use of the scientific method by scientists does not often follow a set formula or recipe, nor should it, since that may stifle human innovation and creativity, often necessary in producing new and revolutionary hypotheses:

> Scientific method is what working scientists do, not what other people or even they themselves may say about it. No working scientist, when he plans an experiment in the laboratory, asks himself whether he is being properly scientific, nor is he interested in whatever method he may be using *as method.* When the scientist ventures to criticize the work of his fellow scientist, as is not uncommon, he does not base his criticism on such glittering generalities as failure to follow the "scientific method," but his criticism is specific, based on some feature characteristic of the particular situation. The working scientist is always too much concerned with getting down to brass tacks to be willing to spend his time on generalities.

> But to the working scientist himself all this *[the steps of scientific method]* appears obvious and trite. What appears to him as the essence of the situation is that he is not consciously following any prescribed course of action, but feels complete freedom to utilize any method or device whatever, which in the particular situation before him seems likely to yield the correct answer. In his attack on his specific problem he suffers no inhibitions of precedent or authority, but is completely free to adopt any course that his ingenuity is capable of suggesting to him. No one standing on the outside can predict what the individual scientist will do or what method he will follow. In short, science is what scientists do, and there are as many scientific methods as there are individual scientists.

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