What is Science?

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This document was first generated no later than 2004; the present format was generated in 2023. For purposes of citation, the date 2004 is recommended.

Section 1: What is Science?

What is science?

Science is the concerted human effort to understand, or to understand better, the history of the natural world and how the natural world works, with observable physical evidence as the basis of that understanding[1]. It is done through observation of natural phenomena, and/or through experimentation that tries to simulate natural processes under controlled conditions. (There are, of course, more definitions of science - see Section 4).

Consider some examples. An ecologist observing the territorial behaviors of bluebirds and a geologist examining the distribution of fossils in an outcrop are both scientists making observations in order to find patterns in natural phenomena. They just do it outdoors and thus entertain the general public with their behavior. An astrophysicist photographing distant galaxies and a climatologist sifting data from weather balloons similarly are also scientists making observations, but in more discrete settings.

The examples above are observational science, but there is also experimental science. A chemist observing the rates of one chemical reaction at a variety of temperatures and a nuclear physicist recording the results of bombardment of a particular kind of matter with neutrons are both scientists performing experiments to see what consistent patterns emerge. A biologist observing the reaction of a particular tissue to various stimulants is likewise experimenting to find patterns of behavior. These folks usually do their work in labs and wear impressive white lab coats, which seems to mean they make more money too.

The critical commonality is that all these people are making and recording observations of nature, or of simulations of nature, in order to learn more about how nature, in the broadest sense, works. We'll see below that one of their main goals is to show that old ideas (the ideas of scientists a century ago or perhaps just a year ago) are wrong and that, instead, new ideas may better explain nature.

So why do science? I - the individual perspective

So why are all these people described above doing what they're doing? In most cases, they're collecting information to test new ideas or to disprove old ones. Scientists become famous for discovering new things that change how we think about nature, whether the discovery is a new species of dinosaur or a new way in which atoms bond. Many scientists find their greatest joy in a previously unknown fact (a discovery) that explains something problem previously not explained, or that overturns some previously accepted idea.

That's the answer based on noble principles, and it probably explains why many people go into science as a career. On a pragmatic level, people also do science to earn their paychecks. Professors at most universities and many colleges are expected as part of their contractual obligations of employment to do research that makes new contributions to knowledge. If they don't, they lose their jobs, or at least they get lousy raises.

Scientists also work for corporations and are paid to generate new knowledge about how a particular chemical affects the growth of soybeans or how petroleum forms deep in the earth. These scientists get paid better, but they may work in obscurity because the knowledge they generate is kept secret by their employers for the development of new products or technologies. In fact, these folks at Megacorp do science, in that they and people within their company learn new things, but it may be years before their work becomes science in the sense of a contribution to humanity's body of knowledge beyond Megacorp's walls.

Why do Science? II - The Societal Perspective

If the ideas above help explain why individuals do science, one might still wonder why societies and nations pay those individuals to do science. Why does a society devote some of its resources to this business of developing new knowledge about the natural world, or what has motivated these scientists to devote their lives to developing this new knowledge?

One realm of answers lies in the desire to improve people's lives. Geneticists trying to understand how certain conditions are passed from generation to generation and biologists tracing the pathways by which diseases are transmitted are clearly seeking information that may better the lives of very ordinary people. Earth scientists developing better models for the prediction of weather or for the prediction of earthquakes, landslides, and volcanic eruptions are likewise seeking knowledge that can help avoid the hardships that have plagued humanity for centuries. Any society concerned about the welfare of its people, which is at the least any democratic society, will support efforts like these to better people's lives.

Another realm of answers lies in a society's desires for economic development. Many earth scientists devote their work to finding more efficient or more effective ways to discover or recover natural resources like petroleum and ores. Plant scientists seeking strains or species of fruiting plants for crops are ultimately working to increase the agricultural output that nutritionally and literally enriches nations. Chemists developing new chemical substances with potential technological applications and physicists developing new phenomena like superconductivity are likewise developing knowledge that may spur economic development. In a world where nations increasingly view themselves as caught up in economic competition, support of such science is nothing less than an investment in the economic future.

Another whole realm of answers lies in humanity's increasing control over our planet and its environment. Much science is done to understand how the toxins and wastes of our society pass through our water, soil, and air, potentially to our own detriment. Much science is also done to understand how changes that we cause in our atmosphere and oceans may change the climate in which we live and that controls our sources of food and water. In a sense, such science seeks to develop the owner's manual that human beings will need as they increasingly, if unwittingly, take control of the global ecosystem and a host of local ecosystems.

Lastly, societies support science because of simple curiosity and because of the satisfaction and enlightenment that come from knowledge of the world around us. Few of us will ever derive any economic benefit from knowing that the starlight we see in a clear night sky left those stars thousands and even millions of years ago, so that we observe such light as messengers of a very distant past. However, the awe, perspective, and perhaps even serenity derived from that knowledge is very valuable to many of us. Likewise, few of us will derive greater physical well-being from watching a flowing stream and from reflecting on the hydrologic cycle through which that stream's water has passed, from the distant ocean to the floating clouds of our skies to the rains and storms upstream and now to the river channel at which we stand. However, the sense of interconnectedness that comes from such knowledge enriches our understanding of our world, and of our lives, in a very valuable way. In recognizing that the light of the sun and the water of a well are not here solely because we profit from their presence, we additionally gain an analogy from which we can recognize that the people in the world around us are not here solely to conform to our wishes and needs. When intangible benefits like these are combined with the more tangible ones outlined above, it's no wonder that most modern societies support scientific research for the improvement of our understanding of the world around us.

How Research becomes Scientific Knowledge

As our friends at Megacorp illustrate, doing research in the lab or in the field may be science, but it isn't necessarily a contribution to knowledge. No one in the scientific community will know about, or place much confidence in, a piece of scientific research until it is published in a peer-reviewed journal. They may hear about new research at a meeting or learn about it through the grapevine of newsgroups, but nothing's taken too seriously until publication of the data.

That means that our ecologist has to write a paper (called a "manuscript" for rather old-fashioned reasons). In the manuscript she justifies why her particular piece of research is significant, she details what methods she used in doing it, she reports exactly what she observed as the results, and then she explains what her observations mean relative to what was already known.

She then sends her manuscript to the editors of a scientific journal, who send it to two or three experts for review. If those experts report back that the research was done in a methodologically sound way and that the results contribute new and useful knowledge, the editor then approves publication, although almost inevitably with some changes or additions. Within a few months (we hope), the paper appears in a new issue of the journal, and scientists around the world learn about our ecologist's findings. They then decide for themselves whether they think the methods used were adequate and whether the results mean something new and exciting, and gradually the paper changes the way people think about the world.

Of course there are some subtleties in this business. If the manuscript was sent to a prestigious journal like *Science* or *Nature*, the competition for publication there means that the editors can select what they think are only the most ground-breaking manuscripts and reject the rest, even though the manuscripts are all well-done science. The authors of the rejected manuscripts then send their work to somewhat less exalted journals, where the manuscripts probably get published but are read by a somewhat smaller audience. At the other end of the spectrum may be the *South Georgia Journal of Backwater Studies,* where the editor gets relatively few submissions and can't be too picky about what he or she accepts into the journal, and not too many people read it. For better or worse, scientists are more likely to read, and more likely to accept, work published in widely-distributed major journals than in regional journals with small circulation.

To summarize, science becomes knowledge by publication of research results. It then may become more general knowledge as writers of textbooks pick and choose what to put in their texts, and as professors and teachers then decide what to stress from those textbooks. Publication is critical, although not all publication is created equal. The more a newly published piece of research challenges established ideas, the more it will be noted by other scientists and by the world in general.

Science and Change (and Miss Marple)

If scientists are constantly trying to make new discoveries or to develop new concepts and theories, then the body of knowledge produced by science should undergo constant change. Such change is progress toward a better understanding of nature. It is achieved by constantly questioning whether our current ideas are correct. As the famous American astronomer Maria Mitchell (1818-1889) put it, "Question everything".

The result is that theories come and go, or at least are modified through time, as old ideas are questioned and new evidence is discovered. In the words of Karl Popper, "Science is a history of corrected mistakes", and even Albert Einstein remarked of himself "That fellow Einstein . . . every year retracts what he wrote the year before". Many scientists have remarked that they would like to return to life in a few centuries to see what new knowledge and new ideas have been developed by then - and to see which of their own century's ideas have been discarded. Our ideas today should be compatible with all the evidence we have, and we hope that our ideas will survive the tests of the future. However, any look at history forces us to realize that the future is likely to provide new evidence that will lead to at least somewhat different interpretations.

Some scientists become sufficiently ego-involved that they refuse to accept new evidence and new ideas. In that case, in the words of one pundit, "science advances funeral by funeral". However, most scientists realize that today's theories are probably the future's outmoded ideas, and the best we can hope is that our theories will survive with some tinkering and fine-tuning by future generations.

We can go back to Copernicus to illustrate this. Most of us today, if asked on a street corner, would say that we accept Copernicus's idea that the earth moves around the sun - we would say that the heliocentric theory seems correct. However, Copernicus himself maintained that the orbits of the planets around the sun were perfectly circular. A couple of centuries later, in Newton's time, it became apparent that those orbits are ellipses. The heliocentric theory wasn't discarded; it was just modified to account for more detailed new observations. In the twentieth century, we've additionally found that the exact shapes of the ellipses aren't constant (hence the Milankovitch cycles that may have influenced the periodicity of glaciation). However, we haven't gone back to the idea of an earth-centered universe. Instead, we still accept a heliocentric theory - it's just one that's been modified through time as new data have emerged.

The notion that scientific ideas change, and should be expected to change, is sometimes lost on the more vociferous critics of science. One good example is the Big Bang theory. Every new astronomical discovery seems to prompt someone to say "See, the Big Bang theory didn't predict that, so the whole thing must be wrong". Instead, the discovery prompts a change, usually a minor one, in the theory. However, once the astrophysicists have tinkered with the theory's details enough to account for the new discovery, the critics then say "See, the Big Bang theory has been discarded". Instead, it's just been modified to account for new data, which is exactly what we've said ought to happen through time to any scientific idea.

Try an analogy: Imagine that your favorite fictional detective (Sherlock Holmes, Miss Marple, Nancy Drew, or whoever) is working on a difficult case in which the clues only come by fits and starts. Most detectives keep their working hypotheses to themselves until they've solved the case. However, let's assume that our detective decides this time to think out loud as the story unfolds, revealing their current prime suspect and hypothesized chronology of the crime as they go along. Now introduce a character who accompanies the detective and who, as each clue is uncovered, exclaims "See, this changes what you thought before - you must be all wrong about everything!" Our detective will think, but probably have the grace to not say, "No, the new evidence just helps me sharpen the cloudy picture I had before". The same is true in science, except that nature never breaks down in the last scene and explains how she done it.

Science and Knowledge

So what does all this mean? It means that science does not presently, and probably never can, give statements of absolute eternal truth - it only provides theories. We know that those theories will probably be refined in the future, and some of them may even be discarded in favor of theories that make more sense in light of data generated by future scientists. However, our present theories are our best available explanations of the world. They explain, and have been tested against, a vast amount of information.

Consider some of the information against which we've tested our theories:

- We've examined the DNA, cells, tissues, organs, and bodies of thousands if not millions of species of organisms, from bacteria to cacti to great blue whales, at scales from electron microscopy to global ecology.
- We've examined the physical behaviour of particles ranging in size from quarks to stars and at times scales from femtoseconds to millions of years.
- We've characterized the 90 or so chemical elements that occur naturally on earth and several more that we've synthesized.
- We've poked at nearly every rock on the earth's surface and drilled as much as six miles into the earth to recover and examine more.
- We've used seismology to study the earth's internal structure, both detecting shallow faults and examining the behavior of the planet's core.

- We've studied the earth's oceans with dredges, bottles, buoys, boats, drillships, submersibles, and satellites.
- We've monitored and sampled Earth's atmosphere at a global scale on a minute-by-minute basis.
- We've scanned outer space with telescopes employing radiation ranging in wavelength from infrared to X-rays, and we've sent probes to examine both our sun and the distant planets of our solar system.
- We've personally explored the surface of our moon and brought back rocks from there, and we've sampled a huge number of meteorites to learn more about matter from beyond our planet.

We will do more in centuries to come, but we've already assembled a vast array of information on which to build the theories that are our present scientific understanding of the universe.

This leaves people with a choice today. One option is to accept, perhaps with some skepticism, the scientific (and only theoretical) understanding of the natural world, which is derived from all the observations and measurements described above. The other option, or perhaps an other option, is to accept traditional understandings[3] of the natural world developed centuries or even millennia ago by people who, regardless how wise or well-meaning, had only sharp eyes and fertile imaginations as their best tools.

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[1] This is the definition that I stated off-the-cuff in response to a question by a science education student a few years ago. It's remarkably close to the one that later appeared in E.O. Wilson's *Consilience*.
[2] Quotation from one of his classes by Dr. Sheldon Gottlieb of the University of South Alabama.
[3] Few modern people will accept traditional lifestyles from centuries or millennia ago - traveling in carts pulled by draft animals, cooking over open fires, herding sheep and cattle, sleeping in poorly heated huts, and watching their children die of smallpox or polio. The advantages of a modern lifestyle are too great for most of us to pass up. Some of us will nonetheless wake up to our clock radios, flip on the electric lights, shower in our heated water carried by our plumbing, put on our polyester suits, grab some breakfast out of our refrigerators and cook it in our microwave ovens, and then travel in automobiles or airplanes to TV studios to broadcast via satellite our opinions that traditional understandings of the world are superior to those developed by science in the modern era.

Section 2: What Science Isn't

What Science Isn't, Part I: A Historical Perspective

Many historians suggest that modern science began around 1600 in the time and with the efforts of Galileo Galilei (1564-1642), Johannes Kepler (1571-1630), and Francis Bacon (1561-1626). Their era punctuated the change from scholasticism of the Middle Ages and Renaissance to science as we know it. **Scholasticism** largely involved deductive reasoning from principles supplied by Aristotle, by scripture, or by notions of perfection (which largely involved circles and spheres). It was thus a "top-down" intellectual enterprise. **Modern science** instead involved induction from multiple observations of nature, and so worked "bottom-up" from basic observation or experiment to generalization. In the words of Bacon's *Novum organum*, "For man is but the servant or interpreter of nature; what he does and what he knows is only what he has observed of nature's order in fact or in thought; beyond this he knows nothing and can do nothing. . . . All depends on keeping the eye steadily fixed upon the facts of nature and so receiving the images simply as they are."

Galileo's and Kepler's work exemplified this fundamental change in attitude. Medieval thinking had assumed a centrality of humanity, so that the earth on which humans lived was thought to be the center of the universe. It had also assumed a perfection requiring orbits of heavenly bodies to be circular. Nicolaus Copernicus (1473-1543, and thus a hundred years before Galileo and Kepler) had cautiously broken with the first of these assumptions to conclude tentatively that the earth orbited the sun, but he clung to the idea of a perfectly circular orbit. Galileo argued much more forcefully for an earth orbiting the sun, ultimately breaking the earth-centered view that was based on human-centered logic. Kepler showed that the orbits of the planets are ellipses, rather than the circles required of a philosophically perfect universe. More recent observations - that those orbits are changing ellipses, that the earth is not perfectly spherical but is an oblate spheroid, and that the sun occupies no central position in just one galaxy among billions of galaxies - would all be very distasteful to the scholastic view of the world, which assumed geometric perfection and human or earthly centrality.

To summarize: The logic of modern science requires that observations or facts govern the validity of generalizations or theories. Previous thinking had often gone the opposite direction. Galileo was reminded of that previous direction when he was taken to Rome and condemned because his "proposition that the sun is in the centre of the world and immovable from its place is absurd . . . because it is expressly contrary to Holy Scripture" (to quote the official judgment of the court). The success and everyday application of modern physics, chemistry, biology, geology, and the other sciences is forceful evidence of the validity of the modern approach.

What Science Isn't, Part II: Science Isn't Art

To say science isn't art may seem trivial, but comparing the two helps illustrate what science is. We'll start with art, and then move to science.

Art is the attempt to express an individual's feelings or ideas about something in a way that others find beautiful, graceful, or at least aesthetically satisfying. Thus art is very individualistic. Outside the performing arts, art is almost always produced by individuals, because it has to have purity of expression that can only come from one person. In the performing arts, art is generally the concept of one person (a composer or choreographer), although it is executed by many. Art is also individualistic in that a painting or sculpture left in the studio is nonetheless art, even if no one else sees it, and even if anyone who saw it thought it ugly, graceless, or tasteless. Undisplayed or unloved art is still art in that it expresses the concept of the artist.

The second part of our definition suggests that art ought to be beautiful or aesthetically satisfying. Until the twentieth century, beauty was a requirement of art. In the twentieth century expression became so important, or the expressed concepts were often so distressing, that pure beauty may have suffered at times. Aesthetics nonetheless remain critical to art. Certainly in the art most popular today (Impressionist paintings; the music of Bach, Mozart, and Beethoven, and even much rock music; ballet and modern dance; poetry from Shakespeare to haikus), beauty remains a critical component.

Science, in contrast, is the attempt to reach demonstrable, replicable, conclusions about the natural world (and social science is the corresponding attempt to reach demonstrable conclusions about the social or human world). Individualism exists, in that what each scientist studies and how they study it are somewhat open to their choice. However, the conclusions reached have to be demonstrable to others with physical evidence. If an artist says, "This work expresses something deep in my heart", everyone nods approvingly. If a scientist says, "I don't have any evidence to show you, but deep in my heart I know . . .", everyone rolls their eyes and leaves the room as quickly as possible. The non-individualistic nature of science is also reflected by how much scientific research is done by groups: a single-authored paper in particle physics is about as common as a multi-authored novel.

Secondly, in working from our definition of art but now comparing science to it, science doesn't have to be beautiful or aesthetically satisfying, or even emotionally satisfying. Electron orbitals can be shown to be distorted, crystal structures can be shown to have defects, ocean basins and their currents can be shown to be asymmetric, planets can be shown to be non-spherical, and that's OK - even though a geometrically perfect world might be more beautiful. Atoms can be shown to decay, species can be shown to change, continents can be shown to move, merge, and split in random ways, the universe can be shown to be changing explosively, and that's OK - even though an invariant timeless world might be more aesthetically satisfying. Humans can be shown to be ill-designed animals genealogically descended from scruffy or slimy ancestors, and that's OK - even though it's not emotionally satisfying to humans.

To summarize (and generalize): art is largely an individual's effort to communicate his or her ideas or feelings in a beautiful way. Science is a group effort to characterize reality. Aesthetics, the *sine qua non* of art, don't count for much in science. It's of course true that many scientists and people who understand science find aesthetic satisfaction in scientific concepts and the patterns of nature, and physicists will even claim to find beauty in their equations. It's also true that many scientists get some aesthetic satisfaction, or at least are able to exercise their artist-wanna-be ambitions, in illustrating scientific concepts. However, beauty never is, or never should be, a criterion for evaluating the validity of a hypothesis or theory.

What Science Isn't, Part III: Science is not Technology

One of the mistakes many people make in thinking about science is to confuse it with technology. As a result, science often either receives undue credit (for the "miracles of modern science" in one's kitchen) or undue blame (for everything from overly firm tomatoes to nuclear war). In fact, science doesn't make things. Scientists developed the understanding of radiation sufficient for the invention of the microwave oven, but neither making a microwave oven nor using it are science. Scientists are in the business of generating knowledge, whereas engineers are in the business of generating technology.
People doing science often use sophisticated technology, but science doesn't require it. Our ecologist observing natural bird behavior and our geologist examining an outcrop neither use particularly sophisticated technology. In fact, the only technology in common to all science is the notebook in which observations are recorded.

In short, science often leads to technology, and it often uses technology, but it isn't technology, and in fact it can operate quite independently of technology.

What Science Isn't, Part IV: Science isn't Truth and it isn't certainty

Some people assume that scientists have generated a body of knowledge that is sure to be true. Some ideas, after all, are known with enough certainty that most of us take them for granted. An example is our common assumption that the earth orbits the sun. Much scientific evidence supports that idea, which is the heliocentric theory of the solar system, and most of us take it as "true". However, no human has observed the solar system and seen the earth traveling in an orbit around the sun. It's just a theory, if a nearly inescapable one.

In that sense, most scientists will concede that, although they seek Truth, they don't know or generate Truth. They propose and test theories, knowing that future evidence may cause refinement, revision, or even rejection of today's theories. Ask a scientist about an issue that's not directly observable, and you probably hear an answer that starts with something like "The evidence suggests that . . ." or "Our current understanding is . . .". You're not hearing waffling or indecision. You're hearing a reasoned recognition that we can't know many things with absolute certainty - we only know the observable evidence. However, we can reach the best possible conclusion based on the most complete and modern evidence available.

That contrasts strongly with the knowledge claimed by many other people. Many people claim that they, or a book or books they endorse, hold all relevant knowledge and that such knowledge is absolutely and unquestionably true. The Bible, for example, is often held up as containing all knowledge, and as being literal and infallible Truth. No science book has ever been endorsed that way, nor should it ever be.

As an example, consider the question "How did the world begin?". A scientist's answer will begin with the evidence that we've gleaned from decades if not centuries of astronomical study, which includes several lines of evidence about the motions of galaxies. It will conclude with a theory that fits the accumulated evidence. There won't be, or at least oughtn't be, any statement about absolute truth.

In contrast, some other people will answer that the world was created by a certain deity a certain number of years ago. If asked about their level of certainty, these people generally respond that they have absolutely no uncertainty. No scientist thinking about what he or she is saying will answer with that degree of certainty, regardless of the evidence available to them, nor will they lay that kind of claim to Truth. They may have a high level of confidence if there's abundant evidence, but they won't claim absolute Truth or absolute certainty.

It's worth remembering that a person's admission of uncertainty doesn't mean they're wrong, whether the issue is in politics, economics, religion, or science. In fact, a person who admits some uncertainty in their thinking is often closer to the truth, or at least understands the issues better, than someone who claims absolute certainty. Shouting loudest does not generate truth.

What Science Isn't, Part V: Science isn't Religion, or a religion

Science and religion are very different, both in what they try to do and in the approaches they use to accomplish their goals. Science seeks to explain the origin, nature, and processes of the physically detectable universe. Religion seeks (or religions seek) to explain the meaning of human existence, to define the nature of the human soul, to justify the existence of an afterlife for humans, and to maintain devotion to a diety or deities. Their goals are thus very different.

Their methods are also very different. Science uses physical evidence to answer its questions and relies on modern humans to make inferences from that evidence. Religions, on the other hand, commonly use divine inspiration, interpretation of ancient texts, and (in some cases) personal insight as the source of the answers to their questions. Science and religion thus are not, or should not be, competing approaches, because they seek to accomplish different things, and by different methods. In light of these fundamental differences in goal and method, science and religion are distinct but mutually compatible paradigms (a term we will explore further in the next session).

Consideration of these goals and methods shows that science and religion have little overlap. Science has no business making inferences about souls, about afterlives, and about deities, because those are not physically detectable or measurable entities about which hypotheses can be tested. Many religions, especially eastern ones, correspondingly make few claims about the origin and nature of the physically detectable universe. Religions that do make such claims generally do so because of their acceptance of the entirety of an ancient text that includes stories about the origin of the earth and its life. Religions that treat their ancient texts' stories as allegorical rather than literal have little or no conflict with science.

To illustrate these differences, some generalizations about religious knowledge, artistic or mystic knowledge, and scientific knowledge are given in the table below. One has to bear in mind the tremendous diversity in both religions (Buddhism, Hinduism, Islam, Judaism, shamanism, Shinto, etc., and the many variations of Christianity) and in science (experimental to observational, physical to biological, etc.), and the almost infinite diversity of mystic experiences. The following isn't meant as a condemnation or idealization of any one of the three, but as a way of seeing each in the light of the other.

Science and other kinds of knowledge

	Religious Knowledge [1]	**Artistic/Mystic Knowledge**	**Scientific Knowledge**
Outrageous stereotype of user	Bible-thumping fundamentalist or imam in a turban; may be fond of Sunday-morning radio, or hadiths and tafsirs.	Crystal-hugging wearer of tie-dyed T-shirts; listens to new-age music.	Geek with pocket protector and calculator; watches *Discovery Channel* a lot.
How one discovers knowledge	From ancient texts or revelations of inspired individuals.	From personal insight, or insight of others	From evidence generated by observation of nature or by experimentation.
Extent to which knowledge changes through time	Little.	May be considerable.	Considerable.
Extent to which future changes in knowledge are expected by user	None.	Can be expected, to the degree that the user expects personal development	Considerable.
How knowledge changes through time	Unchangeable except by reinterpretation by authorities, or by new inspired revelations, or by divergence of mavericks.	As user changes or as user encounters ideas of others	By new observations or experiments, and/or by reinterpretation of existing data.
Certainty of the user	High, given sufficient faith; can be complete.	High	Dependent on quality and extent of evidence; should never be complete.
Assumptions	That ancient texts or inspired revelation have meaning to modern or future conditions.	That personal feelings and insights reflect nature.	That nature has discernible, predictable, and explainable patterns of behavior.
Usual Objectives	To understand the human soul, the nature of a deity or deity, and the conditions of human afterlife.	To understand the physical and/or metaphysical universe.	To understand the origin, nature, and processes of the physically observable universe.
Where users put their faith	In the supernatural beings that they worship or in the authorities who interpret texts and events.	In their own perceptions.	In the honesty of the people reporting scientific data (the incomes of whom depend on generation of that data), and in the human ability to understand nature.
Sources of contradiction	Between different religions; between different texts and/or authorities within one religion; within individual texts (as in the two accounts of human origin in the Judeo-Christian Genesis).	Between users, who each draw on their own personal insights	Across time, as understanding changes; between fields, which use different approaches and materials; and between individuals, who use different approaches and materials.

Note that each of these ways of thinking can have its advantages, depending on how one views the world:

- - - For someone who values constancy very highly and is uncomfortable with changes in knowledge, science can be very unsettling. On the other hand, for someone who can adapt to changing understandings of the world and even enjoys newly discovered ideas, science can be quite attractive.

- - - For someone who places little faith in the integrity and abilities of contemporary humanity, science may hold little credibility. However, it can be of great value for someone who questions past authority and instead is more trusting of the peer-reviewed published reports of some contemporary humans who make their livings as scientists.

- - - For someone who is comforted by traditional views of a special nature of humanity and by the thought of a caring guiding force, science can provide an unpleasant perspective. As one college student put it, "I do not want to be the only kid in the playground who knows the truth about Santa Claus."[2] However, for others, science can provide a useful, if harder-edged, perspective by which to view the world.

Summary

Science is the concerted effort by very real human beings to understand the history of the natural world and how the natural world works. Observable physical evidence, either from observations of nature or from experiments that try to simulate nature, is the basis of that understanding. The results of, and inferences from, those observations and experiments become scientific knowledge only after publication, and the point of publication is to change previous ideas. Thus theories, the large-scale concepts that are based on huge amounts of data and try to explain and predict large bodies of phenomena, may be powerful ideas, but they are constantly subject to revision or even rejection as new knowledge emerges. The result is that scientific knowledge is constantly changing but hopefully proceeding toward a more correct view of the world.

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[1] This caricature of religious approaches to knowledge is written largely with more Western and purportedly monotheistic religions in mind, especially Christianity and Islam. Many eastern religions are more encouraging of sustained inquiry and less insistent on unquestioning faith. The Dalai Lama's enthusiasm for unfettered scientific study of meditation is an example.
[2] Quotation from one of his classes by Dr. Sheldon Gottlieb of the University of South Alabama.

The author thanks Dr. Vemuri Ramesam of Hyderabad, India, for his help in improving the content.

Section 3: Scientific Thought:
Facts, Hypotheses, Theories, and all that stuff

There are different kinds of human knowledge, and it's useful to sort them out in order to understand what's going on in science. We'll consider the following terms: Fact, Deductive Inference, Inductive Inference, Hypothesis, Multiple Working Hypotheses, Theory, Evidence, Ockham's Razor, Natural Law, and Paradigm. The first few may be a little boring, but hang in there - things get more interesting further down.

fact - a truth known by actual experience or observation. The hardness of iron, the number of ribs in a squirrel's body, the existence of fossil trilobites, and the like are all facts.

Is it a fact that electrons orbit around atomic nuclei? Is it a fact that Brutus stabbed Julius Caesar? Is it a fact that the sun will rise tomorrow? None of us has observed any of these things - the first is an inference from a variety of different observations, the second is reported by Plutarch and other historians who lived close enough in time and space to the event that we trust their report, and the third is an inductive inference after repeated observations (see below).

deductive inference - a conclusion based on reasoning from accepted premises. Consider a somewhat loaded example: "The earth is a spherical body, a sphere by definition has equal radius in all directions, and therefore the radius of the earth is equal in all directions." We've taken two reasonable premises and reached a conclusion from them with. In this example, the conclusion is slightly flawed because the first premise is only an approximation: the earth is really a prolate spheriod (it bulges toward the equator because of its rotation). Deductive inference can be a powerful tool when the premises are correct, but the example illustrates what happens when one of the premises is flawed.

inductive inference - a conclusion based on repeated observation of fact. Drop a particular kind of ball on a particular floor from a particular height numerous (n) times, and you can, by induction from those examples, make an inference and a prediction about what will happen the next time you drop the ball. However, your prediction is not a fact, in that you won't know by actual observation the result of the n+1th drop until it has happened.

hypothesis - a testable proposition explaining the occurrence of a phenomenon or phenomena, often asserted as a conjecture to guide further investigation. After dropping the ball from one height several times, you may think that dropping it from a greater height will lead to a different response, and you may predict that different response. Your prediction is a hypothesis, and you can test it by changing the height of the drop and observing the result. At that point, you'll have done an experiment to test your hypothesis.

One important word in the definition of "hypothesis" is "testable". If a proposition contains some component that defies testing or detection, the proposition is not a scientific hypothesis. To continue with the example above, the proposition that "a ball of a particular type dropped from a particular height onto a particular surface will bounce a particular distance" would be a scientific hypothesis, because we can drop that type of ball from that height onto that kind of surface. However, the proposition that "a ball when dropped will bounce a distance determined by the undetectable influence of an undetectable entity" is not a scientific hypothesis because, if we can't detect the entity or its influence, we can't test whether that entity is responsible, or if that entity even exists.

multiple working hypotheses - a method of research where one considers not just a single hypothesis but instead multiple hypotheses that might explain the phenomenon under study. Many of these hypotheses will be contradictory, so that some, if not all, will prove to be false. However, the development of multiple hypotheses prior to the research lets one avoid the trap of narrow-mindedly focusing on just one hypothesis.

theory - a coherent set of propositions that explain a class of phenomena, that are supported by extensive factual evidence, and that may be used for prediction of future observations. For our rather trivial example, a theory would emerge only after a huge number of tests of different kinds of balls at different heights. The theory would try to explain why different kinds of balls bounce differently, and it ought to be useful in predicting how new materials would behave if dropped as balls in the same way.

Scientists have produced lots of familiar theories:

Copernicus's theory of the heliocentric solar system,
Newton's theory of gravity,
Einstein's theory of relativity, and
Darwin's theory of natural selection are a few.

Each of these theories draws on huge numbers of facts:

observations of the passage of the sun and planets for the heliocentric theory;
the behavior of the planets, of projectiles, and rather famously of apples for the theory of gravity, and
the existence and location of fossils, as well as the modern distribution and reproduction of organisms, for the theory of natural selection.

Some people dismiss a given scientific idea with "That's just a theory". They're right - all science can provide is theories. However, those theories have proven quite useful to all of us. Most of us won't step off the top of a building because of the results predicted by Newton's theory of gravitation - and yet it's just a theory.

NASA and other space agencies launch space craft to distant planets on the basis on Newton's theory of gravitation and Copernicus's theory of the heliocentric solar system - and yet they're just theories. It's instructive to remember that Copernicus was required by the authorities of his time to preface his work as *just* a series of "hypotheses", and not even as a "just a theory".

evidence - the physical observations and measurements made to understand a phenomen. Perhaps equally important is what's not evidence: theories aren't evidence, and the opinions of even the most learned scientists aren't evidence.

Note that evidence is one of the critical underpinnings of a theory (see above). A good scientist or observer of science periodically asks, "What do we think we know, and why do we think we know it?" The answer to the second part should be some sort or sorts of evidence, as defined in the previous paragraph.

Ockham's Razor (a.k.a. Occam's Razor) - a philosophical statement developed by William of Ockham, an English monk who died in 1349. His orginal statement was " non sunt multiplicanda entia praeter necessitatem", or "assumptions are not to be multiplied beyond necessity". In thinking about our hypotheses and theories discussed above, perhaps the best modern statement of Ockham's Razor is

"*Our explanations of things should minimize unsupported assumptions*."

If we have multiple hypotheses that can explain a thing, we ought to reject the hypotheses that involve agents or processes for which we have no evidence (bearing in mind how we've defined evidence above). Let's say we've observed a large rock in an otherwise featureless area. One of our hypotheses for the presence of the rock might be that an ancient giant threw it there, and another hypothesis might be that glacial ice transported it there. Ockham's Razor tells us to reject the first and retain the second for further consideration, because we have no evidence for ancient giants - they are an unsupported assumption. We do have modern evidence that flowing ice can transport large stones.

It's not true to say, and William of Ockham wouldn't have said, that "the simplest explanation is the best explanation". The explanation that all matter consists of earth, air, fire, and water was simpler than the explanation involving the modern periodic table of elements, but it was wrong. An even better example is Devil’s Tower in Wyoming. Native American legend tells that this landform originated when a huge bear tried to climb a steep mountain to attack an Indian maiden, and the bear's claws scraped the sides of the mountain away. That's a simple explanation, but it assumes the existence of huge bear capable of clawing the sides of a mountain to leave something like Devil's Tower. The bear is an unsupported assumption that would cause most of us to reject the Native American story as anything other than folklore or myth.

natural law - a term rarely used today, at least by scientists thinking about what they're saying. Nineteenth-century science presumed that it could arrive at immutable, absolutely true, universal statements about nature, and these were to be "natural laws". Newton's ideas about gravitation, for example, were considered the "laws of gravity". To continue that example, in the twentieth century Einstein's theory of relativity showed that Newton's ideas needed correction in some cases. Thus it became apparent that it would be wisest to treat even our most trusted ideas, of which Newton's had been one, as theories rather than absolute laws.

paradigm - a way of thinking, commonly so ingrained in people's behavior or thought that they aren't even aware of it. If a theory presents a broad understanding of a phenomenon or problem, a paradigm may be the mindset that causes us to think that the theory matters one way or the other. In a non-scientific example, the Domino Theory was an explicit statement of what many Americans thought would happen if a single country in a given region (e.g. southeast Asia) had a communist government. The implicit paradigm was that the US ought to be, and had to be, involved in a global struggle with another superpower over what kind of political system would dominate the world's governments.

In science, a major example of a change in paradigms was the change from Scholasticism to Modern Science, roughly around AD 1600. Scholasticism, which assumed that answers to questions about nature could be deduced from ancient texts and philosophical principals, gave way to the modern view of science where induction from accumulated evidence is (or should be) the underpinning of theories. (We talked about this more in the previous section) When Galileo was threatened by church authorities with torture for his claim that the earth orbits the sun, Galileo and his accusers were not only at odds *about* an astronomical theory. They were also arguing, if unwittingly, *because* they were using two very different paradigms: the churchmen were using scholasticism, and Galileo modern science.

Incidentally, the fact that we only call today's way of thinking "modern science", rather than a distinct name, is a sign of how the users of a paradigm generally don't recognize what they're using. Another change of paradigms came when scientists, or at least some scientists, realized the futility of the search for natural laws, as discussed above.

This distinction between paradigm and theory can be seen in the earth sciences. For example, the earth sciences have seen major theories of earth movement and mountain building come and go. Into the early 1900s, a static earth was the largely unquestioned model. Continental Drift, the theory of continents plowing through passive oceanic crust, was a controversial theory accepted in the early to middle parts of this century by many if not most geologists in the Southern Hemisphere, and by many in the Northern Hemisphere. It has been supplanted today by the widely accepted Plate Tectonic theory (in which the oceanic crust has a dynamic rather than passive role).

Implicit behind all this changing theory has been the paradigm that the major goal of the earth sciences should be a theory to account for crustal movement, mountain building, and processes deep in the earth. We may now be going through a paradigm shift: we increasingly expect that the earth sciences should be mostly concerned about cycling of elements and changing conditions at the earth's surface. The paradigm isn't changing our theories, but it's changing our focus from one theory (or group of theories) about one problem to another theory (or group of theories) about another problem.

Section 4: Some Definitions of Science

Each of these sections begins with conventional definitions or comments and moves toward less conventional but perhaps more revealing statements.

Definitions by goal and process:

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1. the systematic observation of natural events and conditions in order to discover facts about them and to formulate laws and principles based on these facts. 2. the organized body of knowledge that is derived from such observations and that can be verified or tested by further investigation. 3. any specific branch of this general body of knowledge, such as biology, physics, geology, or astronomy.

Academic Press Dictionary of Science & Technology

Science is an intellectual activity carried on by humans that is designed to discover information about the natural world in which humans live and to discover the ways in which this information can be organized into meaningful patterns. A primary aim of science is to collect facts (data). An ultimate purpose of science is to discern the order that exists between and amongst the various facts.

Dr. Sheldon Gottlieb in a lecture series at the University of South Alabama

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Science involves more than the gaining of knowledge. It is the systematic and organized inquiry into the natural world and its phenomena. Science is about gaining a deeper and often useful understanding of the world.

from the Multicultural History of Science page at Vanderbilt University.

Science consists simply of the formulation and testing of hypotheses based on observational evidence; experiments are important where applicable, but their function is merely to simplify observation by imposing controlled conditions.

Robert H. Dott, Jr., and Henry L. Batten, *Evolution of the Earth* (2nd edition)

Science alone of all the subjects contains within itself the lesson of the danger of belief in the infallibility of the greatest teachers in the preceeding generation . . .As a matter of fact, I can also define science another way: Science is the belief in the ignorance of experts.

Richard Feynman, Nobel-prize-winning physicist,
in *The Pleasure of Finding Things Out*
as quoted in *American Scientist* v. 87, p. 462 (1999).

Definitions by contrast:

To do science is to search for repeated patterns, not simply to accumulate facts.

Robert H. MacArthur, *Geographical Ecology*

A modern poet has characterized the personality of art and the impersonality of science as follows: Art is I; Science is We.

Claude Bernard (1813-1878), Physiologist and "the father of modern experimental medicine"

Poetry is not the proper antithesis to prose, but to science. . . . The proper and immediate object of science is the acquirement, or communication, of truth; the proper and immediate object of poetry is the communication of immediate pleasure.

Samuel Taylor Coleridge (1772-1834), *Definitions of Poetry*

Fiction is about the suspension of disbelief; science is about the suspension of belief.

James Porter, UGA Ecology Professor, as quoted by Steve Holland

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Religion is a culture of faith; science is a culture of doubt.

Richard Feynman, Nobel-prize-winning physicist

Not quite definitions, but critical statements:

As a practicing scientist, I share the credo of my colleagues: I believe that a factual reality exists and that science, though often in an obtuse and erratic manner, can learn about it. Galileo was not shown the instruments of torture in an abstract debate about lunar motion. He had threatened the Church's conventional argument for social and doctrinal stability: the static world order with planets circling about a central earth, priests subordinate to the Pope and serfs to their lord. But the Church soon made its peace with Galileo's cosmology. They had no choice; the earth really does revolve around the sun.

Stephen J. Gould, *The Mismeasure of Man*

The fuel on which science runs is ignorance. Science is like a hungry furnace that must be fed logs from the forests of ignorance that surround us. In the process, the clearing that we call knowledge expands, but the more it expands, the longer its perimeter and the more ignorance comes into view. . . . A true scientist is bored by knowledge; it is the assault on ignorance that motivates him - the mysteries that previous discoveries have revealed. The forest is more interesting than the clearing.

Matt Ridley, 1999
Genome: the autobiography of a species in 23 chapters, p. 271.

There is no philosophical high-road in science, with epistemological signposts. No, we are in a jungle and find our way by trial and error, building our roads behind us as we proceed. We do not find sign-posts at cross-roads, but our own scouts erect them, to help the rest.

Max Born (1882-1970), Nobel Prize-winning physicist,
quoted in Gerald Holton's *Thematic Origins of Scientific Thought*

The stumbling way in which even the ablest of the scientists in every generation have had to fight through thickets of erroneous observations, misleading generalizations, inadequate formulations, and unconscious prejudice is rarely appreciated by those who obtain their scientific knowledge from textbooks

James Bryant Conant (1893-1978), *Science and Common Sense*

I think that we shall have to get accustomed to the idea that we must not look upon science as a "body of knowledge", but rather as a system of hypotheses, or as a system of guesses or anticiptations that in principle cannot be justified, but with which we work *as long as they stand up to tests,* and of which we are never justified in saying that we know they are "true" . . .

Karl R. Popper (1902-1994), *The Logic of Scientific Discovery*

The real purpose of the scientific method is to make sure Nature hasn't misled you into thinking you know something you don't actually know.

Robert M. Pirsig, *Zen and the Art of Motorcycle Maintenance*

We [scientists] wouldn't know truth if it jumped up and bit us in the ass. We're probably fairly good at recognizing what's false, and that's what science does on a day-to-day basis, but we can't claim to identify truth.

Dr. Steven M. Holland, University of Georgia Geology Professor

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Science is the most subversive thing that has ever been devised by man. It is a discipline in which the rules of the game require the undermining of that which already exists, in the sense that new knowledge always necessarily crowds out inferior antecedent knowledge. . . . . This is what the patent system is all about. We reward a man for subverting and undermining that which is already known. . . . . Man has a tendency to resist changing his mind. The history of the physical sciences is replete with episode after episode in which the discoveries of science, subversive as they were because they undermined existing knowledge, had a hard time achieving acceptability and respectability. Galileo was forced to recant; Bruno was burned at the stake; and so forth. An interesting thing about the physical sciences is that they did achieve acceptance. Certainly in the more economically advanced areas of the Western World, it has become commonplace to do everything possible to accelerate the undermining of existent knowledge about the physical world. The underdeveloped areas of the world today still live in a pre-Newtonian universe. They are still resistant to anything subversive, anything requiring change; resistant even to the ideas that would change their basic concepts of the physical world.

Philip Morris Hauser (1909-), Demographer and Census Expert,
as quoted in Theodore Berland's *The Scientific Life*

Two Illustrative Stories:

A scientist describing for radio broadcast an exciting moment in a baseball game:

Diaz swings a bat, which is apparently made of wood and has no evidence of modifications contrary to baseball rules. He strikes the ball thrown by Johnson, who had not been observed to scratch, scuff, wet, or otherwise modify that ball. The ball is traveling through the air and may pass over the outfield wall on the fly. Yamoto, the rightfielder, heads back to the right field wall, but slows as he reaches the warning track and slumps his shoulders. I believe the ball has passed over the right field wall, and fans seated in the right field bleachers are scrambling as if to retrieve the ball. Meanwhile, the first base umpire has run into right field and is now waving one hand over his head in a circular motion. My own personal observation of the ball's flight, Yamoto's behavior on the warning track, the fans' behavior, and the umpire's signal all lead me to conclude that Diaz has hit a home run and that, if he travels around the bases and touches each base to the satisfaction of the umpires, his team will be credited with a run.

A carpenter, a school teacher, and scientist were traveling by train through Scotland when they saw a black sheep through the window of the train.

"Aha," said the carpenter with a smile, "I see that Scottish sheep are black."

"Hmm," said the school teacher, "You mean that some Scottish sheep are black."

"No," said the scientist glumly, "All we know is that there is at least one sheep in Scotland, and that at least one side of that one sheep is black."

Section 5: A Tabular History of Scientific Ideas That Challenged Fundamental Notions of the World

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This section uses six scientific questions to illustrate how human thinking about six fundamental notions has changed, or not changed, through time. The table on the next page begins that process.

Six Scientific Ideas Challenging Fundamental Notions of the World

.	.	A	B	C	D	E	F
.	.	**Shape of Earth**	**Relative Position of Earth**	**Age of earth**	**Origin of human (and other) species**	**Change in Configuration of Continents and Oceans**	**Origin of Universe**
1	**Traditional (pre-scientific) View:**	Flat**	Center of Universe; Sun orbits earth	~6,000 years	Divine creation	None: Static Geography	Divine creation
2	**Scientific View:**	Roughly spherical	Earth orbits sun (and sun occupies no special position in universe)	4.6 billion years	Evolution from earlier life	Movement of continents in tectonic plates; generation & destruction of sea floor	Initial explosion of matter ("Big Bang")
3	**Most basic evidence for scientific view:**	Disappearance of receding objects; circumnavigation of planet (Magellan); Apollo mission photos	Astronomical observations via telescopes	Rates of formation of geologic features; Radiometric dating of rocks (in 20th century)	Fossil record; structural similarities between humans and other primates; DNA and other biochemical studies.	Geologic trends in continents; age of sea floor; earthquakes and volcanoes	Red shift in spectra of light from distant galaxies
4	**First major proponents of scientific view:**	Ancient Greeks	Copernicus (~1540); Galileo (~1630)	James Hutton(1790s); Charles Lyell (1840-70s)	Darwin, Wallace, Huxley (mid-late 1800s)	Wegner, Wilson, Hess (Early-mid 1900s)	Alexander Friedmann; Edwin Hubble (Early-mid 1900s)
5	**Implication of scientific view for humans:**	Not much	Not inhabitants of center of universe, and thus not necessarily central to the interest of a divine being	Only recent inhabitants of a very old planet; any divine being was content with human-less earth for billions of years	Genealogically descended from non-human "lesser" species; not special	not much	Earth is young in context of entire universe: universe existed without earth and humans for billions of years
6	**Conservative* response to scientific view:**	Not much; a very few still honestly objected in 20th century	Copernicus's book titled "hypothetical"; Galileo imprisoned by Vatican and forced to recant	Creationism (but not the principal focus of creationism)	19th-century attack by Bishop Wilberforce et al.; focus of 20th- and 21st-century creationism	Virtually none	Creationism (but not the principal focus of creationism)
7	**View of people on the street today:**	Round earth (scientific view)	Earth orbits sun (scientific view) for most people	Some scientific; some conservative	Some scientific & some conservative, with heated debate; laws enacted to ensure teaching of conservative view	Don't care	Some scientific; some conservative

*Note that "conservative" is used here to denote people resistant to change with regard to these ideas, and it is not intended to have a political connotation. "Traditionalist" could and probably should be substituted for "conservative".

** European traditional views, partly based on the Bible, involved a flat Earth. Some non-European traditions assumed a round Earth.

From the table on the previous page, some interesting questions, and perhaps their answers, emerge:

1) Why did conservatives accept the idea of a heliocentric solar system (Column B) but refuse to accept other scientific ideas? (Bear in mind that the Church, in its indictment of Galileo, explicitly declared that Galileo’s "proposition that the sun is in the centre of the world and immovable from its place is absurd . . . because it is expressly contrary to Holy Scripture".)

2) Many conservatives cite Darwin's acceptance of religious ideas on his deathbed as evidence against evolution and natural selection. Why isn't Galileo's recantation of his arguments for a heliocentric solar system (Cell 6B) likewise cited as evidence against the earth orbiting the sun?

3) Why don't conservatives care about plate tectonics' implications for major changes in geography (Cell 6E)? Possible answer: because plate tectonics does not challenge the special position of humanity in conservative thinking (Cell 5E).

4) The evidence for biological evolution (Cell 3D) is the most easily observed and tangible of the above lines of evidence for these scientific concepts (Row 3). Why is biological evolution nonetheless the idea most hostilely attacked by conservatives? Possible answer: because it most directly undermines a special place for humans (Cell 5C).

5) (combining Questions 1 and 4) Why do many modern people accept the scientific idea that the earth orbits the sun, despite seeming to see the sun go around the earth each day, but they reject the scientific idea of biological evolution?

Closing Observation:

Row 5 of this table suggests that science hasn't been kind to humanity's notion of itself. Science has consistently been the bearer of bad news: that humans don't live on an earth at the center of the universe and thus at the focus of divine attention; that the world existed long before humans, so that any deity was seemingly quite content with a human-less world for eons; and that humans weren't created in the image of a deity but evolved from a succession of animals whose form and lifestyle was not suggestive of divinity.

Behavioral science has been no more kind. Humans have defined themselves as tool-using animals or as animals with language, to set themselves off from "lower" animals. Behavioral science has undercut such claims by showing that some non-human animals use tools and that many non-human animals, from bees to chimps, have words and/or something like language. Even the ethically dubious definition of humans as creatures that utilize other animals is defied by ants that herd aphids. The only remaining behavorial definition would be that humans are the only animals that enslave each other.

These affronts to human pride aren't the goal of science, but they result from the basic character of science. If the arts are driven to create beauty and express human qualities, the sciences have no such mission. Scientific ideas aren't, or at least shouldn't be, evaluated on the basis of whether they are reassuring to humanity. One result may be that many people dislike science because it has been the bearer of bad (or at least not complimentary) news. However, it hardly makes sense to shoot the messenger.

Section 6: Science and its societal implications

The “What is Science” readings leading to this one, and especially the table of "Scientific Ideas That Challenged Fundamental Notions of the World", concluded that

> science hasn't been kind to humanity's notion of itself. Science consistently has been the bearer of bad news: that humans don't live on an earth at the center of the universe and thus at the focus of divine attention; that the world existed long before humans, so that any deity was seemingly quite content with a human-less world for eons; and that humans weren't created in the image of a deity but evolved from a succession of animals whose form and lifestyle was not suggestive of divinity.

So what does this mean for humans and human society?

Does this mean that there is no god?

No, it doesn't mean that. The results of science suggest that there isn't a god who created the world 6000 years ago, and that there isn't a god who made humans in his or her own image as his or her own special point of attention. Practical experience (e.g., the Holocaust, which took millions of human lives; the 1999 Turkish earthquake that took roughly 40,000 lives; Hurricane Mitch, which took about 11,000 lives in Honduras) suggests that there isn't a god who watches over humans to protect us all. However, none of this precludes the existence of a deity - an as-yet-unseen very knowledgeable being in some way cognizant of, and perhaps even responsible for, what we call the universe. No one will ever be able to prove that there is no god, or are no gods.

If there is a god, what does all this tell us about him or her?

Well, he or she probably doesn't look like an aged human being, if she or he existed billions of years before human beings. In fact, if we follow the traditional logic that he or she created life in his or her image, then we might have to conclude from the fossil record that this god looks like a bacterium. Seemingly we should not follow that particular line of traditional logic.

What would be this god's values?

If this is a god responsible for the origin of life as we know it, it's a god that set life in motion with very primitive life forms. Those life forms only later led to more complex life (eukaryotes, and then animals), and only relatively recently to mammals, and only very recently to bipedal mammals that burn fossil fuels.

The implications of this might be that such a god would value *all* life forms, from bacteria to daffodils to bipedal mammals. If this sounds like touchy-feely environmentalism, bear in mind that it implies that eating broccoli would be as immoral as eating beef (and perhaps eating sprouts would be like eating veal). In fact, all matter in the universe would be equally sacred, having been created alike and only more recently cycled from mineral to biological, and perhaps back to mineral, forms.

So does this mean that humans are animals free from a moral code?

No. It may mean that there isn't a god waiting to punish people for their transgressions against other people, against the universe, or against that god. However, humans are intelligent beings, which makes them responsible for their actions. Intelligence quickly leads to the realization that one cannot live in the midst of others without a code of behavior. That code usually is, "Do unto others as you would want them to do unto you", or at least "Don't do unto others things that you wouldn't want them to do unto you." No absence of a deity, or lack of attention from a deity, frees an intelligent life form from that code.

Can our lives have any meaning if we aren't the special children of a supreme being?

Probably. To quote an anonymous commentator in the *Atlanta Journal-Constitution*, "What makes life worth living is caring about something, no matter what it is." That "something" may be human (for example, a spouse, a child, or children), it may be an institution (e.g., a university, an organization, a church, or a business), it may be a cause (the environment, civil rights, or care for the homeless), it may be a vocation or avocation (a job, an art, a craft, a sport, or a hobby, perhaps), or it may be something else. We're as special as we make ourselves to others. As Jethro Tull* put it, "It's only the giving that makes you what you are".

Does all this mean that there is no afterlife?

Not necessarily. Science can find no evidence of an afterlife in which human consciousness survives after death of the body. That doesn't prove that there is no afterlife. Our scientific understanding of life does indeed suggest that humans have an origin no different than that of other life forms. Reconciliation of a belief in an afterlife with modern science might therefore require believing that all animals, or even all life forms, have an afterlife. Anyone willing to accept that, and willing to believe in something for which there is no evidence, can believe in an afterlife in which human consciousness survives after death of the body.

More importantly, regardless whether one believes that there is an afterlife in which human consciousness survives after death of the body, it's obvious that we have an afterlife in the sense that our thoughts and the effects of our actions live on after we die. The ideas we teach and values we embody to our children, our friends, and our students will live on in them after we die. The institutions we build, and the effects they have, will continue to exist after we die. Even after we as individuals are no longer remembered, our messages and our contributions will survive in the descendants of our descendants, in the friends of our friends, and in the students of our students.

In that sense, even though William Shakespeare, Thomas Jefferson, and Martin Luther King are all dead and may have had no soul that survived in a conscious afterlife, they all have had whopping afterlives. The same is clearly true for anyone now dead whose name you recognize, whose ideas you know, or whose actions affect your life. It's equally true for the deceased of whom you're oblivious - for the great-great-grandparents who instilled a sense of work and justice in your great-grandparents and grandparents and thus onward to you, for the teacher who inspired the teacher who inspired you to explore new ideas or take a new interest, for the ordinary citizen who voted for a bond initiative that raised his or her taxes so that the school in which you were educated could be built. All these people live on, perhaps not in a gauzy light-filled conscious afterlife, but in the world through which we pass each day. If we remember the coming of this afterlife of our thoughts and actions, there's little reason to fear a death that does not promise an afterlife in which human consciousness survives after death of the body.

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*Wond'ring Aloud, Jethro Tull. Aqualung.