

Week 6: Are Scientific Theories True? (Dr. Michela Massimi)

1. Introduction

Hello, I am Michela Massimi and I am a Senior Lecturer in Philosophy of Science at the University of Edinburgh. Today I am at the National Museums of Scotland and I will present one of the most heated and ongoing controversies in contemporary philosophy of science: the debate between scientific realists and antirealists.

This debate is unlike many others that populate philosophy of science. It is not a debate about a specific scientific theory, or topic or theme (be it in biology, or physics or neuroscience), but it is a much broader debate about what science and scientific inquiry is all about. It is a debate about what we should expect from science and what good scientific theories should look like. In other words, it is a debate about the aims of science.

We may all have some intuitions about what science is all about and what the aims and goals of scientific inquiry may be. There seem to be two main possible aims for science:

1. We may expect science to be accurate and to provide us with a good description and analysis of the available experimental evidence in any particular field of inquiry. We may want our scientific theories to save the phenomena.
2. The second possible aim of science is not just to provide an accurate account of the available experimental evidence and to save the phenomena, but to tell us a true story about those phenomena, how they came about, what sort of mechanisms are involved in the production of the experimental evidence and so on. Often telling a true story about a particular phenomenon under investigation involves appeal to scientific entities that may prove elusive not only to the human eye but also to detection via technological devices (from electron microscopes to particle colliders).

So, what do you think? Does science aim at saving the phenomena? Or does it aim at giving us a true story about the phenomena? Depending on which answer you have given to this question, you will either side with scientific antirealism or with scientific realism.

In the rest of this lecture, we take a look at these two philosophical positions, their main arguments and counterarguments. Asking what the aims of science

are may appear somehow otiose, armchair philosophy, removed from the nitty gritty of actual scientific practice. But it is not. It is a central question that has shaped the course of Western science, and it has fuelled some of the most famous debates in our history of science. Our story begins a very long time ago, several centuries before Galileo and Newton.

2. Galileo, the telescope, and the moon

Consider astronomy, one of the most ancient scientific disciplines known to human mankind. The observation of stars and planets was known to some of the oldest civilizations (from the Maya to the Babylonians) and we have historical records in the form of astrolabes like this one of Hispano-Moorish manufacture, or these Japanese planisphere based on a Korean star map from the 14th century.

The ancient Greeks developed a rather elaborate astronomical theory with Ptolemy in the 2nd century AD. In the Ptolemaic system, planets moved along thick concentric orbital shells. This was the simplest astronomical hypothesis about orbital motions, but it required some tweaks to save some important phenomena that already the ancient Greek astronomers knew of. One of those phenomena was the so-called retrograde motion of the planets – during the course of the year, the trajectory of planets as observed by the naked eye at night seemed to form little loops on the blue sky. And to save this phenomenon, Ptolemy hypothesized that planets moved along a small circle called epicycle, whose focus was in turn rotating along a larger circle called deferent. In this way Ptolemaic astronomy was able to save the apparent retrograde motions of the planets at night. But Ptolemaic astronomers believed that the sophisticated system of epicycles and deferents was only a mathematical contrivance to save the phenomena, and not necessarily a true description of the sky. The French philosopher Pierre Duhem in the early twentieth century wrote a short but illuminating book, entitled “To save the phenomena”, where he reconstructed the idea of a physical theory from Plato to Galileo. And in the book, Duhem quotes among others Simplicius’s commentary to Aristotle De Coelo to capture the spirit of ancient Greek astronomy as that of saving the appearances by devising a great number of hypotheses about epicycles and deferents, while also being unable to establish in what sense (if any) these motions were fictitious or real.

Interestingly enough, for the ancient Greeks, the aim of astronomy was then not to tell a true story about planetary motions but to save their apparent motions as observed by the naked eye at night. Not surprisingly, when in 1543 Copernicus’s

book *De Revolutionibus Orbium Coelestium* was published, containing the heliocentric hypothesis, which was bound to change the course of astronomy for ever, in the dedication to the then Pope Paul III, the hypothesis was very modestly introduced as just another hypothesis, but a more promising one, to save the phenomena.

This is what Copernicus, quoted by Duhem, says in the dedicatory letter: “I began myself to consider the movement of the earth. It seemed an absurd notion. Yet I knew that my predecessor had been granted the liberty to imagine all sorts of fictive circles to save the celestial phenomena. I therefore thought that I would be similarly granted the right to experiment, to try out whether, by assigning a certain movement to the earth, I might be able to find more solid demonstrations of the revolutions of the celestial spheres than those left by my predecessors”.

Despite the apologetic tone of the dedicatory letter, Copernicus himself did not hide too much his conviction that his astronomical system was more certain than any of the fictitious hypotheses of his predecessors. Yet Copernicus died the same year his book was published. An anonymous preface accompanied the book. The preface, carefully crafted by Andreas Osiander, mitigated the spirit of Copernicus’ work by presenting it as yet another exercise in the well-trodden astronomical tradition of saving the phenomena: “For the astronomer’s job consists of the following: to gather together the history of the celestial movements by means of painstakingly and skillfully made observations...and then to think up or construct whatever hypotheses he pleases such that on their assumption, the self-same movements, past and future both can be calculated by means of the principles of geometry. It is not necessary that these hypotheses be true. They need not even be likely. This one thing suffices that the calculation to which they lead agree with the result of observation”

No wonder the publication of Copernicus’s book did not set the religious authorities aflame, until almost half-century later, when someone dared to overthrow this received view of astronomy as saving the phenomena and dared to say that Copernican astronomy was true of the heavens. That person was Galileo Galilei.

In the summer 1609, Galileo Galilei built the first telescope. He had heard about similar attempts in the Netherlands to build a spyglass that could magnify the size of the objects and his first toy instrument was used as a naval instrument in Venice to spot boats coming to port. A few months later, an improved and more powerful telescope, able to magnify objects thirty-times was pointed to the moon

and revealed mountains and craters, that Galileo beautifully described in the 1610 *Starry Messenger*. It was unequivocal evidence that celestial bodies shared a morphology very similar to the planet Earth, *pace* the Aristotelian-Ptolemaic tradition that claimed that celestial bodies belonged to a different realm. But more amazing were some of the following discoveries: in January 1610, Galileo observed what he thought were four stars wandering around the planet Jupiter and in December of the same year, he could observe phases in the planet Venus, which were impossible according to the Ptolemaic system, where the planet Venus orbits along epicycle and deferent, without ever going behind the sun. It was the triumph of Copernicanism.

Convinced by the new experimental evidence, Galileo embraced Copernicanism not just as a hypothesis that could save the appearances but as a physical truth that he believed could also be reconciled with religious truths in the Bible (divinely inspired), as he expressed in the famous letter to Marie Christine of Lorraine. It was the beginning of the Galileo affair with the Catholic Church and the rest is now history.

But from a philosophical point of view, what matters for our purposes is that Galileo defended the method of the physicist against the method of the astronomer, to use Pierre Duhem's terminology. He replaced the view that science has to save the appearances, with the view that science should in fact tell us a true story about nature. It was only a matter of time and an open and infinite universe was bound to replace the sphere of fixed stars of ancient Greek astronomy.

3. Scientific realism

Coming then back to the theme of today's lecture, we have seen in Galileo the poignant expression of the view that says that there is more to science than just saving the phenomena. Good science has to be true. The position is known in philosophy of science as scientific realism.

Scientific realism is the view that scientific theories (be it Copernican astronomy, Newtonian mechanics, or any other theory in biology or chemistry or other scientific domain of inquiry) once literally construed, aims to give us a literally true story of the way the world is.

There are two important and distinct aspects in this definition. The first is a semantic aspect: it has to do with the "once literally construed" in the above

definition. We should understand the language of science literally, in other words if we have a theory that talks about “planets” we should understand the term as referring to planets, as we should understand “electrons” as referring to electrons and so forth. In other words, we should assume that the terms of our theory have referents in the external world: they pick out the relevant objects in the world.

The second is an epistemic aspect: it has to do with the “literally true story” in the definition above. We should believe that our best scientific theories are true, namely that whatever they say about the world, or better about those objects which are the referents of their terms, is true, or at least approximately true. So, in the example of Copernican astronomy, one would believe that what the theory says about planets (for example, that they orbit the Sun) is true or approximately true, in the sense of corresponding to true facts in nature.

Appealing and intuitive as this may sound, the story just told about Ptolemaic and Copernican astronomy shows how this was not the way in which Ptolemy, Simplicius and Osiander saw astronomy. So, we need some proper philosophical argument in defense of scientific realism. And the argument is known as the “no miracles argument”. It says that if scientific theories were not approximately true, if their main theoretical terms did not refer, then it would be just a miracle that these scientific theories are so successful. The argument in the formulation originally provided by Hilary Putnam says “the positive argument for realism is that it is the only philosophy that does not make the success of science a miracle. That terms typically refer, that theories accepted in mature science are typically approximately true, that the same term can refer to the same thing even when it occurs in different theories – these statements are the only *scientific explanation* of the success of science”. In other words, “if there are such things, then a natural explanation of the success of these theories is that they are *partially true accounts of how they behave*. And a natural account of the way in which scientific theories succeed each other—say, the way in which Einstein’s relativity succeeded Newton’s universal gravitation—is that a partially correct, partially incorrect account of a theoretical object— say, the gravitational field – is replaced by a *better account* of the same object or objects. But if these objects do not really exist at all, then it is a *miracle* that a theory that speaks of gravitational action at a distance successfully predicts phenomena; it is a *miracle* that a theory that speaks of curved space-time successfully predicts phenomena....”

4. Antirealism

But is that so? Should we really believe scientific theories to be true in order to explain the tremendous and undeniable success of science? Or better, do scientific theories really need be true to be good?

Not so fast, the antirealist replies. Antirealism is a house with many mansions. A prominent variety in contemporary antirealism in philosophy of science is the view elaborated by the American philosopher Bas van Fraassen in the early 1980s and known as “constructive empiricism”. A distinctive aspect of constructive empiricism is that it agrees with realism about the aforementioned semantic aspect: we must understand our theories at face value, we must understand scientific terms as referring / picking out objects in the world. But it disagrees with the epistemic aspect: we do not need to believe theories to be true for them to be good. Truth is not a measure of how good scientific theories are. The very name “constructive empiricism” stresses that there is an important element of construction in our scientific activity, especially in how we build scientific models that must be adequate to the phenomena. Moreover, this is ultimately an empiricist position in claiming that our knowledge comes from experience and what we are warranted to believe should be confined to empirically accessible data, as opposed to discovering truths about the unobservable.

But what is the unobservable? And what does it mean to say that we construct models that must be adequate to the phenomena, as opposed to discover truths about the unobservable?

Consider minerals, there are some observable phenomena that we can study about minerals, for example, their melting points, their hardness, how easily they may combine with each other. But there are other aspects which are strictly speaking unobservable to the human eye: for example, chemistry identifies gold as the metal with atomic number 79, and the atomic number is (for elements with neutral charge) defined in terms of number of protons (and hence also electrons) distinctive of that element. Strictly speaking, whereas we can observe with our naked eye, the property of melting point, hardness and so forth, we cannot observe with our naked eye the atomic number or the molecular composition of minerals. But we do construct models of them, indeed, we do construct very informative models like these crystal models of minerals such as muscovite and halite, which nicely represent the molecular composition of the minerals by representing atoms with balls of different colors arranged according to some geometric structure that is meant to be adequate to the phenomena, for example,

how easily we can slice the mineral along some of these chemical bonds (represented by the transparent balls). Yet, the constructive empiricist would insist, we should not take the models to provide the truth about the unobservable, namely about atoms, molecules, and their chemical arrangements. Models must only be adequate to the observable phenomena, they are useful tools to get calculations done, but they do not deliver any truth about the unobservable entities.

So, constructive empiricism, as a very influential variety of antirealism in science, would say that scientific theories (and the models they comprise) need not be true to be good. They must only be empirically adequate. And a theory is empirically adequate if what it says about the observable (past, present and future) things in the world is true. In other words, a scientific theory is empirically adequate if it saves the phenomena, and acceptance of a theory involves only the belief that the theory is empirically adequate, not that it is true. Empirical adequacy, rather than truth, becomes the aim of science.

This conclusion chimes in many ways with the old adage of saving the phenomena, which as we have seen was typical of the way ancient Greeks saw the aim of astronomy, for example. But there are some crucial differences that we must not overlook. For ancient Greek astronomers, science could only aim at saving the phenomena because human science could not vie with divine knowledge. After Galileo and the scientific revolution, this could no longer be maintained, for as Galileo said, the book of nature is written in mathematical characters and can be studied by us. So, for modern science and for contemporary philosophy of science, the reason why according to some we should only aim at saving the phenomena as opposed to truth, has nothing to do with human knowledge versus divine knowledge, and all to do with both the metaphysical commitment that scientific theories bring with them on the one hand, and the abstract and idealized nature of the scientific models that we build, on the other hand.

As far as the latter are concerned, in the past thirty years or so, an increasing literature in philosophy of science has stressed how abstraction and idealization enter into the construction of models so that although the models are very useful and explanatory tools in everyday scientific practice, they may not necessarily be true of states of affairs in the world, if not in very idealized circumstances (for example, in this double-helix stick-and-ball model of the DNA sequence, we need to abstract from the terribly complicated cellular environment in which DNA sequences can be found in nature (some with high-salt others with low-salt), we need to idealize the atoms involved as perfectly spherical balls of different colors

– transparent for hydrogen, red for oxygen, green for phosphorous), we need to idealise the direction of the helix spiral (right-handed or left-handed) to represent different (A, B, C, and Z) forms of the DNA molecule. Models can be very useful and explanatory even if we do not have to think of them as providing a perfectly true picture of the target system, in the sense of thinking of atoms as tiny billiard balls, whose chemical interactions are represented by sticks, and so forth.

As far as the metaphysical commitment is concerned, a constructive empiricist would claim that she can do exactly the same good quality science as the realist, and she can vindicate why we have a very successful science, without the extra baggage of truth. Our scientific theories are successful because they have survived a ferocious struggle for survival across centuries. Our present science is so successful because present theories have proved—to use a Darwinian metaphor – survival-adaptive: they have proved to save the phenomena, the available experimental evidence, where their predecessors failed. But in response to the realist’s no miracles argument, the constructive empiricist would reply that the success of science is neither miraculous nor surprising. The success of science can be explained in terms of empirical adequacy, not in terms of truth about unobservable entities. Calling a theory true is some sort of honorific title, which does not really explain why the theory is both good and successful. Moreover, scientific realism is a high-risk strategy: what if the unobservable entities that our best theories postulate prove wrong? What if in a few centuries from now, DNA and electrons end up being like the ether and the caloric, discarded remnant of a past scientific history?

5. IBE and fossil evidence: realism vindicated?

Should we then give up realism and embrace antirealism about science? The scientific realist is not going to be impressed by van Fraassen’s arguments. Here are two realist rejoinders. First, empirical adequacy would not do when it comes to explaining the success of science, and van Fraassen’s Darwinian response to the no miracles argument does not cut any ice against scientific realism.

One thing is to explain why only successful theories survive; another thing is to explain why a theory is successful in the first instance. The scientific realist seems to have a story about why theories are successful in a way that the constructive empiricist does not. Namely a realist would explain that what makes a theory successful has to do with the unobservable entities that the theory postulates and how true the story about those entities is. So the theories that have survived are successful because they are true – the realist would claim;

those that failed (caloric, ether, phlogiston), failed because they are false.

The realist's second rejoinder attacks van Fraassen's alleged distinction between observables and unobservables – this distinction has been at the center of a huge literature which I won't have the time to cover here. After all, why should we suspend belief about unobservables (be they atoms, electrons, or DNA) and believe only that our best theories about atoms, electrons and DNA save the observable phenomena? The empiricist criterion of suspending belief about unobservable entities seems too narrow to capture the complexity of scientific practice where the vast majority of entities postulated by theories are indeed unobservable. And why should not we trust our scientific instruments (be they a microscope or a particle collider) to deliver a reliable image of the unobservable any more than the human eye?

Here I won't enter into the intricate details of the arguments pro and against the observable / unobservable distinction but I do want to mention one particular line of attack formulated by two philosophers of science: Philip Kitcher and Peter Lipton. And this is the line of attack that says that we are justified to believe in atoms, electrons, DNA and other unobservable entities because the inferential path that leads to such entities is not different from the inferential path that leads to unobserved observables. Consider how many things may go unobserved although they are strictly speaking observables. None of us has ever seen a dinosaur and yet dinosaurs are in principle observables, if we could travel back in time and take a look at them. So how do we know about dinosaurs?

Fossil evidence is what paleontologists use to reconstruct the past history of our planet. From fossil evidence of this type, we can reconstruct some important information about the life of extinct marine species like these trilobites in the Paleozoic era: for example, we can come to know whether they swam or they moved on the sea-bed, whether they ate plankton, how many different genera there were, how geographically distributed and so on. But as fossils provide evidence for now extinct species, similarly one can argue, evidence from the Large Hadron Collider can provide evidence for an elusive particle like the Higgs boson. The inferential path to the unobservable Higgs boson is one and the same as the inferential path that leads to the unobserved observable trilobites. Philosophers of science call this inferential path "inference to the best explanation". The idea behind IBE is that we infer the hypothesis which would, if true, provide the best explanation of the available evidence. Thus, we infer the existence of marine arthropods like trilobites as this is the best explanation for this fossil evidence, as we infer the Higgs boson as the best explanation for the sort of evidence coming out of the LHC. Namely we choose from a pool of

competing explanatory hypotheses the one that we regard the best, namely the one that if true, would provide a deeper understanding of the available evidence.

IBE is a powerful tool in the scientific realist toolkit: it shows that the scientific hypotheses that we choose and we are willing to believe tend to be those that if true, would provide the best explanation of the evidence. And this is what we tend to do every day from medical diagnostics (say the doctor inferring the hypothesis that best explain the patient's symptoms) to particle physics when we infer the existence of the Higgs boson to explain some salient features of the so-called standard model, to astronomy where we infer that the universe is expanding as the best explanation for the cosmological red shift in the spectrum of the light coming from the stars. The realist would say: this is what science is all about! We do not rely necessarily on our senses or technological instruments to believe in the unobservable entities that our scientific theories talk about, but on the validity and robustness of our inferential practices informed by a wealth of experimental data, to draw conclusions about what our universe may be like.

6. Conclusion

In this lecture, we covered briefly some of the salient points of the ongoing debate between scientific realism and antirealism in philosophy of science. To sum up, scientific realists see truth as the aim of science, and claim that we should believe our best theories to be true of the world. They appeal to the no miracles argument, which says that if theories were not true, it would be just a miracle that we have such a successful science. Next, we considered a prominent antirealist response, elaborated by Bas van Fraassen, that goes under the name of constructive empiricism. Under this account, science does not aim at truth but at saving the phenomena, and good theories are those that are empirically adequate, as opposed to true. We saw some of the rationale for constructive empiricism, namely how we build models that are adequate to the phenomena but not necessarily true in some strong sense of the term, and how we can still have a perfectly good account of how science works without the need to add the extra metaphysical commitment to truth. Finally, we considered two possible realist rejoinders to constructive empiricism, in particular the appeal to inference to the best explanation as a way of delivering beliefs in the truth of electrons and Higgs bosons no less than in dinosaurs and trilobites.

Where does all this discussion leave us? As always in philosophy, the debate goes on, with more and more refined objections and counterarguments from both sides, and with an array of new philosophical positions being recently elaborated

in between these two extremes of scientific realism and antirealism, and promising to overcome the standoff between them. After all, as science grows and develops, so do also our philosophical images of science. But this is a story for some other time.