Res Cogitans

Volume 6 | Issue 1 Article 10

5-29-2015

Explanation in Science and Technology

Josué Martín Peña Almonte
Universidad Nacional Autónoma de México

Explanation in Science and Technology

Josué Martín Peña Almonte
Universidad Nacional Autónoma de México

Published online: May 29 2015

Abstract

This article seeks to emphasize the fact that technology, like science, can also offer us explanations about the world. The article begins by adopting a definition of technology as knowledge, thus establishing a continuity between science and technology that allows us to extend the work done on the issue of scientific explanation. Three proposals are analyzed for defining the concept of scientific explanation, with emphasis on Wesley Salmon's causal mechanical model. Next, the case of the pressure and volume indicator diagram in the steam engine is analyzed, in which, despite the lack of a competent scientific theory to interpret the data obtained through a new instrument, our technological knowledge allowed for the generation of the explanations that the scientific theory of the time was unable to provide. The example meets the demands stipulated by the causal mechanical model of explanation but differs in that here the explanation was not the result of scientific knowledge. Rather, it was the technological knowledge provided by the indicator what generated a new explanation of the steam engine's efficiency and functioning.

Introduction

Modern science has managed to explain with enormous success a wide range of phenomena. Classical mechanics, for example, has provided us with a scientific explanation of the movements of terrestrial and celestial objects that allows us to predict their trajectories, impacts and exchange of forces with extreme precision. The rationality and the effectiveness of prediction that are normally offered to us by scientific explanations have become, for some time now, an important theme in the philosophy of science. Nevertheless, it is worthy to pay attention to the fact that philosophy absolutely ignores that technology is also capable of offering explanations that are as rational and predictive-effective as the ones offered by science.

Indeed, science has traditionally been seen as a means to explain and predict phenomena while technology has been seen as a way to control and manipulate phenomena at will.[1] In this article I will argue that this vision of science and technology is exceedingly strict and will defend the thesis that technology not only allows us to control and manipulate phenomena at will but can also offers us explanations of reality that are as precise and trustworthy as the ones offered by science. I will call these explanations "technological explanations".

Explanation, Science and Technology

Philosophical works that refer to science and the concept of scientific explanation have been developing vigorously for over half a century.[2] Philosophical research on technology however, constitutes a field that has only recently begun to be acknowledged by academia.[3]

As mentioned above, it is generally accepted that one of the main tasks of science is to provide explanations. However, little or nothing has been explored about the kind of explanations that technology has offered us. To properly develop the relationship between explanation and technology, we will first begin by establishing a consensus between science and technology. For this purpose we will take as a starting point Ian Quallenberg's work, *The Difference Between Technology and Science*[4]. In his work Quallenberg establishes a continuity between science and technology, breaking with the doctrines that establish hierarchical relationships between both disciplines. Under this perspective technology is not mere applied science, nor is science a means for obtaining 'pure' knowledge. Quallenberg tells us:

> It is a gradual and complex relationship[…] The higher the amount in which the level of practicality of the objectives operates in such a way that it delimits the level of generality, the more the research will tend towards technology. The lower this amount is, the more the research will tend towards science. We use the verb *to tend* because we suppose there is a continuum between science and technology and not an absolute dichotomy.[5]

---

[1] When we talk about science in this article we are referring only to the natural sciences, especially physics and sciences close to engineering practice.

[2] In contemporary philosophy the topic of scientific explanation dates back to Carl Hempel and Paul Oppenheim's famous work, "Studies in the Logic of Explanation", published in 1948.

[3] Hugo López Araiza Bravo, in "Cómo y por qué una filosofía de la tecnología" for example, drafts a history of the philosophy of technology that dates back to 1835 but finds himself in need to argue in the midst of 2012 in favor of the independent existence of this discipline.

[4] The original title in Spanish reads, *La diferencia entre tecnología y ciencia.*

[5] The original Spanish version reads "Se trata de una relación gradual y compleja[...] Entre mayor sea el grado en que el nivel de practicidad de los objetivos opere de tal manera que delimite el

In the rest of this article we will take Quallenberg's stance on the relationship between science and technology in our developing of the relationship between scientific and technological explanations. In this way, if we think of technology as analogous to science, defining it as a kind of knowledge, then the concept of explanation in relation to technology becomes twofold. On the one hand we have the traditional relationship between scientific explanation and technology; on the second hand we have the concept of technological explanation—for if there exists a continuum between science and technology, and science can offer us explanations, it is plausible to think that technology can also do the same.

To make an analysis of the two sides of the concept of explanation in technology, it will first be necessary to review three of the classical proposals offered by philosophers in relation to the features that constitute a scientific explanation. The proposals that we will review will be the deductive-nomological model, the unificationist models and the causal mechanical model.

Hempel and the Philosophical Tradition

Traditionally, the starting point for the philosophical discussion regarding scientific explanation is Carl Hempel's work, *Aspects of Scientific Explanation*. Carl Hempel was the most influential advocate of the deductive-nomological model, also called DN model of scientific explanation. In a concise manner, the model can be characterized as the attempt to comprehend, under a logical structure, the necessary and sufficient conditions for something to be called an authentic explanation in science. Under Hempel's perspective, to explain an event would be equivalent to providing a valid deductive argument with the following structure:

General Laws
Particular Facts
⇒
Phenomenon to be explained

In the model, the premises that constitute the explanation are called *explanans*, while the conclusion or phenomenon to be explained is given the name of *explanandum*. The importance of the DN model is that it was the first modern attempt to proffer a definition of scientific explanation. Under Hempel's model the explanation of an event is a valid deductive argument of the structure previously outlined. Within this structure

---

nivel de generalidad, la investigación tenderá hacia la tecnología. Entre menor sea este grado, la investigación tenderá hacia la ciencia. Usamos la palabra *tender* puesto que suponemos que hay un *continuum* entre la ciencia y la tecnología y no una dicotomía absoluta." Ian Quallenberg, "La diferencia entre tecnología y ciencia," p. 246.

it is important to highlight the role played by the general laws as principles under which we can deduce—and explain—particular phenomena. Thus, for Hempel, to explain is the equivalent of deducing a particular phenomenon out of a general law.

In spite of its initial charm, Hempel's model failed to capture the essence of the concept of scientific explanation. There are cases that, while fitting the DN model, would be absurd to consider as authentic scientific explanations. One of the most famous counterexamples to Hempel's model is the one developed by Sylvain Bromberger regarding a flagpole. The counterexample more less states the following[6]: a vertical flagpole of a certain height raises itself on a flat piece of land. The sun shines intensely and finds itself at a certain elevation to the horizon. Under these conditions the flagpole emits a shadow of a certain length. If we are asked to explain why the shadow is as long as it is, we could mention the data regarding the height of the pole and the position of the sun, which together with the law of rectilinear propagation of light allows us to deduce the length of the shadow. This deduction fulfills the DN model and it appears to be a legitimate explanation of the length of the shadow. The problem here is that, in a similar way, we could mention the data regarding the position of the sun, the length of the shadow and the law of rectilinear propagation of light to deduce the height of the flagpole. This second example, even though it fulfills perfectly the requirements of the DN model, fails to construct a legitimate explanation of the height of the flagpole. It is simply contrary to intuition to think that the length of the shadow can explain the height of the flagpole. The real reason of why the flagpole has the height that it does, surely relates with the fact that someone deliberately made it that way and not with the fact of the shadow having a determined length. Upon the DN model's failure to overcome such counterexamples alternative models of scientific explanation have appeared. In the following pages we will mention two of these models: the unificationist model and the causal mechanical model.

The Unificationist and the Causal Mechanical Model

Michael Friedman and Philip Kitcher inherit Hempel's nomological concerns—i. e., of the necessity of subsuming phenomena under general laws—and try to correct his errors through what is known as the 'unificationist models'. Unificationist models of scientific explanation center their attention on the power that laws and scientific theories have of unifying phenomena that previously appeared to be unrelated. The main premise of these models is to state that our comprehension of the world increases while the number of hypothesis needed to explain it decrease. The more phenomena

[6] Even though this counterexample is attributed to S. Bromberger it seems to never have been published. The version presented here is a paraphrase taken from Wesley Salmon, "Four Decades of Scientific Explanation", P. Kitcher and W. Salmon (eds.), *Scientific Explanation*, p. 47.

that a law or a theory can unify, the greater its explanatory power. Thus, to explain is to unify in a single law or theory phenomena that were previously unrelated.

On the other hand, the causal mechanical model of scientific explanation found its best representative in Wesley C. Salmon. Unlike Hempel's logical model that defined scientific explanation as a deductive structure, Salmon develops it in terms of a causal structure. In this sense, to explain a phenomenon is equivalent of simply determining what caused it.

Salmon has contended that the causal mechanical model of explanation doesn't oppose the unificationist model.[7] For him both models are compatible and, in a sense, complementary. A way of seeing this is to consider unificationist explanations as global explanations, i. e., that try to unify different phenomena previously unrelated within a general theory or a set of laws of nature, and causal explanations as local explanations, i. e., that focus on describing the particularities of the mechanisms that cause the phenomenon we are seeking to explain.

However, before continuing it is necessary to go into detail on the difference that Salmon establishes between explaining why a phenomenon has happed and how the phenomenon came to occur. As we will try to demonstrate, this difference can help us outline certain features shared by scientific and technological explanations.

Why and How

Traditionally it has been thought that explanations are answers to why-questions. Why do planets move in elliptic orbits? Why does the sun hide under the horizon? These are questions that demand an explanation. The models we have revised are, in a sense, attempts to define the features that a good scientific answer should have when answering a why-question.

Nevertheless, in repeated occasions Wesley Salmon pointed out that not always can an explanation request be expressed as a why-question, and that in numerous occasions the search for scientific explanations doesn't respond to why but to *how*[8]. The quest for the how, assures Salmon, requires a description of the mechanisms that produce the phenomenon we seek to explain, this is, it requires a genuine causal explanation.

---

[7] Wesley Salmon, "Scientific Explanation: Causation and Unification".
[8] Wesley Salmon, "Four Decades of Scientific Explanation", P. Kitcher and W. Salmon (eds.), *Scientific Explanation*, pp. 136-138; *id.*, "Scientific Explanation: Causation and Unification", pp. 19, 20.

As we have seen there exists two models of explanation that we can currently accept in science. Salmon sets the following example to illustrate how it is that these two models respond depending on if the explanation is sought throughout a why-question or throughout a how-question:

> If one asks *why* a penny conducts electricity, one good answer is that it is made of copper, and copper is a good conductor. If one asks *how* this penny conducts electricity, it would seem that a mechanism is called for. A story about electrons that are free to move through the metal would be an appropriate answer. In this case, the why-question elicits an appeal to a general law; the how-question evokes a description of underlying mechanisms.[9]

Until now we have focused on presenting the generalities of the philosophical discussion regarding scientific explanation. In the following pages we will address the problem on the relationship between the concept of explanation and the concept of technology.

Scientific Explanation and Technology

As we said above, we will address technology as a knowledge similar to scientific knowledge, but different from it regarding the level of practicality of its objectives and the way that they delimit the generality of the research.

Now then, when talking about the relationship between science and technology, tradition has tended to see technology as a sub product of science. It is thought that technology simply makes use of scientific explanations; in this sense the epistemological accent is centered on science. In other words, traditionally it has been thought that technology simply holds still and waits for the understanding of the world given by scientific explanations. Examples often used to prove the previous point include the technological developments given after the discovery of nuclear fission in which scientific explanations that employed the atomic theory permitted technological development on the manipulation of the nucleus for military and energetic ends.

Although there is no doubt that scientific explanations are of enormous importance for technological developments in such cases, the issue here is that this is the only relationship philosophers have explored between the concepts of explanation and technology, even though there are a large number of cases in which technological developments have anticipated any scientific explanations. In the following pages we will analyze a case in which, even though lacking a scientific theory to adequately interpret the data obtained by a new instrument, the technological knowledge of the

[9] Wesley Salmon, "Scientific Explanation: Causation and Unification," pp. 19, 20.

time was nonetheless able to generate the explanations that the scientific theory was unable to provide.

Technological Explanation

Seeking to make the steam engine more efficient, James Watt found himself in the need to measure the variations of pressure during the machine's cycle. In 1796 Watt, along with his assistant, John Southern, develops for this purpose the first pressure and volume indicator diagram.

Back then the accepted scientific theory was the caloric theory. However, the explanation of the steam engine's functioning was a real conundrum when trying to explain the efficiency of the machine at the end of the XVIII century. Applying the caloric theory Watt never managed to explain the relationship among pressure, the latent and sensible heats and the steam engine's efficiency. Watt wanted to measure the pressure during the machine's cycles because he thought that it affected the amount of latent heat, and thus, according to the caloric theory, the steams elasticity. However, after the invention of the indicator, it was necessary to discard the caloric theory and to create a whole new explanation to interpret the instruments' results. Finally, based on the indicator's measurements and a new conceptual framework, the machine's efficiency began to be explained in relationship with the measurements of pressure, volume and work (Watt used the word 'duty' instead of 'work'). What Watt discovered was that while tracing pressure and volume, the resulting area under the indicator diagram indicated the amount of work done by the machine. Even though in Watt's day the concept of work didn't form part of any theoretical framework, Watt and his contemporaries understood that the information given by the indicator could be used to measure the engine's efficiency. While describing the development of the explanation of the steam engine's functioning, Davis Baird states:

> We should not infer from this history that the substantive theory of heat or the lack of an established theory of work caused Watt or others to fundamentally misunderstand the information provided by the indicator[…] [it] did not cause him to understand the information supplied by the indicator as anything other than what we would now call the work produced by his engines. Watt used the term 'duty'. On the other hand there was no theoretical framework within which to embed this newly measured quantity, 'work' or 'duty'. We cannot say that Watt's indicator measured a certain well-understood quantity –work– of a given physical system –the steam engine. Nonetheless, Watt's indicator did measure work as we know think of it[…][10]

[10] Davis Baird, "*Thing Knowledge: A Philosophy of Scientific Instruments,"* pp. 171, 172.

Even though Watt was lacking a scientific theory competent to properly interpret the information given by the indicator, with the data given by it, the machine's functioning was finally understood and properly explained, moreover, its efficiency was improved. I quote Baird once more:

> Nonetheless, those using the instrument were able to improve the performance of their engines. I suggest that the indicator operated "according to known principals" in the sense that the relation between efficiency and the area under the indicator diagram was easily recognized and applied[…][11]

Certainly the indicator provided knowledge on the machine's efficiency and functioning. This knowledge, on the relationship between pressure, volume and work, produced a suitable explanatory framework of the machine's activity that hadn't been able to be explained by the caloric theory. What is most interesting is that that knowledge wouldn't have been achieved if Watt had abided by the scientific knowledge of his time. The explanation was obtained throughout a technological invention. In fact, the measurements given by the steam and volume indicator diagram were baffling to the caloric theory. A new explanation had to be made in order to understand the steam engine's functioning in a clearer and more suitable matter. Thus, it wasn't a scientific theory that helped engineers understand and explain the steam engine's functioning. The understanding and explanation of its efficiency was achieved throughout a measuring instrument. From the analyses on the relationship between pressure, volume and the area below the curve produced by these two measurements, a new concept was formulated: what nowadays is called 'work'. Finally with a new conceptual framework, we were able to predict the engine's efficiency based on the pressure applied and the volume changes within the machine's cylinder.

The new conceptual understanding of the data given by the indicator, not only allowed for the generation of a technological explanation of the steam engine's efficiency and functioning, but was also, the starting point to elaborate a new scientific explanation different from the one given by the caloric theory. It was the new measurement, 'work', that Watt promoted as a useful measurement to compare the efficiency between steam engines, what years later Sadi Carnot would use as a main concept in the developing of thermodynamic theory. Giving a stable record on the changes of pressure, volume and work, the indicator provided a novel theoretical ground for the subsequent development of a new science. Hence, it was the development of the technological explanation obtained by the records of the indicator what created a new conceptual framework that would subsequently foster the creation of thermodynamic theory. This proves and openly illustrates that technology produces knowledge, moreover, it proves that not only do technological explanations exist, but that they even permit the development of new scientific theories.

[11] Ibid., p. 178.

Conclusion

The concept of explanation is an important concept to science. However, a careful revision on the way our knowledge progresses reveals to us that technology too offers worthy explanations of the world. As illustrated with the case of the explanation of the indicator's data, technological explanations, just as scientific explanations, can help us answer how-questions. In this specific case the indicator's data offered, undoubtedly, a different explanation on how the steam engine functioned than the one given by caloric theory. In the example, the technological explanation established causal relationships between pressure, volume and—the new concept—work. With a new conceptual framework, the technological explanation fostered with time the creation of thermodynamic theory. Undoubtedly thermodynamics widened the knowledge given by the indicator and then elaborated a theory that unified all the thermodynamic phenomena that surround us. Thus, properly understood the only difference between scientific and technological explanations resides in the fact that scientific explanations are of a wider generality than technological explanations.

The lesson here is simple: we have to acknowledge that we still lack a sufficient comprehension on how scientific and technological knowledge relate with each other and feed back on one another. The simplistic view that technology is applied science must disappear, for it is a fact that technology is as rich as science in terms of knowledge and explanations.

This paper has sought to emphasize the fact that technology, just as science, can offer us too explanations of the world. Both science and technology move on a continuum, on a relationship of interdependence that is much more complex than what tradition has allowed us to see. Under the philosophical tradition the topic of explanation has focused on the study of scientific explanation, but it is clear that we need to widen our view to include technological explanation as well. It is important to acknowledge technology's epistemological role for only in this way can we achieve a better understanding of how our knowledge of the world articulates and develops.

Acknowledgements

I want to thank the Dirección General de Asuntos del Personal Académico (DGAPA), of the Universidad Nacional Autónoma de México, for providing support from the PAPIIT for carrying out the Project IN401314, *The role of technology in science*, of which this work is a part.

References

Baird, Davis, *Thing Knowledge: A Philosophy of Scientific Instruments*, Berkeley, University of California Press, 2004.

Hempel, Carl, *Aspects of Scientific Explanation and Other Essays in the Philosophy of Science*, New York, The Free Press, 1965.

Hempel, Carl and Paul Oppenheim, "Studies in the Logic of Explanation", *Philosophy of Science*, vol. 15, no. 2, 1948, pp. 135-175. Reprinted in Hempel, 1965.

Kitcher, Philip, "Explanatory Unification and the Causal Structure of the World", *Scientific Explanation*, Edited by P. Kitcher and W. Salmon, Minneapolis, University of Minnesota Press, 1989, pp. 410–505.

López Araiza Bravo, Hugo, "Cómo y por qué una filosofía de la tecnología", *Argumentos de Razón Técnica*, no. 15, 2012, pp. 111-124.

Newton-Smith, W.H., "Explanation", *A Companion to the Philosophy of Science*, Edited by W.H. Newton-Smith, Massachusetts, Blackwell Publishers, 2000, pp. 127-133.

Okasha, Samir, *Philosophy of Science. A Very Short Introduction*, New York, Oxford University Press, 2002. http://dx.doi.org/10.1093/actrade/9780192802835.001.0001

Quallenberg, Ian, "La diferencia entre tecnología y ciencia", *Iberofórum. Revista de Ciencias Sociales de la Universidad Iberoamericana*, año 7, no. 14, 2012, pp. 228-252.

Salmon, Wesley, "Four Decades of Scientific Explanation", *Scientific Explanation*, Edited by P. Kitcher and W. Salmon, Minneapolis, University of Minnesota Press, 1989, pp. 3–219.

Salmon, Wesley, "Scientific Explanation: Causation and Unification", *Crítica. Revista Hispanoamericana de Filosofía*, vol. 22, no.66, 1990, pp. 3-23.

Woodward, James, "Scientific Explanation", *The Stanford Encyclopedia of Philosophy*, (Winter 2011 Edition), Edited by Edward N. Zalta, URL = <http://plato.stanford.edu/archives/win2011/entries/scientific-explanation/>.