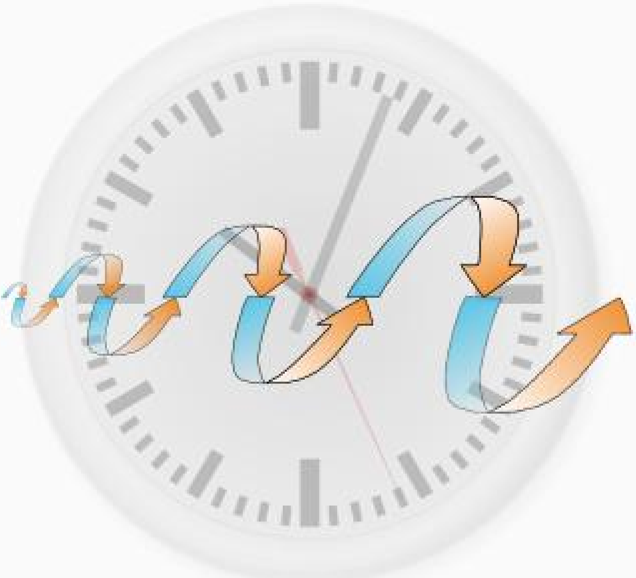
The Philosophy of Science



A brief introduction

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The Philosophy of Science

A very brief introduction to the philosophy of the scientific method.

The Philosophy of Science

The philosophy of science looks into what we call the scientific method. It seeks to answer questions like:

- What's the best way to investigate nature?
- How confident can we be that what science tells us is correct?
- How can we discriminate good science from bad or pseudo-science?
- Does science help us to understand what the universe actually is?

The philosophy of science crosses several areas of philosophy. Epistemology, which is the study of knowledge, distinguishes reliable knowledge from belief and opinion. Reasoning deals with how we should organize our thoughts to arrive at valid conclusions. Empiricism is about deriving knowledge from things that we can actually see, hear, touch etc. Metaphysics seeks a mental framework or world-view that best complements the empirical knowledge that comes from scientific measurements and observations. In terms of Plato's cave, we can think of empiricism as studying the shadows on the cave wall and metaphysics as imagining what we might see if we could look outside the cave.

In case you are not familiar with the scientific method, it is the way that scientists go about a scientific investigation. This usually starts with a specific question that science aims to answer. The search for answers will include experiments and the method will ensure, for instance, that they are objective and repeatable. Having obtained data from observations or measurements, the next step is to analyse the data. This virtually always involves the use of mathematics. Scientists try to explain patterns in the data in terms of causes and effects. These explanations are developed into one or more hypotheses. Further experiments may follow to test the hypotheses leading to a cycle of experiment-hypothesis-experiment-hypothesis. Finally, a series of investigations may result in the publication of a complete theory. A theory will show how experimental results back up a significant new understanding of nature's phenomena and make predictions of the results of future experiments.

The scientific method has not always existed and in fact scientists, until quite recently, were called "natural philosophers". Nature, in this context, means the whole of reality, not just biological nature. Several of the famous classical philosophers had things to say about how nature works. For instance, they described a universe in which the Earth was at the centre. They identified four natural Elements: earth, air, fire and water. They even had an explanation for why things move, known as Teleology. Motion was thought to be due to elements tending towards their correct place. Air and fire want to go up; earth and water want to go down. So the elements were not seen as passive stuff that just sits there doing nothing. Elements were seen as stuff that moves all by itself. Somehow it knew its rightful place and tried to get there.

Another concept that went along with active elements was Atomism. You could always break big things down into smaller and yet smaller things. It was supposed that there must be some point at which you arrive at whatever elements are made of, little bits of indivisible stuff moving through the void. These classical ideas, that nature was made of material stuff, have persisted until this day. It is what philosophers call materialism but this term hides the very important notion that the material moves, changes and interacts in ordered ways. It is strange, when you think about it, how we glibly accept that inanimate stuff acts all by itself or by the influence of invisible forces.

In the early 1600's, Sir Francis Bacon, the philosopher and statesman, established a scientific method with the rather arrogant aim of giving mankind dominion over nature. He put in writing a sort of recipe of how science ought to be done. Scientists who followed this method could all repeat and therefore check each other's work. The method started scientific Empiricism, ensuring that data would be gathered directly from nature itself. Scientists' conclusions were required to be drawn from actual observations and measurements. As a consequence, the importance of experiments with strict record keeping was established. The specifics of the scientific method have changed since Bacon's days but the principles are still those put forward by Sir Francis.

Bacon also brought the use of inductive reasoning to science. Ancient philosophers had used what's called ablative reasoning, essentially just intelligent guessing, which can only be tested by judging the strength of the argument. Inductive reasoning is a big step up from this. It is the drawing of general conclusions from a wide body of evidence. It is a bottom-up rationality: starting with what we can observe or measure, then seeking general principles that might explain what we discover. For example, if scientists find that gases expand when heated, they can propose the general conclusion that all gases expand when heated. This hypothesis can then be tested on all newly discovered gases. Inductive reasoning does not lead to cast iron proof because conflicting evidence may be found in future. But it does add weight-of-evidence to strength-of-argument as a test for the validity of scientific knowledge. By the way, Sir Francis Bacon had been Attorney General, Britain's chief law officer, so he was used to accepting strong evidence as an alternative to proof. To summarise, the key features of the scientific method are repeatability, through a well-defined systematic method; empiricism through observation and measurement of nature itself; and inductive reasoning, which adds weight of evidence to strength of argument.

The scientific method turned out to be amazingly successful. Galileo, by making and using telescopes, started astronomy as we know it. He confirmed Copernicus's description of the heavens with the sun at the centre and the earth relegated to just another planet going around it. Galileo also made great advances in understanding how things move. Myth has it that he had two objects of different weight dropped from the leaning tower of Pisa. They both hit the ground at the same time, showing that gravity accelerates all objects at the same rate. Then there were Sir Isaac Newton's physics. Newton explained how and why things move using the concepts of mass, force and acceleration. For instance, he explained the motions of planets (and apples from trees) using gravity. Newton also explained how white light is made of all the colours of the rainbow. Many other scientists, too many to mention here, developed new theories using the scientific method. The industrial revolution grew out of this success. The feeling began to grow that science had all the answers, even for metaphysics. Science seemed to indicate that we live in a universe that behaved like a machine. This period was known as the Age of Enlightenment because human reason replaced tradition and superstition as the source of knowledge.

In the 1700's, David Hume, a Scottish philosopher, launched a strong attack on the scientific method. He recognized its success in describing how nature behaves but argued that many of its concepts should not be treated as true knowledge. Hume was very strict about what constitutes knowledge as opposed to belief. According to Hume, you can observe raw facts with your own senses and you can deduce facts using logic and mathematics. Everything else involves an element of belief. Every time that science uses inductive reasoning to draw general conclusions from experiments, it is believing that the same experiments will always give the same results. It is believing that nature has a strict unchanging order of cause and effect. In short, inductive reasoning embodies beliefs about nature that may be wrong.

Hume also objected to science's use of man-made concepts in its theories. As an arch-empiricist he was deeply sceptical of anything that we cannot sense directly. Take, for example: energy, atoms and gravity. Hume accepts that these are useful metaphors for whatever really exists. Science needs to use such concepts in its mathematical book-keeping. But, according to Hume, we have no justification in taking them literally. They are human inventions, contrived to explain experimental data. There will be many different concepts that would also explain the data. We cannot know that we have found the correct concepts and the true explanations. We can only believe that we have.

Hume's scepticism seems pedantic. He implies that nothing less than perfect, logic-backed proof will do. Others pointed out just how successful the scientific method had been. Surely it would be a miracle if science had succeeded while being fundamentally wrong. Nature did seem to obey strict laws and be the same today as it was yesterday. But nobody could fault Hume's arguments so his attack carried weight.

Moving on to the 1800's, Auguste Comte, a French philosopher, rescued science from Hume's attack but only by diminishing the scope of science. He said that the scientific method was justified in explaining how nature works but it was not justified in stating what actually exists. Science goes too far when it strays into metaphysics. Comte coined the term Positivism, derived from the French word for imposed, and expressing the idea that knowledge can only be imposed on the mind through the senses. And crucially, the senses can only detect *what* happens, not why. He argued that societies pass through three phases as their knowledge grows: theological (gods as causes) metaphysical (unobservable things as causes) and finally Positive (no causes.) In short, we stop trying to explain why things happen. Comte's point was that science is valid, so long as it rejects the metaphysical from its method, just as it had earlier rejected the theological. Where the enlightenment had diminished the role of religion as a source of knowledge, the Positivists now diminished the role of science. Science could give us a toolbox to predict and control nature but neither science nor anything else could tell us what reality actually is.

In spite of Hume, Comte and many other sceptics, by the later 1800's, there were scientists who believed that science was nearly complete. Science had reached a very good understanding of the workings of nature. There were still a few T's to cross and I's to dot, and more decimal places to reach but the age of great scientific discoveries was drawing to a close.

Then, into the 1900's, two major discoveries in science changed everything. One was Einstein's relativity. He started out trying to explain why light, when measured, always has the same speed even if you are moving when you measure it. Speed is distance divided by time (e.g. miles per hour). If the speed of light is always fixed, Einstein reasoned, it must be our scales of distance and time that vary. Einstein concluded that distance and time were relative, not fixed. So, things moving at or near to light's speed seem to have miles of different length to our miles and clocks that run slower than our clocks. He also suggested that mass literally distorts space and time, and found that this idea gave a much more precise account of gravity. If this all seems counter-intuitive, it gets worse: Relativity allows space and time to be distorted enough to make time travel possible. Yet we never see visitors from the future. And what if you went back in time and killed your parents? You wouldn't be born... so you wouldn't kill your parents...so you would be born.

The other great discovery was Quantum Theory, led by Danish physicist Niels Bohr. He was investigating what goes on inside atoms. Bohr found that what we thought were particles inside atoms did not move like ordinary objects. They disappeared from one place and appeared at another. It's as if we can only see a particle in a sequence of snapshots. The particle is here now and there later, but we never see it move. And in getting from here to there, a particle can take what seems like impossible routes: around corners, through solid objects, even many different ways at once. So Quantum Theory, like Relativity, raises deep paradoxes. Whatever atoms are made of, it certainly isn't ordinary material objects. Quantum Theory casts doubt on the very existence of material, at least in the naive form that we tend to think about it in everyday terms. Whatever nature is, it isn't like a machine made of moving parts. You may be tempted to doubt Quantum Theory and Relativity. Yet these two theories have turned out to be science's most successful theories ever. They have both been around for about one hundred years and have been confirmed by experiments more than any other theories. Quantum Theory and Relativity are now our best tested and most accurate theories of all time. Yet they both seem like nonsense when we relate them to our everyday experiences.

Those who thought that science had done it all must have been shocked. In just a few decades, the naive materialist view of nature was overturned. Relativity and Quantum Theory both showed that, deep down, nature is not made of ordinary material objects. Space is not an empty stage but is shaped by what goes on on-stage and whatever is on that stage, it isn't little bits of stuff whizzing around. This all sounds paradoxical in the context of our everyday experience where we think of things as static or moving material. Bohr and Einstein famously argued about the metaphysical implications of their theories but they couldn't agree. Einstein was sure that nature was made of material particles, in spite of Quantum Theory. Bohr was sure that Einstein was wrong. Yet he allowed the concept of a particle to live on, even though quantum so-called particles are unlike anything that you or I would call a particle. Bohr justified this by coming up with what became known as The Copenhagen Interpretation of Quantum Theory. It presents a correspondence between the **properties** of quantum things like electrons and classical things like bullets. But the correspondence is strained because the **behaviour** of an electron is highly abstract and nothing like a bullet. Only when one takes the average behaviour of millions of electrons does the behaviour look bullet-like. So we are left with real objects being "made of" abstractions that are called particles yet are not actually particle-like. By the way, Einstein did not accept the Copenhagen Interpretation but Bohr won because the Interpretation still stands to this day.

Around the same time as the Copenhagen Interpretation was coming into existence, philosopher Karl Popper was looking at the scientific method from a different angle. He was seeking to understand what distinguishes science from pseudo-science. He saw that the metaphysical implications of ordinary physics had been squashed but he knew that Newton's physics was outstanding at describing how nature behaves at everyday scales. In fact, most of Newtonian physics is still used today, even for space navigation. Popper noted that some non-science disciplines claimed to follow the scientific method yet their theories seemed to be much more doubtful than the theories of physics. Two examples are Marx's sociology and Freud's psychology. So Popper set out to distinguish "good" science from bad or pseudo-science. And he concluded that science's self-falsification is what matters. Popper poured cold water on the Positivists' claim that science-based knowledge is justified only if it is built bottom-up, from empirical evidence. According to Popper, the old bottom-up versus top-down arguments were irrelevant. Deduction, induction, intelligent guessing and even miraculous insights are all valid ways of doing science. But they are not valid ways to justify its correctness. Indeed there is no way to guarantee that any scientific theory is correct. But there is a way to weed out theories that are definitely incorrect. And that is to build testability into the theories themselves. Good science, said Popper, has theories that are explicitly falsifiable.

Popper found that scientific theories are alone in making precise and risky predictions. For example, they often forbid a specific occurrence so that just one case would destroy the theory. Pseudo-sciences, he found, made non-specific predictions, too vague to be falsifiable. And anyway, Popper found that pseudo-sciences were casual about failed predictions. They would just make some ad-hoc change to the theory to overcome the failure. So Popper decided to state what constitutes a good scientific theory. Where Sir Francis Bacon had defined what scientists should do, Popper defined what they should produce at the end of their efforts. He asserted that a scientific theory must be explicitly disprovable to be classed as good science. And, the theories that survive the most precise and the riskiest predictions, are thereby the best theories. The problem of induction was removed at a stroke. Theory falsification had taken over the role of justfying scientific knowledge. Hume's arguments against induction were no longer relevant. The Positivists' arguments for abandoning metaphysics no longer applied.

Popper saw science as a sort of accelerated evolutionary process, an ongoing quest to mutate and adapt the theory-gene-pool and survival of only the fittest theories. Popper, an anti-Positivist, argued that metaphysics is a necessary part of this process. It is the source of radically new abstract ideas, products of the imagination, but subject to top-down analysis and testing by science before being given any credence. Top-down deduction is a complement to bottom-up induction. Popper considered that Positivists were naive to think that metaphysics could be expunged from science. The philosophy of science has long struggled to find the demarcation between empirical and metaphysical content in scientific theories. At one extreme, reliance on what we can directly sense fails because our sensory inputs are heavily altered, first by the physiology of our sense organs, then by the mental process of perception, and finally by the mind's subjective interpretation in the context of its prejudices. At the other extreme, metaphysics failed when the old materialist metaphysics could not account for the results of quantum experiments. The pragmatic conclusion must be that there is no demarcation. The theories of science contain a convoluted mix of top-down metaphysical deductions and bottom-up empirical induction.

Later in the twentieth century, Thomas Kuhn analysed what scientists actually do. He looked behind the scenes at the scientists themselves. He found that scientists tend to have a pseudo-religious belief in existing theories. They focus much more on developing established ideas than questioning their correctness. Kuhn found little or nothing of searches for things that would throw doubt on existing theories. Senior scientists are, unsurprisingly, reluctant to undermine their whole life's work, which they risk doing if they give room to radically new ideas. Dissenters have more difficulty getting funding and advancing their careers. Education, not just of scientists, tends to deeply entrench current scientific views. Popularisations in books, magazines and television establish science's views almost universally. Evidence against the established views is dismissed or made light of. But slowly and inevitably, over many decades or longer, this counter-evidence grows to a critical level. Eventually and relatively suddenly, an alternative view gains wide support. Kuhn called this a paradigm shift. It is not just one theory being replaced by a new and better theory, although this may be part of it. It is a complete revision of the scientific community's consensus view. All theories, or at least all theories within the relevant branch of science, are now seen in a new light. There is a revolution in our understanding of nature. Kuhn pointed out that paradigm shifts were changes in the mental framework within which theories are understood, and this must be a metaphysical framework, a world-view, the subjective consensus view of the scientific community.

Kuhn's findings showed that Postivism still lived on in science. Belief in the absolute correctness of theories, because they are built upon evidence, is a typical Positivist stance. Building ever more detail around existing theories, and shunning new (usually metaphysical) ideas, is typical of Positivist methods. Popper had undermined Positivism and shown that metaphysics could not be rejected. This seems to have had little impact on twentieth century scientists. Science accepted Popper's falsification but only as an ad-hoc addition to its existing Postivism. The scientific method had not changed in spite of Popper's arguments. The pre-Popper scientific method merely gained, as an appendix, Popper's definition of a good theory. Yet, as Kuhn had shown, the Positivists had always harboured an unintended element of metaphysics in their consensus views. This backed up Popper's argument that Positivists were in denial about the metaphysical element within the theories of science. This led to the end of Positivism, at least formally. We are now said to be in the post-positivist era. Whether this is so, we must wait for future historians of science to discover.

So, in the twenty first century, we find the scientific method alive and well. Science is hugely successful at discovering how nature works. Science tells you explicitly how you can prove it wrong as no other source of knowledge does. It has given us modern medicine that makes long healthy lives commonplace. It has given us modern technology that is indistinguishable from magic to most people. If science is on the wrong track, it is surely a miracle that it achieves so much. But science still only aims to tell us how nature behaves. It has not taken up metaphysics as an intended part of its method.

Does it matter that the scientific method still shuns metaphysics? The main argument for abandoning it was that metaphysical ideas are not derived from empirical evidence. But Popper had shown that metaphysical conjectures could and should be tested against empirical evidence. This is largely how Einstein worked: propose an abstract idea, convert it to mathematical form, predict the consequences, then check against current data. And Kuhn showed that this is how major advances in science generally come about. Radical new ideas cannot be derived from raw data. They are abstract, metaphysical, products of the inventive mind. Another problem is that the old materialist metaphysics is still out here in the public consciousness. It is in media stories about science and astronomy and in school text books. Even scientists still refer to the old metaphysics explicitly. In television documentaries and popular-science books, scientists describe a material world, but explain away relativity and quantum effects as "weird" behaviour of the material. So it matters that the scientific method has abandoned metaphysics because abandoning the search for a new metaphysics simply allows the old one to continue unchallenged.

In fact, some philosophers and scientists have challenged the old metaphysics, Alfred North Whitehead for example. His "Process philosophy" explains reality as a process. He famously said, almost poetically, that existence is: Not being but becoming. Events are real and events are what we experience but that's all there is, no objects, no material stuff. Werner Heisenberg, one of Niels Bohr's co-founders of Quantum Theory said that atoms are not things. Lee Smolin, a current leading physicist, said that the universe is made of processes, not things. One current view in metaphysics is called "Ontic Structural Realism". When new scientific theories oust older ones, they often retain the mathematical structure of those old theories and merely add a more sophisticated layer of new structure. As science goes deeper, it finds ever more evidence of structure but, crucially, ever less evidence of anything material. The trend is towards a picture of nature as structured patterns. Ontic Structural Realists conclude that there are no "things" of any sort at the fundamental level of reality. Structured patterns are all that there is. It is perfectly feasible that reality is, at its most fundamental, information patterns. Material, space and time are secondary concepts: structure in the patterns. It is difficult to grasp ideas like this because they are so far removed from our day-to-day experience.

So metaphysics continues, largely ignored by science, and not as part of the scientific method but as part of the philosophy of science. Metaphysics now interprets the theories of science and attempts to build around science, using ordinary language and simple logic, an overall picture of reality. This picture builds upon knowledge obtained from empirical and rational science. Modern metaphysics is therefore strongly bound to science. It is no longer the mere intelligent guesswork of pre-science metaphysics. In going beyond science, metaphysics must be more speculative than science but speculation is vital to the advancement of science. We cannot know for certain what reality is, as an absolute fact, but we can still distinguish better and worse attempts to explain it. Better ones should give a unifying picture of all of science, not just physics. Better ones should overcome the paradoxes of Relativity and Quantum Theory. Better ones ought to explain and predict real data and therefore be falsifiable. Ultimately, scientific investigations would determine which are the better ones by testing them against existing data and attacking them with new experiments.

I started by saying that the philosophy of science seeks to ask some basic questions so I want to conclude by giving an answer to each of those questions:

What's the best way to investigate nature?

- The best way to investigate nature is probably the one proposed by Karl Popper. The scientific method should continue its bottom-up induction from empirical data but also accept the need for top-down deduction from metaphysical conjectures, not least because that's the way that many great advances in science originated.

How confident can we be that what science tells us is correct?

- Established theories have made precise, non-obvious, testable predictions and survived genuine tests of those predictions. These theories are the best knowledge available to us about the workings of nature. Unfortunately, science magazines and the media in general often announce new ideas that may also go under the name "theory", such as String Theory, but only because the field of research hopes to produce a theory eventually. But what about new medical research that may be relevant to a current crisis? In this case, as with any other field of study, we have to rely on expert opinion and the reputations of the experts and their institutions.

How can we discriminate good science from bad or pseudo-science?

- Bad or pseudo-science is not explicitly falsifiable. Of course, it may claim that it is. We need to be wary of vague predictions and ad-hoc responses to failed predictions.

Does science help us to understand what the universe actually is?

- Science doesn't claim to offer any metaphysical views of reality. Yet, as Kuhn showed, scientists have world-views or paradigms that are not difficult to recognize. They are the classical materialist view, the relativistic view and the quantum view. Scientists step easily from one view to the other but these views are not compatible with each other. They cannot be combined without raising major paradoxes. Could there be a new science-based view from which the three existing ones can be derived while avoiding paradoxes? Such a view is certainly possible (see "It So Happens" on www.eobar.org) but may have to be so revolutionary that we just cannot believe it. Perhaps at most, science can only help us to understand what the universe is not. And all the signs are that the universe is not at all what we typically think that it is.

Recommended reading

- Understanding Philosophy of Science. James Ladyman 2002
- Unended Quest (An Intellectual Autobiography). Karl Popper 2002 (1st ed. 1974)
- Every Thing Must Go (Metaphysics Naturalized). James Ladyman and Don Ross 2007
- Particle Metaphysics (A Critical Account of Subatomic Reality). Brigitte Falkenburg 2007

Chronology:

- Roger Bacon: 1214 - 1294 Early use of mathematics and systematic experiment
- Copernicus: 1473 - 1543: Heliocentric model of the universe
- Sir Francis Bacon: 1561 - 1626 Scientific method: Empiricism, Inductivism
- Galileo Galilei 1564 - 1642 Telescope, Heliocentric universe and Kinematics (how things move)
- Renes Descartes: 1596 - 1650 Rationalism (nature is logical)
- Baruch Spinoza: 1632 - 1677: Rationalism but opposes Descartes' mind-body dualism
- Isaac Newton: 1642 - 1727 Mechanistic physics
- David Hume: 1711 - 1776 Empiricism, Scepticism
- Immanuel Kant: 1724 - 1804 Rational Empiricism (no such thing as objective data)
- Auguste Comte: 1798 - 1857: Positivism (no metaphysics)
- Alfred North Whitehead: 1861 - 1947 Process philosophy: Not being but becoming
- Albert Einstein 1879 - 1955 Relativity
- Niels Bohr: 1885 - 1962 Quantum theory
- Karl Popper: 1902 - 1994 Empirical falsification
- Thomas Kuhn: 1922 - 1996 Paradigm shifts, Consensus view