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Science in General

Scientific knowledge is based on observations of nature. From observations of many different events and situations, scientists try to find patterns and create generalizations as to the underlying fundamental processes involved. Then they experiment again to see if the right guess was made of what the rule is that nature follows under a given situation. *Experiments determine scientific truth.* The scientist usually learns about nature by using controlled experiments in which only one thing at a time is varied to determine whether or not a particular situation, feature, or circumstance can be determined to be the *cause* of an observed effect. The experiments can be repeated by anyone as many times as they want to verify that the effect is reproducible. The astronomer cannot do controlled experiments. They cannot even examine things from a variety of angles. What astronomers do is collect light and other radiation from celestial objects and use all of their information and creativity to interpret the signals from afar. They look for the experiments nature has set up for us and hone on a few basic characteristics at a time.

Scientific Models

Scientists will create **models** (simplified views of reality) to help them focus on the basic fundamental processes. In this context a **model** is an abstract construct or idea that is a simplified view of reality, not something made out of paper, wood, or plastic (or some good-looking person). Scientific models must make testable predictions. Like any scientist, the astronomer makes observations, which suggest hypotheses. These speculations are made into predictions of what may be observed under slightly different observing and/or analysis circumstances. The astronomer returns to the telescope to see if the predictions pan out or if some revision needs to be made in the theory. Theory and observation play off each other.

Often the evidence for a particular hypothesis is indirect and will actually support other hypotheses as well. The goal is to make an observation that conclusively disproves one or more of the competing theories. Currently unresolvable questions may be resolved later with improved observations using more sophisticated/accurate equipment. Sometimes new equipment shows that previously accepted theories/hypotheses are wrong!

Scientific models and theories must make testable predictions. If an explanation is offered that has no concrete test that could disprove the explanation in principle, it is not a scientific one. This characteristic of scientific explanations is often the distinguishing one between scientific and other types of theories or beliefs (religious, astrological, conventional wisdom, etc.). Do understand that a scientific theory can be *incorrect* but still be considered a *good* scientific theory because it makes a testable prediction of what will happen under a given set of observing or analysis circumstances.

A Definition of Scientific Truth

Explanations and theories that correctly predict new results from new observations or experiments bring us closer to a true understanding of nature and the rules by which it operates. This true understanding of nature is what I call ``scientific truth'' in this text to distinguish it from other definitions of truth as in religious truth, for example. Scientific truths are based on clear observations of physical reality and can be tested through observation. Certain religious truths are held to be true no matter what. That is okay as long as it is not considered to be a *scientific* truth. Some things like love, honor, honesty, and compassion are known to be right or true without the test of experiments. Confusion between the religious and scientific types of explanation has been, and still continues to be, the source of a huge amount of conflict between many people. Yes, it is possible to be a scientist and a devout member of a spiritual faith---I know of many scientists who are serious practitioners of their religion. In fact, several significant advancements in science were made by clergy. In the astronomy history chapter you will find several examples of scientists who were guided by their spiritual faith. Not all scientists are believers in a spiritual faith just as not all non-scientists are believers in a spiritual faith.

Since this is a science textbook, I will focus on the scientific type of explanations. Whether or not you, the reader, chooses to *believe* what is discussed here is up to you. However, I want you to *understand* the physical principles discussed here and be able to apply them to various situations. The scientific method for finding scientific truth is discussed in more depth in the scientific method chapter.

Value of Astronomy in the Scientific Endeavor

Even though astronomers cannot do controlled experiments and are confined to observing the universe from locations near the Earth, the universe gives us a vast number of different phenomena to observe. Many of these things cannot be reproduced in Earth laboratories. There are gas clouds in such a rarefied state that they give off radiation not seen on Earth. Some objects are so dense that their gravitational fields bend light so much that it is prevented from leaving the object! Many things that are unlikely or impossible on Earth are routinely observed in the cosmos. Many of the scientific theories in other fields make predictions of what would happen under very extreme circumstances. Sometimes those extreme circumstances are the only situations distinguishing two or more contradictory theories. Unfortunately, the scientists of those other disciplines cannot test their ``wild'' ideas---is it hogwash or reality? Astronomy allows those theories to be tested. Very subtle and easily missed but crucial processes may be missed by observers focussing on the Earth, but the astronomer can see those processes magnified to easily noticeable levels in some other celestial object.

In addition you will see later that the light coming from far-away objects in all parts of the universe tells us about the laws of physics (the rules of nature governing how physical things interact with each other) there. Astronomers find that the laws of physics discovered here on the Earth are the same throughout the cosmos. The fact that nature makes nearly an infinite variety of things from the same types of material we have here on the Earth and has those things interact with each other in so many different ways using the same rules we see followed here on the Earth is awe-inspiring.

Now back to the long term evolution side of the coin. We actually have a time machine! Not the H.G. Wells variety or G. Roddenberry's Guardian of Forever but something much simpler due to the large distances and finite speed of light (300,000 kilometers/second!). It takes time for radiation from a celestial object to reach the Earth. Therefore, when you examine an object at a large distance from us, you see it as it *was*. The farther away the object is, the longer it took the radiation to reach the Earth, and the further back in time you observe it. The Sun is 150 million kilometers from us, so you see the Sun as it was 8-1/3 minutes ago. The farthest object you can see without a telescope is the Andromeda galaxy about 2.8×10^{19} kilometers from the Earth, so you see it as it was almost 3 million years ago. Recall that a **light year** is how far light travels in one year (about 9.46×10^{12} kilometers). Therefore, the Andromeda galaxy is almost 3 million light years away from us. (The speed of light is the key in the relationship between space and time, a fact used by Albert Einstein in developing his Relativity theories that are described in other chapters.

To study the evolution of long-lived objects like stars (with lifetimes of millions to billions of years) or galaxies, astronomers observe the objects of interest at different distances from the Earth so they are seen at different epochs. Therefore, the objects are seen at various different ages or evolutionary stages. Since light from remote objects can take millions to billions of years to reach the Earth, astronomers find out about the laws of physics at different times. What they find is that the universe has used the same laws of physics throughout its 15-billion year lifetime (and presumably will continue using those same rules). Pretty amazing!

Astrology

Many astronomy students take the class believing they are going to ``learn about the stars and planets.'' You will learn about these things! However, quite often when I probe a little more what people mean by that phrase ``learn about the stars and planets'', I find out that many people are thinking about astrology---a belief system in which the positions of the planets among the stars are thought to hold the key to understanding what you can expect from life. I find that even many of those who have a four-year college degree (including some college professors!) are thinking this when I tell them that I teach astroNOMY. Astronomy is a science, astrology is NOT. Today the two subjects are very different from one another, but hundreds of years ago astronomy and astrology were very similar to one another.

History of Astrology

Astrology began about 4000 years ago in the religions of Babylonia that believed the future of the nation and ruling class depended on the planets, Sun, and Moon and their motions. Astrology spread through most of the western world when the Greeks became the world power and incorporated the Babylonian culture into their own. The application of astrology expanded to all social classes---the planets were believed to influence every person, not just the ruling class. Eventually, people came to believe that the position of the Sun, Moon, and planets at a person's birth was especially significant.

While most astrologers were developing ways to predict the future of human events by careful observations of the sky, early *astronomers* were developing ways to predict the motions of the planets, Sun, and Moon. Most early astronomers were motivated by the idea that if they could accurately predict the motions of the planets then they would be able to accurately predict the future of persons. Astronomy broke away from astrology and became a science when astronomers became more interested in explaining what made the planets move the way they do and not in divining the future and interactions of individuals.

The Horoscope

The horoscope is a chart showing the positions of the planets, Sun, and Moon in the sky at a person's birth. Their positions are located in the **zodiac**---a narrow belt of constellations centered on the ecliptic. The **ecliptic** is the path the Sun takes through the stars throughout the year (as opposed to the arc it travels from sunrise to sunset). The zodiac is divided into 12 signs named after the constellations through which the Sun, Moon, and planets passes. Your ``sign'' is the zodiac sign which the Sun was in at your birth.

Right away you run into a problem with the zodiac constellations---some are large (like Scorpio or Virgo) and others are small (like Aries and Cancer). Because the rate that the Sun moves along the ecliptic is nearly constant, the Sun spends more time in the large zodiac constellations than in the small ones. It does not matter whether you use the ancient constellation boundaries or the modern boundaries recognized by the International Astronomical Union (though, the IAU boundaries have the Sun spending part of its time in the non-zodiac constellation Ophiuchus!). However, the dates listed in the newspaper for the horoscope signs are all 30 or 31 days long (even for tiny Aries) and the horoscopes do not include the constellation Ophiuchus.

Because of an effect called precession, the zodiac constellations slide westward along the ecliptic, making a complete circuit in about 26,000 years. Since the zodiac signs were named over 2000 years ago, the stars have moved by about 1/12 of the zodiac (about one sign's worth). Your ``sign'' may be one month off! (The different sizes of the constellations prevents me from making a more definite statement.) For example, if your sign is a Sagittarius, then the Sun was actually located in the constellation Scorpio when you were born. Actually, for part of the Sagittarius timeframe, the Sun is in Ophiuchus, so perhaps that is not a good example (what do you think?).

The horoscope includes the position of each planets in the zodiac and where they are with respect to the person on the Earth at the time of his/her birth. Because of this, creating a horoscope is a bit complicated. There are some standard rules (most of which have not changed for thousands of years despite the dramatic improvements in our knowledge of how the planets and stars move), but how much emphasis an astrologer will give to each rule in developing the horoscope, depends on the creativity of the astrologer. This lack of objectivity is one reason why astrologers cannot agree on the right prediction for any given person. *Unlike astronomy, astrology does not have clear objective observations of nature (experiments) determine the truth.*

Testing Astrology

There is no known *physical* force from the planets that can have any effect on a person at the moment of birth. The only possible force would be gravity but the gravitational pull of the obstetrician delivering the baby is greater than the gravity from any of the planets! The Earth's gravity on the baby is tens of thousands of times stronger than the gravity on the baby from the Sun or Moon. Astrologers are forced to invoke mystical forces for which there is NO physical proof.

Many people read their horoscope in the newspaper not to get a prediction of what will happen to them, but, rather, to get advice on what they should do in the day (in the United States the horoscope columns focus on who to date and how best to gain money). A person who is serious about using astrology to guide their actions should consult several horoscope columns every day to be sure they have the most accurate information. Unfortunately, that person would find out that the horoscopes for him/her are not consistent with one another even though the horoscopes are phrased as vaguely as they are. Astrology is not as systematic as it claims to be.

Many tests comparing the birthdates of national or state leaders have found the birthdates to be randomly distributed among the twelve signs. If astrology could determine a person's future or his/her personality, then the leaders should have birthdates in one or two signs. Other tests on the birthdates of those who *re-enlist* in the Marines have also found a completely random distribution of birthdates among all of the signs. A recent episode of NOVA (on PBS) showed a researcher testing astrology by giving each person in a college class of astrology believers their own individual authentic horoscope. Not surprisingly, they found some event in their day that fitted their horoscope. The students then gave their horoscope to the person sitting behind them. To their surprise or dismay, the students discovered the substituted horoscopes were just as good! (Yes, the students had birthdays spread throughout the year.) There are numerous cases of twins or triplets having different personalities and life events even though their birth times and places were very close to one another.

Usually, those who seek out astrologers just want some guidance of any kind. If they feel the horoscope interpretation was prepared just for them, then they will find agreement with reality. To test this, Michel Gaugelin (a French researcher) sent a horoscope of a mass murderer to 150 people but told each one that the horoscope was prepared just for him or her. Over ninety percent of them said they could see themselves in that horoscope. If a person is already convinced ahead of time of the validity of something like a horoscope or a psychic's prediction, then he or she will be easily able to use his or her natural problem-solving capabilities and creativity to make sense of the vague, even contradictory statements. The Australian researcher Geoffrey Dean substituted phrases in the horoscopes of 22 people that were opposite of the original phrases in the horoscopes. Ninety-five percent of time they said the horoscope readings applied to them just as well as to the people to whom the original phrases were given. An astrologer relies on her client's ability to create meaning in even random data and to fill in the gaps of incomplete information if some context is given (or if the creative client makes up a context himself). The astrologer's predictions will always be ``correct'', not testable as a scientific theory or prediction must be.

Further Testing of Astrology

What other tests of astrology can you come up with? Perhaps you might try setting up a study of astrology predictions with your classmates and friends. Ask them about what happened to them yesterday and then compare that to what the horoscope in the newspaper said should have happened. Should you look at their horoscope before you ask them what happened? Would that bias how you interpret what they tell you or would it help you ask appropriate questions to jog their memory? If your astronomy class is large enough and everyone in the class is involved in the study, you will probably have several people sharing the same zodiac sign and comparisons can be made. Be sure to keep track of both positive and negative results. You will need to decide how much of the horoscope prediction should be valid (the whole thing or at least one point?). Your astronomy professor may have other suggestions for possible tests.

For Further Exploration

1. Andrew Fraknoi's Astrology Defense Kit. Select the link to view it.
2. Andrew Fraknoi's pseudoscience bibliography. Select the link to view it.
3. Kendrick Frazier's article in *Skeptical Inquirer* vol. 10, Spring 1986 ``Double-blind Test of Astrology Avoids Bias, Still Refutes the Astrological Hypothesis''. Reprinted in *The Outer Edge* p. 40, eds. Nickell, Karr, & Genoni (CSICOP, Inc., 1996).
4. Ray Hyman's article in *The Zetetic* Spring/Summer 1977 ```Cold Reading': How to Convince Strangers That You Know All About Them''. Reprinted in *The Outer Edge* p. 70.
5. Paul Kurtz's and Andrew Fraknoi's article in *Skeptical Inquirer* vol. 9, Spring 1985 ``Scientific Tests of Astrology Do Not Support Its Claims''. Reprinted in *The Outer Edge* p. 36.

Vocabulary

astrology	**ecliptic**	**model**
zodiac		

Review Questions

1. What is the scientific method? Give a description of each of its parts. (See the scientific method chapter for more on this).
2. How are controlled experiments helpful in understanding the rules of nature?
3. What is a scientific **model** and what must the model be able to do to be useful?
4. How can an incorrect scientific theory still be considered a good scientific theory?
5. What distinguishes a scientific truth from a religious truth?
6. In what way can scientists use astronomical observations to find the correct explanations for physical events here on the Earth?
7. How do we know that the laws of physics on the Earth are the same throughout the rest of the universe?
8. How do we know that the laws of physics are the same throughout time?
9. How is astrology different from astronomy?
10. Why is astrology not considered a science?

Go to Astronomy Notes beginning

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In your astronomy course you will cover a lot of explanations as to how the universe and its constituent parts work. All of these explanations were arrived at by using the scientific method in one form or another. One goal of this web site is to give you some familiarity with the process of science and how its tools are used to find out about the physical reality around us. Hopefully you will find the method of science a useful one to use in your future to understand the physical universe. The scientific method and the tools of science are powerful tools of knowledge, but there are limits to its applicability and certainty.

There is confusion of what is ``scientific" and what is ``non-scientific" in the popular media today and undoubtedly you've heard testimonies of one science expert or group contradicting the testimony of another science expert or group. What is the truth? How do we know? How do we tell the difference between mere opinions and real accurately predictive explanations? We will use astronomy as a vehicle to arrive at an answer to these important questions. With all the material we cover in this course, it will help to keep the approach of the two-year-old (or rebellious teenager) in mind. Ask yourself, ``How do you know that's right?" and ``Why does that happen that way?" What follows is a close adaptation of a chapter from Ronald Pine's book *Science and the Human Prospect.* I would recommend this book be a part of your personal library. The vocabulary terms are in **boldface**.

A Scientific Theory Is...

What distinguishes a scientific theory from a non-scientific theory is that a scientific theory must be refutable in principle; a set of circumstances must potentially exist such that if observed it would logically prove the theory wrong.

Here is a simplified version of the logic of the scientific method: we begin the encounter with nature by making observations and then through some creative process a **hypothesis** is generated about how some process of nature works. On the basis of this hypothesis, an experiment is logically deduced that will result in a set of particular observations that should occur, under particular conditions, if the hypothesis true. If those particular observations do not occur, then we are faced with several possibilities: our hypothesis needs to be revised, the experiment was carried out incorrectly, or the analysis of the results from that experiment was in error.

The actual process often involves a great deal of insight and creativity. Keep in mind, though, that this interpretive process may have biased the outcome or conclusions. This point will be addressed later. For now, simply note that without a disconfirmation being possible in principle, a belief is not acceptable as even a potential *scientific* hypothesis. *There must be a possible concrete test.*

Summary

- A scientific theory must be testable. It must be possible in principle to prove it wrong.
- Experiments are the sole judge of scientific truth.
- Scientific method: observations, hypothesis/theory, experiment (test), revision of theory

Correlations May Not Prove the Cause

Often the observation of a **correlation** between two observables is used to proclaim a cause-effect relationship between them. For example, suppose that there was a possible correlation between sex education in schools and a recent rise in venereal disease and teenage pregnancy. One could say that sex education has caused the rise in VD and teen pregnancy, but the scientist cannot say that without a more detailed investigation.

After all, there are many other factors that could be the causal agent behind this problem. A rise in the population of teenagers is possible, causing every activity related to teenagers to go up: automobile accidents or purchasing particular types of clothing and albums. Few would claim that sex education in schools has been the cause of increased purchases of acne lotion. There could be an increase in the population of particular types of teenagers, those in an area of the country where sex education is not taught or where early sexual experimentation is encouraged by various social or family pressures. There are many variables possible to produce that correlation. *Correlation does not prove causation.* A correlation between sex education and teen sex problems does not prove a causal connection, and, by itself, it does not give us a clear indication in which direction there may be a connection. For all we know at this point, an increase in teen sex problems has led to an increase in sex education classes!

Another example is the correlation between smoking and lung cancer occurrences. After a couple of decades of study the government decided in the 1970s that there was a causal connection between smoking and lung cancer and changed the warning label from ``Caution, smoking *may* be hazardous to your health" to ``Caution, smoking *is* hazardous to your health". A 1950s study only controlled the basic environmental variable-lung cancer for smokers living in the cities vs. lung cancer for smokers living in the country. This study was roundly criticized and rightly so. There were many other important factors that needed to be looked at such as diet, healthy or unhealthy occupations, stressful occupations, or genetic factors.

By the 1970s, more careful studies each incorporating tighter and tighter controls based on possible oversights of the previous studies had proven to the government's satisfaction the causal connection between smoking and lung cancer. By the 1980s other diverse corroborating factors had been identified-from the effects of secondhand smoke to chemical analysis of cigarette smoke revealing over 200 toxic substances, including radioactivity.

Despite all of this study, we really cannot say that cigarette smoking has been *proven* to be the principal cause of lung cancer. A scientific proof is not known with absolute logical certainty. A controlled study can never be completely controlled-there are just too many possible variables. The link between smoking and lung cancer cannot be known in the sense of ``known beyond any logical or conceivable doubt." The point is, however, can we say we know that cigarette smoking is a principal cause of lung cancer beyond a ``reasonable doubt"? Is it rational if we claim to know something even if we are not absolutely sure that we know something? Can we distinguish between what is ``conceivably" true and what is ``reasonably" true?

A humorous example of the difference between a correlation and a cause-effect relationship is the Coalition to ban Dihydrogen Monoxide. To find out more about this ``dangerous" chemical, select the links below:

1. Ban Dihydrogen Monoxide!
2. Coalition to ban DHMO headquarters.
3. Dihydrogen Monoxide Research Division.

Summary

- A correlation between two things does NOT prove one thing *causes* the other. The second thing could cause the first or some other underlying factor could cause the correlation.
- Scientists have to be very careful to rule out other possible underlying factors before concluding one thing *causes* something else.
- Though scientific proofs are not known with absolute certainty, enough evidence can be accumulated to be reasonably certain.

The Problem of Induction

Science has the **problem of induction:** *No matter how much evidence we have for a conclusion, the conclusion could still conceivably be false.* The best we can say is that it is ``unlikely" that our conclusion is false when we are using inductive reasoning. Here's an example: suppose there is a barrel filled with 100 apples and the first apple I pull out off the top is very rotten. Few would wager from this single apple that we know *all* the apples in the barrel are rotten. However, small amounts of evidence need not always be weak. A biologist might be willing on the basis of this one apple to wager that all of the apples are likely to be rotten, if other information were provided like what temperature the apples were stored, and for how long, because of her general knowledge of bacteria and their ability to spread rapidly. If we have some world view or **paradigm** (a framework of a general consensus of belief of how the world works), we can do a lot of hypothetical work with just a few observations.

But without anything else to go on, concluding that all the apples are rotten from a single positive case is a very weak inductive inference.To make the inductive inference stronger, more apples need to be sampled. If I pull out 4 more apples off the top and all of them are also rotten, we'd now have a better basis for concluding that all the apples are rotten. This is called **induction by enumeration.** In general, *the more positive cases in favor of a hypothesis, the stronger the hypothesis is.* But how about the apples at the bottom? A stronger case could be made by choosing a **representative sample**---a sample that matches in characteristics the total population of things under investigation. In the case of the barrel of apples, a representative sample could be gathered by selecting one from the top, one from the very bottom, one from each side of the barrel, and one from the middle. If all five are rotten, this would strengthen the hypothesis considerably. *A small representative sample is much stronger logically than is a large unrepresentative one.* Five representative apples are better than 20 just off the top.

If you found that another 45 were rotten, would you bet your life savings that all the remaining 50 were rotten? Probably not, since it is still possible that some, even many, of them are not rotten. If you found that another 49 were also rotten, would you bet your life savings that the last remaining apple was rotten? Most people would, but they'd still have a lot of anxiety as the last apple was pulled from the barrel because it was still possible that the hypothesis, ``all the apples are rotten," was false. Hypotheses can only be confirmed, not logically proven to be true. Understand that *it is possible to deduce true conclusions* (the 5th apple will be rotten) *from premises that may be false* (all the apples are rotten). Because we can deduce true predictions from a false theory, no matter how long a theory has been successful in making predictions, it cannot be known to be true absolutely. It could be found to be false tomorrow.

Critics of science often attempt to use this logical window to repudiate many scientific conclusions. They also often commit the logical fallacy of appealing to ignorance, arguing that because the theory cannot be proved absolutely true, it must be false. But absence of evidence for absolute proof is not evidence of absence of truth. Critics of science fail to recognize the positive aspect of this logical doubt. Without room for doubt, there would be no room for self-correction, and we would be left with a cluttered clash of irrefutable beliefs.

Summary

- No matter how much evidence we have for a conclusion, the conclusion could still conceivably be false.
- The more positive cases in favor of a hypothesis, the stronger the hypothesis is.
- The most logically sound samples are those that are representative of the entire set.
- It is possible to make true conclusions from false assumptions.
- A hypothesis can only be confirmed but it cannot be proven absolutely true.
- Even though a scientific hypothesis cannot be proven absolutely true, that does not mean that it must be false.

Science as a Human Endeavor

We probably won't have time to analyze fully the evidence for every claim made in this course but keep in mind that this critical attitude lies behind all the explanations presented. Science does not claim to know all the answers. It does, however, claim to provide us with a method of test and interaction by which we can become more and more intimate with the physical universe.

Because science is done by human beings, many aspects of our humanity also play a role in scientific discovery: artistic creation and imagination, political manipulation and personal exploitation, wishful thinking, bias, egocentricity, critical review, and premature skeptical rejection. At its best, however, there is only one absolute truth: that there are no absolute truths. Every solution to a mystery creates new mysteries. Science is a game that never ends, a game whose completion would render life boring. Science then involves a logical process that is fallible, and it involves much more than just a logical process. Every scientist and the science of a time are subject to the forces of human nature and culture. Scientists are forced to make many assumptions; some are conscious and some are not.

Assumptions of Scientists

Let's take a brief look at some these assumptions or philosophical backdrop. Many scientists today will claim they are interested in *how* things work, not *why* they work as they do, because a scientist's task is to conduct experiments, make observations, and find mathematical connections. Influenced by a philosophical tradition known as **positivism,** these scientists will want to know what atoms will do, for instance, not what they are. Or, rather than trying to understand why gravity is attractive and not repulsive, these scientists figure out how the gravitational attraction affects the interaction of objects.

Another position held by many (but not all) scientists consciously or unconsciously is known as **materialism.** Metaphysical materialism states that there is no evidence that anything called ``mind'' exists and that all that exists are concrete material things, forces, and empty space. However, the scientific method does not depend necessarily upon making this assumption. Some have argued that recent developments in physics and neurophysiology warrant a reexamination of this question.

Some scientists have even held a position that is a form of classical **idealism,** believing that the universe can be best understood by assuming that ``thought'' or ``consciousness'' is the most fundamental reality. Certain mathematical concepts are ideas in the mind of God and that any physical reality, such as the motion of a planet, must conform to these ideas.

Summary

- Science provides a way of testing and interacting with the physical universe that will better our understanding of the physical universe.
- Science is a human effort and is subject to all of the best and worst of cultural biases existing at the time.
- Most scientists are interested in *how* things work, not *why* things work they way they do.
- Though the assumption is not necessary for science, many scientists assume that science needs to consider only the physical, concrete objects around us.
- Some scientists assume that thought or consciousness is the most fundamental reality.

Ways of Finding the Truth

Some science critics claim that science is absolute and dogmatic in terms of how it approaches the best way of knowing something. Much of our personal knowledge is based upon **testimony.** Someone may tell me that Bogus Basin, just 30 minutes from Boise, ID, has great skiing. If I believe this even though I have only skied at Snoqualmie or Stevens Pass, my belief is based on testimony. Sometimes the testimony is based on **authority,** as would be the case if an Olympic gold medalist told me about Bogus Basin. Many religions claim that **revelation** is a valid method of knowing, whereby important truths about life, impossible to find out any other way, are disclosed to human beings by a divine being or God. Mystics, in general, claim that after years of special training it is possible to know some very important things about life and the universe ``intuitively'' or in a **mystical vision** while in a deep state of meditation. Mystical visions are not necessarily revelation, because the visions not only involve personal effort and training but also do not necessarily involve divine aid or God.

Science's Way of Finding the Truth

Science assumes the position of **empiricism,** because *observational experience is necessary,* either indirectly via robot sensors and cameras or directly through human senses to understand the physical universe. *The experience must be objective and communicable or describable in public language.* Another way of knowing often opposed to empiricism, but historically greatly influenced by the discovery and development of mathematics, is called rationalism. The rationalist has a great faith in the logical power of the human mind and is skeptical about the universal validity of our observational perceptions. Some things are so clear logically or mathematically that we just know that they are true, like the absence of round squares on the dark side of the Moon. We know that round squares are impossible. The rationalist believes that we can know some things about life ahead of time, so to speak; we can know some things that no conceivable experience will contradict.

It is difficult for many people today to imagine that the Earth is moving and not the Sun. We do not experience ourselves moving at 1,000 miles per hour; instead we ``observe'' the Sun to move. That a belief is inconsistent with our common observational experience is not by itself a conclusive argument that it is false. Empirical scientists do believe in the ability of the human mind to figure things out. Any fundamental inconsistency between common sense and reason is seen as nature's way of taunting us, of revealing one of her important secrets. The confidence in the logical and mathematical powers of human thinking has been a key ingredient in the development of modern science.

Theory Must Agree With Reality

The modern scientific method synthesizes rationalism and empiricism. The logic of the rationalist is combined with the observational experience of the empiricist. There is an overwhelming consensus, though, that empiricism is the main emphasis. *No matter how much logical deduction and mathematical analysis is used, at some point the world must be checked for the confirmation of a belief.* Historically, however, spurred on by the power of mathematics and the tendency to conclude that we know something even though complete empirical observations are not available, rationalism has played both a constructive and creative role in development of science. The criticism of those who are too rationalistic and who create ivory-tower fantasies from speculative logic, overlooks the fact that many great discoveries have been made by scientists sitting at desks, following the elegant trails of mathematical equations. Creative ideas are the result of a complex web of influences. *The key is to have ideas with which to make connections.*

Of course, not all ideas are fruitful in making connections. Nor have great scientists been immune from detrimental rationalistic tendencies. Tycho Brahe was the best observational astronomer of the sixteenth century. Mathematically, he knew that one of the implications of his extremely accurate observations of planetary motions was that the Sun was the center of motion of all the planets, which further implied that the universe was very large and that the stars were an immense distance away. He could not bring himself to accept this radical conclusion, however, and accepted instead a more traditional view for his time because God would not be foolish to ``waste'' all that space!

Johannes Kepler, who used Tycho's data to finally solve the problem of planetary motion, was motivated by his belief that the Sun was the most appropriate object to be placed in the center of the universe because it was the material home or manifestation of God. Galileo, in spite of his brilliant astronomical observations and terrestrial experiments, failed to see the importance of Kepler's solution of planetary motion because it did not involve using perfect circles for the motion of the planets.

Summary

- Possible ways of knowing: testimony, authority, revelation, mystical visions, scientific method.
- Observational experience is a crucial part of scientific knowledge.
- The experience must be objective and communicable in public language.
- Scientific theories must logically agree with known physical truths or well-established physical laws.
- No matter how much logical deduction and mathematical analysis is used, the scientific theory must be checked against the real world to confirm the theory.
- However, the exploration of the implications of a logical train of thought is a vital part of the scientific process.
- The best ideas are those that enable us to make connections between rational theories and the physical world.

Is the Scientific Method the Only Way to Truth?

Must science assume some ideas dogmatically? Must we assume that the scientific method, a synthesis of reason and experience, is the only avenue to truth? The mystics claim that some simple acts of knowing cannot be described by an objective language. Consider the experience of seeing a death on the highway. Does a cold scientific description, ``the cause of the cessation of bodily function was due to a rapid deceleration," accurately convey the truth? What about our own deaths? There seems to be much more to the truth that we will die someday than can be described in the statement ``I am mortal." Are there subjective truths that cannot be described in an objective language?

Ideas Change, Physical Laws Do Not

Most scientists today accept an assumption that can be traced to the ancient Greeks: *Whatever they are, the basic truths of the universe are ``laws" that do* not *change-only our ideas about them do.* Scientific objectivity presupposes that there is one truth, a collective truth, and our personal beliefs or the beliefs of scientists of a particular time either match these truths or they do not. Most scientists assume that beliefs about what is real do not affect what is real. Truth results only when our beliefs about what is real *correspond* to what is real.

Perception Changes Reality?

This traditional assumption may not, however, be essential to science. Some quantum physicists have proposed that the points of view implied by our experiments can affect the nature of reality: instead of assuming that there is only reality, there can be ``complementary" realities. And reputable physicists and medical researchers are not only reexamining this traditional scientific assumption, but also are wondering candidly if a person's state of mind may have a bearing on whether he or she is prone to diseases such as cancer and whether cures and remissions are possible using a mental therapy. The belief that there is only one reality can itself be subjected to scientific scrutiny. There could be multiple realities or none at all! Even if controversial, these ideas are at least discussed.

Value of Examining Assumptions

Although we may be caught at any given time within a web of many assumptions, science at its best does not rely on many assumptions. Science also assumes that the more we think critically about our beliefs, the more likely we are to know the truth. There are cynics, however, who believe that critical thinking is not a marvelous human characteristic at all. They argue that critical thinking makes life more complicated and distracts us from discovering the simple solutions to life's problems. There are also nihilists who argue that our so-called intelligence and our ability to be aware of the details of the universe are an evolutionary dead end, that far from producing the good life, our awareness and rationality are the cause of our craziness.

Defenders of science often argue that even if some assumptions are necessary in the application of scientific method, these assumptions are validated by the record of success. However, there is a major logical problem with this justification. It simply raises the problem of induction again. It is circular reasoning to attempt to vindicate inductive reasoning by asserting that so far inductive reasoning has worked, because this vindication itself is an inductive argument. It is logically possible for the scientific method to completely fail tomorrow even though it has been successful for centuries. Is it reasonable to continue to believe in the scientific method as helpful for our future? Can science be self-corrective? Philosophers believe these abstract questions are important because they are intimately related to our more personal concerns about who we are, where we have come from, and what may be in store for us in terms of the survival of our species on this fragile fragment of the universe.

Summary

- A basic assumption of science: fundamental physical laws do exist in the universe and do not change. Our understanding of those laws may be incorrect or incomplete.

- Recent developments in our knowledge of the universe seem to challenge this basic assumption. Our perception *may* affect the physical laws or events.
- Scientists must be aware of the assumptions they make and how those assumptions affect our understanding of the universe.

Go to Astronomy Notes beginning

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Logic of Discovery? Beliefs and Objectivity

Often a mathematical idea or model is discovered with no apparent application to the physical world until many years later. This aspect of pure, basic scientific research is not popular among government officials who want practical applications NOW! How are scientific discoveries made? There are several views about how we make discoveries and why humans are able to do this.

Kepler believed that there is a *creationary resonance* between the human mind and the laws of nature. In this view God creates humans with the gift of reading the mathematical harmonies of God's mind. It is only a matter of time for someone to discover God's plan. A more modern view held by some says that there is an *evolutionary resonance* between the human mind and the laws of nature. Given the infinite variety of paths of evolution, it is inevitable that creatures will eventually evolve capable of reading the laws of nature. In this view, scientific progress is inevitable.

Is creativity actually a logical process in disguise? It is a common belief today that one's religious/philosophical beliefs are merely along for the inevitable revolutionary ride and are not necessary to make revolutionary scientific advances. Some believe that there are many technically-capable paths by which the universe can be modeled. Kepler's neoplatonism was not logically necessary for the discovery of the planetary laws of motion, but, historically, it may have been absolutely necessary for his time and place.

Every age has its paradigms. Though scientists try to be objective, philosophical considerations do intrude on the scientific, creative process. That is not a bad thing because these beliefs are crucial in providing direction to their inquiries and fuel for the creativity mill. Scientists have faith that there is some order in the universe and this faith keeps them striving to solve the cosmic problems.

Facts have little meaning without ideas to interpret them. Because science is a human discipline, there is no machine-like objectivity. Often crucial facts supporting an idea come after a commitment is made to the idea. So is science then all based on an individual's whim; relative to the scientist's time and place? The self-corrective enterprise of science is messier than most science textbooks would have you believe. Besides the inevitable cultural prejudices, scientists have, in principle, an infinite number of conceivable ideas to choose from. How do you separate reasonable ideas from the infinite number of merely conceivable ideas?

Sure, there are cultural biases, but science does make us confront the real world---reality kicks back. You can ignore the discrepancies between nature's truth (observations) and your theories of what should happen only for so long. Experiments are the sole judge of scientific truth---nature eventually wins. The ideas are crucial to understanding the world but they eventually yield to the facts. Science makes us confront the world.

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