Method for Finding Scientific Truth

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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 Dihydrogen Monoxide. 3. Coalition to ban DHMO headquarters. 4. 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.

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