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Excerpt
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1 Why Explanation Matters in Science

The Primary Aims of Science

While it isn't necessary to do so, it's often good to start a book by saying something that is clearly true. So, let's do that. Science has had (and continues to have) a significant impact upon our lives. This fact is undeniable. Science has revealed to us how different species arise, the causes of our world's changing climate, many of the microphysical particles that constitute all matter, among many other things. Science has made possible technology that has put computing power that was almost unimaginable a few decades ago literally in the palms of our hands. A common smartphone today has more computing power than the computers that NASA used to put astronauts on the Moon in 1969! There are, of course, many additional ways in which science has solved various problems and penetrated previously mysterious phenomena. A natural question to ask at this point is: why discuss this? While we all (or at least the vast majority of us!) appreciate science and what it has accomplished for modern society, there remain – especially among portions of the general public – confusions about science, how it works and what it aims to achieve. The primary goal of this book is to help address some specific confusions about one key aspect of science: how it explains the world.

A first step in getting clearer on *how* science explains the world is to consider *why* science even attempts to explain the world. What exactly does science try to achieve? Or, perhaps putting the question more accurately, what do we (humans) seek to accomplish by employing the methods of science? It is widely accepted that there are three primary aims of scientific activity: prediction, control, and explanation of natural phenomena. Different domains of science emphasize some of these aims more than others. For instance, paleontologists don't spend a lot of time focusing on controlling phenomena, whereas biomedical researchers devote a tremendous amount of effort to controlling infections and diseases. Despite these differences in emphasis, explanation is a common thread linking all these aims. For this reason, it isn't uncommon to hold explanation to be the most important of these three primary aims of science. As the US National Research Council has said, "the goal of science is the construction of theories that can provide explanatory accounts of features of the world."

What makes explanation so important to science? The answer lies in what successful scientific explanations give us: understanding. Very roughly, understanding arises when we grasp how various features of the world depend upon one another. When we come upon the scientific explanation of some phenomenon, our understanding of the world increases. By virtue of this increased understanding, we are often able to better predict and control phenomena. For example, having scientific explanations of why and how something like the 2019 novel coronavirus (SARS-CoV-2, the virus responsible for the COVID-19 pandemic) evolved, helps us to better understand the mechanisms by which this virus reproduces and is transmitted. Of course, once we understand how this virus is transmitted from person to person, we can predict which situations are likely to increase or decrease its spread, as well as when we are apt to see significant rises in the number of infected people. Additionally, this understanding can allow us to put into place guidelines that (if followed!) may help control the spread of the virus. Furthermore, it is understanding of SARS-CoV-2 that has allowed us to produce effective vaccines. Without such understanding, it is difficult to see how we could manage any of these feats.

Considering the role that understanding plays in both prediction and control, it is maybe a bit misleading to characterize science as having three primary aims as we did above. P. W. Bridgman, a Nobel Prize–winning physicist, once said "The act of understanding is at the heart of all scientific activity." Another Nobel Prize laureate, Erwin Schrödinger, claimed that the foundation of the entire modern scientific worldview rests upon the "hypothesis that the display of Nature can be understood." Understanding is central to science, and perhaps it is most accurate to say that the primary *epistemic* (pertaining to knowledge/cognitive success) aim of science is to produce understanding via scientific explanations. Using the understanding gained via scientific explanations to yield accurate predictions and to allow for increased control of phenomena are important secondary aims of science. There are, of course, important caveats and qualifications of this relationship between the goals of science. For instance, science often makes use of models (representations of events/phenomena in the world) in order to explain and predict phenomena. In many cases, however, we might be forced to make choices between models that offer better scientific explanations and models that make more accurate predictions. This trade-off is especially clear when we look at what is called "robustness analysis," which is common in climate science. Robustness analysis involves analyzing a number of incompatible models (i.e., models that make different assumptions about the phenomena being modeled) in order to come up with predictions. In many cases robustness analysis leads to predictions that are considerably more accurate than can be achieved by looking at a single model. However, this often comes at the expense of explanation because we can't really explain what is going on by consulting models that disagree with one another. Hence, at times we seem forced to choose between having better explanations of important phenomena or being able to make more accurate predictions about those phenomena.

For now, we can set aside this and other concerns (we will come back to them later) and consider the general picture of science that emerges when we consider its primary aim(s). Understanding is the central aim of science, and we gain understanding in science by way of scientific explanations. As is often the case, with new insights come new questions. What exactly is understanding? What are scientific explanations, and when are they successful? How do scientific explanations, when they are successful, provide us with understanding? We devote considerable attention to answering these, and many other, questions throughout this book. For the remainder of this chapter, the goal will be to get a firmer grip on the general ideas that will be more fully explored later.

Scientific Explanation

The nature of scientific explanation was a major focus of philosophy of science in the twentieth century, since at least the late 1940s. And, given the difficulties of philosophical analysis of important concepts and the nuances of explanation in science, it is unsurprising that the nature of scientific explanation remains a topic of much debate among philosophers of science even today. Over the course of the history of this discussion there have been many accounts of the nature of scientific explanation and a lot of objections, rebuttals, revisions, and developments of various theories. In fact, there have been too many theories of scientific explanation for us to explore or give much of an overview of even just the most influential accounts here. However, scientists have been using scientific explanations to better understand the world since science began. Furthermore, they have been evaluating scientific explanations to great success – and, there's no reason to think that they'll stop succeeding in this way. Importantly, all of this progress in terms of developing, testing, and evaluating scientific explanations has taken place despite it remaining unsettled which account of the general nature of scientific explanation is correct.

This notwithstanding, a plausible working model of scientific explanation will be helpful to have in hand. This should be ecumenical in the sense that it is at least compatible with the major theories of scientific explanation that have been put forward. Here is such a model: scientific explanation is a matter of tracking dependence relations. The idea here is that a scientific explanation consists of information about how or why one thing depends upon other things. Importantly, this "dependence" view of scientific explanation allows for all sorts of relations – causal relations (when something causes something else), constitution relations (when some things make up something else), mereological relations (relations that exist between the parts of an object), and so on – to count as explanatory. As a result of this, the dependence view of scientific explanation is consistent with all the major views of the nature of scientific explanation that have arisen in the philosophical literature.

Let us consider very briefly one scientific explanation on this model. Consider, for example, cystic fibrosis. People with this disease produce an excess of mucus that can cause passageways in the lungs to clog and obstructions to form in the pancreas. What explains why a particular person has cystic fibrosis? Mutations of the cystic fibrosis transmembrane conductance regulator (*CFTR*) gene. In terms of the dependence view of scientific explanation, we have a (at least partial) scientific explanation of cystic fibrosis. The scientific explanation of a particular person having cystic fibrosis (what is known as the *explanandum* – what is being explained) consists of information about how the person's having this disease is dependent upon other things, in this case the person's having mutated alleles of the *CFTR* gene (this is the *explanans* – what does the explaining, in other words, what provides the information about how or why the *explanandum* depends upon other things).

Here's a very brief recap. Our general picture of scientific explanation is that it consists of information about dependence relations that exist between a particular phenomenon (whether it is a general process or a particular event) and other phenomena. More specifically, we have a scientific explanation of X when we have information about how or why X depends upon some other things, such as Y. In this sense, the explanation can be represented in a question-and-answer format: "Why X? Because of Y," where X is the explanandum and Y the explanans.

Scientific Understanding

We've mentioned that understanding is the key epistemic goal of science. Let's take some time to get a bit clearer about what we mean by understanding in this context. We use the term "understanding" in myriad ways. For instance, we sometimes say things like "I understand that you're angry with me" as a way of expressing a belief that we have while hedging a bit. We're letting the other person know that we think that they are angry with us, but we don't want to fully commit to being correct about this. We might also use "understand" in a way that is synonymous with knowing that something is a fact. "I understand that humans have 23 pairs of chromosomes" is just another way of expressing "I know that humans have 23 pairs of chromosomes." Finally, we might experience an "aha" moment in which a particular scientific explanation feels as if it is giving us insight into the workings of the world. We might be tempted to call this feeling itself understanding. Even if "understanding" is the appropriate term to use for this particular sort of feeling, that is not what we mean when we say that science provides understanding. We're looking for more than just a good feeling because such feelings sometimes are misleading.

The sense of understanding that we're interested in isn't a matter of hedging, merely expressing knowledge of a simple fact, or experiencing a feeling that a scientific explanation is correct. The sense of understanding that matters for our purposes and is the aim of science is a kind of cognitive success. It involves really grasping how the world is – not how we want it to be or what would make us feel good. When we genuinely understand some phenomenon, we are in an epistemic state that may or may not be accompanied by the phenomenal feeling of "aha." Like almost everything else that philosophers study, there are numerous minute differences when it comes to accounts of understanding (and many differences that are not so minute). This shouldn't dissuade us in our discussion though. After all, philosophers have been arguing about the exact nature of knowledge for many years (and they still don't seem to be anywhere near a consensus), but this hasn't hindered our general ability to recognize whether something is known or not.

While there is live debate among philosophers about whether understanding is itself a kind of knowledge, it is generally agreed that understanding is something beyond mere knowledge of facts. To illustrate the plausibility of this idea, consider a student who simply parrots what their biology teacher tells them. This student knows, for example, that the DNA sequences of humans and chimpanzees are extraordinarily similar because the teacher has said this. However, the student may be clueless as to why this is so, or the importance of this similarity within the larger context of biology. The student may have no grasp of how this fact provides support for evolution in general and common descent in particular. What is missing? It seems that whereas the student simply knows this (and perhaps many other) isolated facts, understanding requires seeing how these facts hang together. The person with understanding grasps biology (or any other object of understanding) as an interrelated body of information with many connections between the various facts. This person can appreciate how these various facts depend upon one another. Furthermore, the person who understands biology can use this understanding to explain and sometimes predict particular biological phenomena.

Following philosopher of science Henk de Regt, we can helpfully distinguish between two varieties of understanding. The first is what we've been primarily considering until now: understanding phenomena. We achieve this sort of understanding by coming to know why or how a particular phenomenon occurs. In other words, we come to understand phenomena when we grasp correct scientific explanations of what causes the phenomena, the mechanisms or processes involved in the production of the phenomena, how the phenomena fall under natural laws, and/or how various changes to other things might have led to changes in the phenomena. A classic example of this is the understanding of the variation among the finches of the Galapagos Islands. As Charles Darwin noted, we can explain this phenomenon (variation among the different kinds of finches on these islands) by recognizing that it was the result of adaptation by natural selection. Recognizing the process (natural selection) and the causes (differences in environmental conditions, variation in characteristics such as beak size within populations) that led to the diversification of the finches yields understanding of the phenomena. This sort of understanding is the primary aim of science.

The second sort of understanding that we are concerned with is understanding a theory. One can genuinely understand phenomena only if one understands the relevant scientific theories. What exactly does it mean to understand a scientific theory though? And, what do we even mean by calling something a scientific "theory"? Let's start with the second question. We don't mean by "theory" the sort of thing that is far too often meant by it in public discourse. In such cases "theory" is often used to signify a claim or hypothesis that is still the subject of significant, reasonable doubt. It is exactly this sort of use of "theory" that is operative when critics erroneously charge that evolution is *just a theory*. Instead, when we speak of theories in science, we are talking about well-established domains of science that enjoy strong empirical support and include many widely accepted foundational facts, methods, and laws or principles. When it comes to understanding a theory this consists of being able to use the scientific theory to construct (or at least appreciate) scientific explanations or make predictions about phenomena within a particular domain. For instance, someone who understands evolutionary theory can construct scientific explanations of a number of things such as the variation that one finds among the different species of finches in the Galapagos Islands; or make predictions about where specific fossils could be found, as in the case of *Tiktaalik*, an extinct lobe-finned fish that has many similarities with four-limbed animals.

Possessing understanding of a scientific theory will depend on various factors. Some of those factors have to do with the scientific theory itself – the simplicity of its structure, its facility to be utilized for predictions, and so on. Other factors will depend upon the individual – things like background knowledge and intellectual capacity are key factors when it comes to whether someone is able to come to understand a scientific theory. Of course, understanding is something that comes in degrees. So, one person might have a deeper understanding of a scientific theory (or phenomenon) than another. An easy way to see this is to consider the different levels of understanding that an expert and an informed layperson may have when it comes to particular scientific theories. An expert can generate a new evolutionary explanation of some disease, such as COVID-19, which suggests that the virus SARS-CoV-2 likely evolved naturally rather than being designed in a lab. A layperson can appreciate this explanation when hearing of it, but typically the layperson couldn't come up with this explanation on their own. In such a case, both the expert and the layperson are exhibiting some degree of understanding of theories of viral evolution. However, the expert is exhibiting a significantly higher degree of understanding of the scientific theories in question, and plausibly as a result of this the expert has a deeper understanding of the phenomenon that the scientific theories are being employed to explain – for instance, how the sequences of the genomes of the various viruses can be compared and how such comparisons can form the basis for estimating evolutionary relations.

It is worth briefly pausing to emphasize the importance of distinguishing between understanding phenomena and understanding theories. Two primary reasons this is important to do are that this distinction helps us better appreciate how science achieves understanding and why such understanding really is an *achievement*. As we have discussed, coming to understand phenomena requires exercising one's cognitive faculties, in particular one's understanding of scientific theories, to generate or appreciate scientific explanations of the phenomena in question. For genuine understanding of a phenomenon, it is not enough that one is simply informed of a scientific explanation; one must appreciate how the scientific explanation provides an account of why or how the phenomenon occurs. At the heart of this process lies scientific explanations – generating them, comparing them, or at the very least appreciating them. The central cognitive aim of science cannot be had without scientific explanations.

Key Successes of Scientific Explanation

The history of science is replete with examples of successful scientific explanations. Often, as we discuss in later chapters, these scientific explanations lead to significant new discoveries. In other cases, they provide deep understanding of phenomena that were previously mysterious. And, in many other cases, they help aid in controlling various phenomena (such as infections) and developing new technologies. Arguably a big part of the reason that science advanced so quickly after the scientific revolution began is that key scientific explanations were hit upon. That said, let's take a brief look at two of the incredible successes of scientific explanation (we'll consider others in later chapters).

In the early 1800s, it was discovered that the orbit of Uranus (at that time believed to be the last planet in our solar system) didn't follow the path predicted by Newton's theories, coupled with the assumption that there were no other planets. What was to be made of this? Since the empirical evidence was undeniable, there were only two options. Either give up Newton's theory of universal gravitation or abandon the assumption that there were no other planets beyond Uranus in our solar system. At that time, especially given its tremendous successes, dropping Newton's theory wasn't appealing. Two scientists, John Couch Adams and Urbain Leverrier, working independently of one another, hit upon a better explanation. They postulated that there was a thus far undiscovered planet that was causing the orbit of Uranus to be different than expected. This explanation accounted for the strangeness of Uranus' orbit without abandoning Newton's theory. The great success of this scientific explanation came shortly after it was put forward, when the existence of Neptune was observationally confirmed.

Another great success of explanation in science was the line of reasoning that led Charles Darwin to the theory of natural selection. As he described in *The Origin of the Species*: "It can hardly be supposed that a false theory would explain, in so satisfactory a manner as does the theory of natural selection, the several large classes of facts above specified. It has recently been objected that this is an unsafe method of arguing; but it is a method used in judging of the common events of life and has often been used by the greatest natural philosophers." The explanatory success of evolutionary theory in the life sciences can hardly be overstated. As evolutionary biologist Theodosius Dobzhansky once said, "Nothing in biology makes sense except in the light of evolution." The understanding of various phenomena that has resulted from understanding evolutionary theory is nothing short of astounding.

There are innumerable other instances where scientific explanations have been tremendously successful – the oxygen theory of combustion, the discovery of electrons because of the explanations their existence provides, and many others. Scientific explanations have been tremendously successful as the method of achieving the primary aim of science: understanding.

At this point one might be inclined to wonder: What is the relationship between understanding and truth? Does science ever get to the *absolute* truth? Can we really understand without knowing the whole truth? Does science even aim at discovering the truth? These questions mark a good place to briefly pause to avoid a potential misunderstanding about how truth figures into the discussions in this book. While scientific knowledge and the depth of our understanding is always apt to change over time, this doesn't mean that science doesn't seek truth – it does. The sense in which scientific knowledge changes over time is that we often learn that what we *thought* was knowledge wasn't genuine knowledge. When we speak of the current state of scientific knowledge or our depth of scientific understanding, we are speaking of what we have good evidence to think is actually the truth. However, because that evidence is never sufficient for absolute certainty, our judgment is always open to revision, that is, our judgment of whether something is the absolute truth and whether we fully understand something is tentative.

What's to Come

In this chapter we've properly begun our investigation into how science explains the world. Predominantly, our discussion has so far centered on *why* science explains the world. As we have seen, the reason for this is fairly simple. Science explains the world because it is by way of scientific explanations that the chief cognitive aim of science is achieved. We only come to