Asking "Why, why, why?" or The Tree of Science

Richard Feynman explains to his student audience how they should go about integrating their newly acquired knowledge on quantum mechanics in the sixth of the 1964 series of lectures called the Messenger Lectures[1]. When he was asked in an interview how magnets attract or repel each other, he answers "they just do". We could ask "why, why, why" ad infinitum without being satisfied, he says. On other occasions he defends the position that science is about *knowledge*, about being able to make accurate predictions, and not about *understanding*. I will argue here, that from a more general perspective, this idea about science is not in accordance with historical reality and will most likely not be in the future.

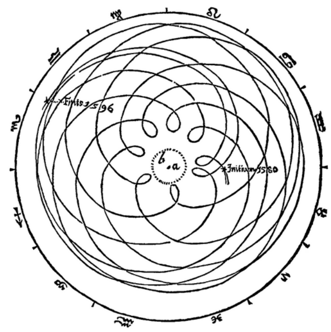
If we take a look at the history of science, we can see that in essence the great advancements in science amounted to a better understanding of nature. Describing or modelling reality is only a part of the process of scientific discovery. Understanding may be seen as being able to describe phenomena in terms of a more general model, and that seems to (temporarily) satisfy our need for understanding the world around us. Explaining and understanding may be seen as two sides of the same coin. Science is almost never fully experimental, although some scientists proclaim it to be so. Generally, hypotheses are formulated using our understanding of what could be a better explanation than the one we already know, otherwise we would be condemned to blind guesswork, which would result in a very ineffective process of scientific discovery.

One of the most well-known statements by Isaac Newton on this subject is made in the last scholium of the *Principia* (in the third edition of 1726), where he says that he "does not think up hypotheses", "Hypotheses non fingo". Often it is thought that he meant by this, that hypotheses should be built upon observations, but, interestingly, that is in contrast to what Newton actually declares in the scholium. In the 1999 translation by Cohen and Whitman we find[2]:

> *I have not as yet been able to discover the reason for these properties of gravity from phenomena, and I do not feign hypotheses. For whatever is not deduced from the phenomena must be called a hypothesis; and hypotheses, whether metaphysical or physical, or based on occult qualities, or mechanical, have no place in experimental philosophy. In this philosophy particular propositions are inferred from the phenomena, and afterwards rendered general by induction.*

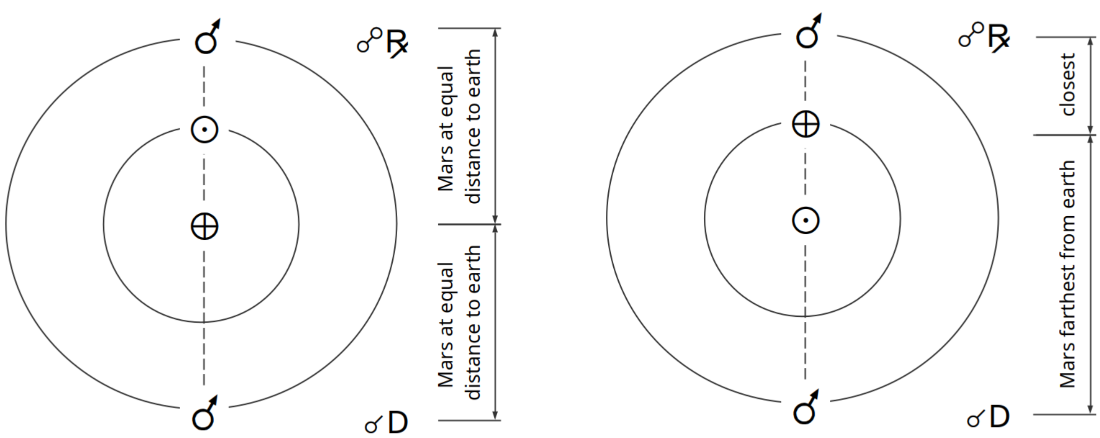
Apparently Newton is of the opinion that empirical research is done on the basis of deduction instead of guessing. What he calls *hypothesis* here, is indeed no more than a guess, as it is thought up without *any* logical connection to the phenomena involved. Feynman also remarks that having criticism of the old is easy, while creating the new is difficult. Of course at first glance it seems he is right, certainly from his perspective, where guessing is the only possible option left. On the other hand, Newton makes it look like it should be possible to directly *deduce* the new from the old.

We could take a look here at an example from the history of science, perhaps even the most significant example in the whole of its history, of the shift from the geocentric to the heliocentric worldview, as it was presented by Nicolaus Copernicus in his work *De revolutionibus orbium caelestium*. (On the Revolutions of the Heavenly Spheres) How did he come up with his completely new view of the universe? First, perhaps we should acknowledge that the heliocentric world view was not completely new at the time. Copernicus had already studied several ancient Greek texts mentioning the heliocentric worldview texts. One of these texts was Claudius Ptolemy's *Almagest*. In the days of Ptolemy however, heliocentrism was already a controversial point of view. Copernicus realised perfectly well how controversial his work would be in his day, and he chose wisely to arrange for the book to be published after his death. In his foreword he addressed Pope Paul III directly, explaining why he published it all the same, despite the controversy it would stir. In his foreword, his ideas are presented as a hypothesis, but in the chapters of the work itself, he shows that he is strongly convinced that the view he presents is the best explanation of the data which were at his disposal at the time.



So how could Copernicus be so sure that the earth was not at the centre of the solar system, if it was not on the basis of a proven hypothesis? In *De revolutionibus* he gives two "facts" which are, as he formulates it, "enough to show" that the centre of all known (then circular) planetary orbits is the sun, and not the earth. His first argument is the "apparent nonuniform motion of the planets" while the second is that their distance from the earth varies significantly. Both these observations are inconsistent with the sun and the planets moving in concentric circles around the earth. At that time, there was no proper explanation for the retrograde movements of the planets, and it was unclear why the sun and moon did not show any retrograde movement. Also the differences between the movements of the inner and outer planets were not properly understood. He writes (English translation by Charles Glen Wallis[3]):

> *For [these outer planets] are always closest to the earth, as is well known, about the time of their evening rising, that is, when they are in opposition to the sun, with the earth between them and the sun. On the other hand, they are at their farthest from the earth at the time of their evening setting, when they become invisible in the vincinity of the sun, namely when we have the sun between them and the earth.*

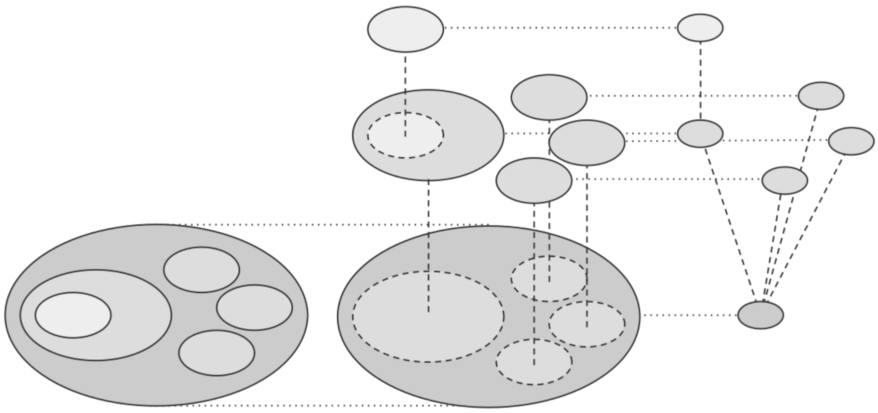


In the two figures above, we can see how Mars in the geocentric model always has more or less the same distance to the earth, while in the heliocentric model, the distance varies between the longest distance around the conjunction with the sun, and the shortest distance around the opposition, when Mars is in the middle of its retrograde movement. This behaviour can be explained by the heliocentric, but not with the geocentric model. There were enough data at his disposal, so that on the basis of these data Copernicus could deduce with great certainty that the heliocentric model was superior.

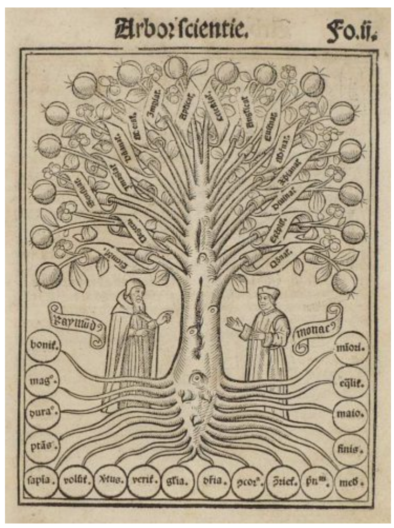
However, at that time the predictive value of the heliocentric model did not surpass that of the Ptolemaean model: the results of its calculations were not particularly more accurate. Still, in our days we consider Copernicus' work the epitome of revolutionary scientific achievement. To cut it short, its significance lies in our better understanding of, in this case, the solar system. So what does it actually mean that we understand something? Is it perhaps some esoteric or unscientifc principle at work?

Most people working in the area of natural science will be able to confirm that creating hypotheses is not just blind guesswork. Of course creating hypotheses is a complex process, but at least one clue to what may often be happening is actually given by Feynman himself, when he argues that one should not be using examples or analogies which explain a phenomenon in terms of something more commonly known to clarify physical phenomena, in particular in case of the "strange" phenomena of quantum mechanics. One of the ways science moves forward is that someone discovers that the model which is currently in use is wrong, often because it refers to known phenomena. We can think of many examples of this in the history of science, a simple one being the idea that objects only move when a force is exterted upon them, as for example Aristotle believed. Newton, in his First Law of Motion, states that objects without any force acting upon them will move with constant or zero velocity. The former idea has its origin in observing from a human perspective, living on the earth's surface, where objects are stopped by the earth when they are falling, or by its resistance when they are moving on its surface. This is often called an anthropocentric or humanocentric bias. Also in the case of Copernicus' discoveries the same principle is at work, in a most exemplary way. We could systematically search our present-day models for this type of bias, and try to take a different, universal, viewpoint, and try to cleanse physics from this type of models, and also in modern times scientists have done so. Discovering the too narrow-minded worldviews of today obviously presupposes specific abilities, which may not be present in all of us, or may perhaps be developed over time, but exactly those abilities served as a key ingredient for the most significant discoveries in the history of science. An important part of the advancement of science is apparently the careful examination of existing models, perhaps from a philosophical therapeutical standpoint, or perhaps even a psychological one.

Either by deduction or by hypothesis, what does it mean to better understand the world around us? We can ask ourselves: how does science actually advance? We could think that perhaps explaining or understanding things leads to unification of models. If we are able to describe a phenomenon A in terms of phenomenon B, it makes a separate model of A superfluous, unifying the two models. This process eventually ends in a single "unified theory". Such a theory can be described in two dimensions as a Venn-diagram of collections, containing—but never crossing—each other. In three dimensions we can describe it as a tree, where the final unified theory is represented by the trunk, and the most fundamental problems as large branches. Alternatively, such a tree may be seen as a model of the history of science, or a superstructure of different areas of science. In the following figure, the analogy is shown of a Venn-diagram of collections containing each other, and a tree diagram.



This idea has also been recognised by several of the earlier philosophers of science. For example, in 1297 the well-known Catalan philosopher and alchemist Ramon Llull, in his encyclopedic work *l'Arbre de Ciència*[4] already described the interconnections of different areas of knowledge as a tree structure. A few centuries later, Francis Bacon also compared the progression of science to a tree. In *The Advancement of Learning*[5] (1605), and the enlarged Latin version of the same work *De augmentis scientiarum*[5] (1623), the trunk representing the unified theory he calls the *philosophiae prima*, the primary philosophy, or the *summary* of philosophy.



Particularly in natural science, advancement is driven by explaining effects in terms of their causes. Empirical research generally tries to produce effects by setting up presumed causes, and if in a certain number of a series of experiments the desired effect is produced, the principle of induction is called upon, to declare that the presumed causes are indeed responsible for this effect. We may call this causal relation "proven", or we may say that the phenomenon is "explained". This basic process may also be characterised as "answering a why-question": why does the phenomenon take place, or what causes it? What we call natural science is essentially formed by asking why-questions, perhaps not ad infinitum as Feynman suggests, but repeatedly and systematically.

Let us now return to Feynman's lecture. We have seen that at least one of the most important advances in science was decided by the criterium of having a better insight into the nature of things. Advancement is in this case primarily an advancement in understanding. They were not so much based on guessing hypotheses, as they were on trying to correctly model available data. Looking for explanations was the most important driving force, that is, asking the important why-questions. Now, has this all changed with the advent of quantum mechanics in the twentieth century? Is there something special going on in modern physics causing that our why-questions, our urge to understand things, are suddenly not good enough anymore? In the same series of lectures[6], there is another well-known quote from Feynman, perhaps his most famous one, where he says "I think I can safely say that nobody understands quantum mechanics". For him it is safe to say that, because as one of the greatest experts in the field he is well aware that quantum mechanics does not have a connection with a more abstract layer of knowledge, in terms of which it can be explained. It cannot be explained in terms of more familiar concepts, higher up in the tree of knowledge, but the "trunk" of physics, or a connection with any existing trunk, or "primary philosophy", is still to be found.

Feynman, a Nobel-prize laureate, was indeed left with guessing hypotheses and was not able to deduce a new model from the available data or find a relevant bias to see through. His visible irritation with why-questions is a reflection of that, of his ambition, or his deep personal quest for the great answers. ■

Notes

1. Videos of all seven Messenger Lectures held by Feynman at Cornell University in 1964 are to be found here: https://www.feynmanlectures.caltech.edu/messenger.html They were published as a book under the title *The Character of Physical Law* by British Broadcasting Corporation, 1965. My 2017 copy is by The MIT Press, and has ISBN 9780262533416.
2. In the 1999 translation of Newton's *Principia Mathematica* by Cohen and Whitman, published as *The Principia*, Oakland: University of California Press, we find this quote on p. 589, and in the 974 page edition on p. 943.
3. Nicolaus Copernicus (tr. C.G. Wallis), *On the Revolutions of the Heavenly Spheres*, Encyclopaedia Britannica, Chicago [etc.], [1955], p. 17-20. The Latin first edition is Nicolaus Copernicus, *De revolutionibus omnium coelestium*, Neurenberg: Johannes Petreius, 1543 ed., p. 7r-8v. "Constat enim propinquiores esse terrae semper circa vespertinum exortum, hoc est, quando Soli opponentur, mediante inter illos et Solem terra: remotissimus autem à terra occasu vespertino, quando circa Solem occultantur, dum videlicet inter eos atque terram Solem habemus." The diagram of the retrograde motion of Mars is taken from Johannes Kepler, *Astronomia Nova*, 1st ed. 1609, p. 4
4. Ramon Llull, *Arbor Scientiae*, [1297] The tree is from the 1635 Leiden edition by Ioannes Pillehotte.
5. Francis Bacon, *The Advancement of Learning*, 1605. The enlarged Latin version of the same work is *De augmentis scientiarum*, 1623. I used the Latin edition by Joannis Ravenstein, Amsterdam, 1662 ("Lib. IX"), where the fragment is to be found on pages 179-180.
6. In the sixth lecture at 8:10. In my book on page 129. (see note 1)