Phenomenological understanding and electric eels

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Received: 22/11/2016
Final version: 24/04/2017

BIBLID 0495-4548(2017)32:3p.293-302
DOI: 10.1387/theoria.17294

ABSTRACT: Explanations are supposed to provide us with understanding. It is common to make a distinction between genuine, scientific understanding, and the phenomenological, or 'aha' notion of understanding, where the former is considered epistemically relevant, the latter irrelevant. I argue that there is a variety of phenomenological understanding that does play a positive epistemic role. This phenomenological understanding involves a similarity between bodily sensations that is used as evidence for mechanistic hypotheses. As a case study, I will consider 17th and 18th century research into the mechanism behind the electric eel's power to shock.

Keywords: Understanding; explanation; subjective; phenomenology; electric eels.

RESUMEN: Se supone que las explicaciones nos dotan de comprensión. Es habitual hacer una distinción entre comprensión científica, genuina, y la noción fenomenológica, o 'ahá', de comprensión, donde la primera se considera epistemológicamente relevante y esta última irrelevante. Argumento que hay un tipo de compresión fenomenológica que sí juega un papel positivo epistémico. Esta comprensión epistemológica conlleva cierta semejanza con las sensaciones corporales que se usan como evidencia de algunas hipótesis mecanicistas. Como caso de estudio, consideraré la investigación en los siglos XVII y XVIII del mecanismo tras la capacidad de la anguila eléctrica para provocar un shock.

Palabras clave: Comprensión; explicación; subjetivo; fenomenología; anguilas eléctricas.

Introduction

With the rise of the new mechanist movement, Hempel-style models that (broadly speaking) equate explanation with nomic subsumption no longer enjoy the level of support they once did.[1] The gist of this movement can be stated as follows: to explain a phenomenon, simply showing that the phenomenon was to be expected, given some regularities and initial conditions, is not enough. An explanation must provide *understanding* of the explanandum phenomenon, where this understanding is achieved by describing the mechanism responsible for the phenomenon (Bechtel 2011, 536; Bechtel & Abrahamsen 2005, 430; Craver 2006, 372; Machamer, Darden & Craver 2000, 21; Weiskopf 2011, 329).

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1 For an interesting exception, see Díez (2014).

Although the new mechanist movement is relatively young and focuses chiefly on explanation in the life sciences, its appeal to understanding is part of an older and broader development in philosophy of science. Whereas for logical empiricists, understanding was a pragmatic, hence subjective notion that was of little importance to philosophy, subsequent generations of philosophers have increasingly looked to understanding as the (desired) product of scientific explanation (Salmon 1984, 259; Schurz & Lambert 1994, 109; Cushing 1994, 10; Weber 1996, 1).

With this development in mind, it is tempting to say that expectability has given way to understanding as the aim of explanation. However, as I will shortly explain, this would not be entirely accurate. As Hempel noted (1965, 425-426), reference to the notion of understanding makes explanation a three-term relation between explanandum, explanans, and the scientist providing the explanation. Since what is understandable may differ from scientist to scientist, or from community to community, this seemingly poses a threat to the objectivity of explanation. Yet Hempel acknowledged that intuitively, it feels right to say that a scientist seeks and provides explanations as a means of satisfying his "deep and persistent desire to know and to understand himself and his world" (1965, 333). Accordingly, he differentiated between two senses of understanding, namely a psychological sense, or the 'aha' feeling we get when we grasp an explanation, and theoretical understanding, namely showing that the phenomenon to be explained is an instance of a more general regularity, and therefore was to be expected. Although the idea of explanation as nomic subsumption has been largely abandoned, in section 2, I will show that Hempel's distinction between these two types of understanding is still common currency in contemporary philosophy of science, and moreover, that philosophers still share Hempel's distinction between an objective or 'genuine' sense of understanding, and a subjective, psychological one. Finally, they also share his judgment that the latter is epistemically irrelevant.[2]

In this article, I will argue that the existing dichotomy between genuine, epistemically relevant understanding, and subjective psychological understanding, is misleading. On the basis of a case study about 17th and 18th century investigations into the mechanism behind the electric eel's capacity to stun, I will argue that the phenomenological sense of understanding has been unduly restricted to the 'aha' sense; In particular, I will argue that there is a type of understanding that, although intimately tied to the personal experience of researchers, can nevertheless play an important epistemic role. This phenomenological understanding is not a 'feeling of satisfaction' that results from grasping a certain explanation, but rather an insight that is bestowed by a direct bodily sensation. The epistemic role of this phenomenological type of understanding is evidential: it supports a particular hypothesis over its rivals.

Let me conclude with a brief overview. As I already remarked, in section 1, I will show that Hempel's distinction between a psychological and a theoretical sense of understanding, and his dismissal of the former as epistemically irrelevant, are still widely embraced in the literature. In section 2, I will present the case study in full, arguing that a particular type of phenomenological understanding played a positive epistemic role in discovering the mechanism responsible for the eel's capacity to numb. In section 3, I will argue that this type of understanding escapes the dichotomy sketched above: it is neither objective, theo-

2 Of course, this is not to say that these authors believe that such understanding can *never* lead one to a correct explanation, but just that it is not a reliable indicator.

retical understanding, nor the feeling of satisfaction we get after having grasped an explanation. Finally, in section 4, I will flesh out the epistemic role that this type of phenomenological understanding plays in the explanatory process. A short conclusion sums up the results.

1. Hempel's legacy

As recounted in the introduction, Hempel distinguished between a psychological and a theoretical notion of understanding, and thought that only the latter had any epistemic impact, since the former is subjective in character. Of course, this judgment ties in with the general dominance of logical empiricism in the first half of the twentieth century. These days the influence of logical empiricism has waned considerably for a host of reasons, yet this particular aspect of it, namely the distinction between theoretical and psychological understanding, has by and large survived. Although many philosophers do feel that there are other epistemologically important notions of understanding besides theoretical understanding in the sense of expectability, they share Hempel's dismissive verdict on the 'aha' sense of understanding.

Salmon for instance, has this to say about how understanding:

> To understand the phenomena in the world requires that they be fitted into the general world-picture. Although it is often psychologically satisfying to achieve this sort of agreement between particular happenings and the worldview, it must be emphasized that psychological satisfaction is not the criterion of success. To have *scientific* understanding, we must adopt the worldview that is best supported by all of our scientific knowledge [...]. The superiority of understanding based on a scientific worldview lies in the fact that we have much better reason to regards that worldview as true – even though some other worldview might have more psychological appeal. (Salmon 1998, 76-77, original italics)

Clearly, the idea is that a psychological sense of understanding is epistemologically inferior to scientific understanding, since it is not a good proxy for the truth. Craver makes a similar point:

> ...in neuroscience, and in other sciences as well, explanations are not developed merely for the explainer's intellectual satisfaction – the ineffable 'a ha' feeling that comes with understanding something. Such emotions and feelings are terrible indicators of how well someone understands something. (Craver 2007, 5)

Perhaps the most forceful critic of the phenomenological sense of understanding is J. D. Trout. He argues (2002, 2005) that such understanding is tightly bound up with hindsight and overconfidence biases. Trout calls this 'counterfeit understanding' (2002, 215), and believes it a poor indicator of genuine understanding, since we often have the feeling of understanding without real understanding, and real understanding may occur without being accompanied by a feeling of understanding. This counterfeit understanding can even be dangerous: "By prioritizing the phenomenology of understanding, philosophers of science risk a fundamentally psychological notion of explanation, thereby threatening its objectivity" (Trout 2005, 199).

Finally de Regt and Dieks, who have developed a contextual theory of understanding that focuses on intelligibility and use of theories (2005, further developed in de Regt 2009) in order to rehabilitate the notion of scientific understanding, nevertheless make it very clear that they are not interested in the psychological sense of understanding. In a discussion note about Trout's 2002 article[3], de Regt says of such subjective experience that "nobody would want to maintain that such a feeling is either necessary or sufficient for anything that deserves to be called scientific understanding [...] surely they are neither an aim of science nor a condition for scientific understanding." (de Regt 2004, 103-104).

These are just some examples of how Hempel's rejection of the feeling of understanding manifests itself in contemporary philosophy of science, but I think they are indicative of a general consensus (see Gopnik 1998 for a dissenting view however). The general state of affairs then is as follows. There is a genuine, objective sense of understanding provided by scientific explanations, and a phenomenological feeling of satisfaction that is accompanied by explanations. The latter is regarded by most parties as subjective and unscientific, or at least a bad indicator for truth, and the major differences are on how exactly to spell out the former. In the rest of this article, I shall have little to say on the feeling of satisfaction, nor will I make an attempt to contribute to the debate about the objective, theoretical notion understanding. Rather, I will argue that there is more to phenomenological understanding than just the 'aha' experience, by presenting a type of understanding that although phenomenological in character, does have a positive epistemic role to play.

2. *Electric eels and the phenomenology of understanding*

I believe that the phenomenology of understanding played an important epistemic role in 17th and 18th century research into the mechanism behind the electric eel's capacity to produce numbing sensations.[4] Before the electric eels[5] of South-America were discovered, two types of 'numbing fish' were already known in the old world: the sea Torpedo, and the African Silurus (a catfish found in the waters of the Nile). Their mysterious power to produce numbing sensations in the persons handling them was already commented on in Antiquity. Galen attributed this numbing power to poison the fish supposedly emitted when touched.[6]

With the exploration of South-America in the 16th and 17th centuries, a third numbing fish became known: the South-American eel. This fish roused the interest of European scientific community, partly because it came from exotic places like river-systems in the Ama-

[3] The discussion between de Regt and Trout seems to revolve around the question whether the problems associated with the psychological notion of understanding should lead us to abandon the notion of understanding altogether (Trout's view), or whether there is a notion of understanding that, although not objective, is important to understand science (de Regt's view). For the purposes of this paper, this dispute is not relevant.

[4] The following case study draws upon Koehler, Finger & Piccolino (2009).

[5] In the interests of taxonomical accuracy, it should be pointed out that nowadays, the *Electrophorus Electricus* is classified as a member of the knife fish group (*gymnotiformes*) rather than the eels – they were just called eels by the early explorers because of the physical similarities with European eels. Anyway, let's just call them eels.

[6] It is not always clear to which of the two numbing fish the early commentators were referring to. The Greek word *νάρκη* (which also means numbness) refers to both, as does the Latin word *torpedo*. In any case, the phenomenon was known and studied.

zon, but also because the numbing sensation they produced was much more powerful than the previously known Torpedo and Silurus (as we now know, 600 volts as opposed to 50 and 300 volts respectively). The first descriptions of the fish were made in the 16th century by Spanish administrators and officials, but gradually, more detailed accounts appeared. In the 1670s, French astronomer Jean Richer visited Cayenne and described his encounter with the eel:

> I was even more surprised to see a three to four foot fish, similar to an eel [...] that by simple touch with a finger or the tip of a stick, so numbs the arm and that part of the body closest to it that one remains about 15 minutes without being able to move [...] I was witness to this effect and I felt it, having touched the fish with my finger one day when I met up with some savages. (Richer 1679)

We may view reports like this as constituting the first step in the process of mechanism discovery, namely the identification of the explanandum-phenomenon, after which a phase of hypothesis generation starts (Darden 2009). And indeed, in the case of the South-American eel, the description of the explanandum phenomena led to much speculation among scholars back in Europe about the nature of the mechanism responsible for it.

According to one hypothesis, the numbing sensation was produced by animal spirits; according to another, it involved a biochemical process akin to fermentation. The Italian physician and ichthyologist Stefano Lorenzini (1678) thought that the process was mechanical rather than chemical. He proposed that the stunning power of the fish was due to the violent emission of large quantities of corpuscles that were so tiny that they penetrated the skin and interfered with the nerve conduction of the hand touching it – the inspiring idea here being that of a coiled up spring which is released upon making contact with the skin. His colleague Giovanni Borelli (1680-1681) latched on to the idea, but in his hypothesis, the corpuscles were too large to penetrate the skin, and caused the numbness by hitting the hand at high speed (percussive and concussive action). René-Antoine de Réaumur on the other hand, said about the earlier known torpedo that it caused numbness by quickly changing its shape. Normally the shape was flat or concave, but upon being touched, it would become convex very rapidly, due to elastic action of tiny muscular fibers, causing numbness in the hand by nerve compression. Although de Réaumur was talking about the torpedo, his hypothesized mechanism was applied to the South-American eel by others (Allemand 1756). Finally, there is the proposal that the mechanism is electric in nature.

No shortage of hypotheses then, and in the 17th and early 18th centuries, it was by no means clear that the electricity hypothesis would come out on top. So how did this hypothesis ultimately prevail over its many rivals? Phenomenal understanding played an important role here.

During this period, the European scientific community became increasingly interested in the phenomenon of electricity. A number of spectacular experiments were carried out that demonstrated the electrical nature of lightning. Further experiments showed that a clear distinction could be made between conducive and non-conducive materials, and that electricity could travel at high speed through metal wires. Of particular importance was a development in technology: the invention of the Leyden jar in the 1740s. An early capacitor, it stores static electricity between two layers of metal foil, attached to the inside and outside of a glass jar filled with water. The two layers of foil stop at the mouth of the bottle so as not to touch each other. A metal rod through the stopper is electrically connected to the inner foil to charge it. Using an electrostatic generator and keeping the outer foil grounded, the inner and outer surfaces receive equal but opposite charges. Bringing these into contact would release the charge and produce the characteristic sparks.

The invention greatly helped the study of electricity, as it was small and convenient enough to carry around, so that experiments could also be performed outside of the laboratory, and the Leyden jar became the principal means of storing electricity across the continent. It stands to reason that scientists investigating the properties of electricity were highly interested in the accounts of the numbing eels coming from the colonies. However, they had great difficulty in obtaining live specimens. In the 18th century, the voyage was still long and arduous, and keeping the fish alive for such a long time proved difficult. In effect, the problem was that the necessary research facilities were located on one side of the Atlantic Ocean, and the eels on the other. Nevertheless, the descriptions coming back to Europe reminded scientists of their own experiences with electricity. What was needed was for someone to *first touch the Leyden jar, and then travel to the colonies and touch the eels*.

This is exactly what happened. The Swiss-Dutch naturalist Jean-Nicholas-Sébastien Allemand, failing to obtain a live specimen, wrote to his friend Laurens Storm van 's Gravensande, a Dutch official working in the Dutch west indies, to seek out and study the fish. van 's Gravensande had previously touched the Leyden jar, and wrote back to Allemand, recounting his experience:

> The experiment was done with an eel called a tremble fish [...] It produces the same effect as the electricity that I felt with you, while holding in a hand a bottle [the Leyden jar] that was connected to an electrified tube by an iron wire. (Allemand 1756)

This, I would say, constitutes a clear example of phenomenological understanding: a first-person experience that leads us to accept, or at least pursue, a hypothesis about the mechanism responsible for an explanandum-phenomenon. As it is undeniably first-person, it is not objective, but for 's Gravensande, the experience must have been a compelling reason to pursue the electric hypothesis.

3. *How does phenomenological understanding relate to other types of understanding?*

Let us now turn to the question how this type of understanding relates to other types as they feature in the literature. First, note that it does not fall under the heading of 'theoretical' or 'scientific' understanding. It is not expectability (Hempel), it is not based on a 'best supported worldview' (Salmon), nor does it seem to have anything to do with intelligibility and use (de Regt and Dieks). Also, there is an important difference in character between the first-person phenomenological, and the third-person theoretical types of understanding. Consider the type of third-person understanding the new mechanists aim at. This understanding seems to develop gradually, tying in with the idea that mechanistic explanation consists of adding details about activities and entities to skeletal models of mechanisms, so that as we move from how-possibly models, via how-plausibly models, to how-actually models (Machamer, Darden & Craver 2000; Craver 2006, 2007) our understanding grows. We conjecture that a mechanism is (to keep with the case study) electric in nature, and then start investigating, trough intervention experiments, the actual mechanism. As the results of the experiments confirm our hypothesis and we fill in more and more blanks of the model, the confidence in our hypothesis grows, so that we gradually come round to the viewpoint that the mechanism is electric. In contrast, the first-person psychological understanding obtained by touching the eel after having touched the Leyden jar, seems instantaneous, its characteristic being more like that of a divine revelation rather than a gradual increase in confidence. Clearly then, we are dealing here with a different type of understanding.

Being phenomenological, does this understanding then belong to the realm of the 'aha' experience? No. *Pace* Trout (as quoted in the introduction), while it is a phenomenological type of understanding, it is not some kind of feeling of satisfaction we get by grasping the electricity-explanation, but an insight brought on by recognizing the phenomenological similarity of touching the eel, to the previous experience of touching the Leyden jar. In fact, to put it into philosophically familiar terms, 'what it is like to be shocked by a Leyden jar' is similar to 'what it is like to be shocked by an eel'. Of course, it is not incompatible with the feeling of satisfaction, and indeed, van 's Gravensande may well have experienced an 'aha' moment upon noting the similarity between the two sensations, but they are distinct. It seems that there is more to phenomenological understanding besides the 'aha' experience.

4. The epistemic role of phenomenological understanding

In the case of van 's Gravensande, we see how the phenomenological sense of understanding can play a positive epistemic role. It instils in anyone who has touched both the eel and the Leyden jar the acute realization that the mechanism by means of which the eel produces numbness is electric. Conversely, would the experiences be phenomenologically different, surely this would dissuade the scientist from positing a similar mechanism.

One might wonder at this point to what extent our understanding of the mechanism responsible for the eel's capacity to numb is increased by van 's Gravensande's experience. After all, not much was known about the nature of electricity at the time. Hence, how much understanding is gained by the similarity of mechanisms that is inferred on the basis of the perceived similarity of sensations, is to a certain extent contingent upon scientific progress. It is conceivable (though perhaps historically unlikely) that the eels would have been discovered during the late 19th century, by which time electricity was much better understood. In that case, the phenomenal experience would have yielded a much deeper understanding.

Besides the extent of understanding bestowed by such experiences however, there is another worry. As I have argued above, the epistemic role of this type of phenomenological understanding, is evidential: it increases (or decreases in the case of dissimilarity) our confidence in a particular hypothesis over its rivals. But of course, confidence may be unwarranted. The problems of hindsight and overconfidence biases Trout discusses, although targeted at the 'aha' sense of understanding, affect phenomenological understanding as well.[7]

[7] See Grimm (2009) for a dissenting view. He presents some interesting evidence coming from cognitive psychology, which suggests that the seriousness and extent of these biases may be overstated by Trout. Of course, this is an empirical question that needs much more systematic attention than I can give it here; pending that, it is wise to take the possibility of bias seriously.

The hindsight bias (the 'I knew it all along' feeling) is traditionally established by letting participants in an experiment estimate the likelihood of an event in the future, and asking them to recall these estimates after the event occurred or failed to occur. Almost invariably, if the participants correctly predicted the event, they remember their estimates as higher than they actually were. If the prediction failed, they remember their estimates as lower than they were. In the case at hand, this would presumably translate into something like rating the degree of similarity between touching the Leyden jar and the eels before subsequent experiments confirmed the electric hypothesis, and recalling this rating after. While it is not clear how such an experiment would take place in practice, we can see that it is certainly possible that the ratings differ in the way described above. Overconfidence bias is demonstrated by letting people rate the confidence in their judgements, and compare the results with the accuracy of these judgments. The data here show that confidence routinely exceeds accuracy. Again, we can well imagine that in particular cases, the phenomenological similarity between two sensations may lead us to be overconfident in our hypothesis, even though in the case of the eels, that was not the case.

It should be stressed then that the phenomenological sense of understanding is not infallible, and that it is neither necessary nor sufficient for explanation: it would be unwise to rely on phenomenological understanding alone, without combining it with other evidence. Indeed, in the case of the eel, the phenomenological evidence was backed up by evidence obtained by means of intervention experiments. For example, it was found that touching the eel with a wooden rod would result in a less severe shock, that if five persons held hands and the first touched the eel, the fifth person would be shocked less severely, etc. (Gronov 1758). Nevertheless, it seems that a first-person experience like this can cause a scientist to doggedly adhere to a hypothesis, even in the face of third-person evidence against it. In the case of the eels, one problem was that the fish did not produce sparks, which at the time was considered the hallmark of electricity (the 'electric fire'). In 1776, scientist John Walsh successfully drew a spark from a live specimen brought to London, and when he repeated the experiment before the Royal Society, this helped a great deal in persuading the scientific community to accept the electric hypothesis. Another piece of third-person evidence against the electrical hypothesis had to do with water. It was widely believed that electricity and water did not mix: electric devises such as the Leyden jar did not work under water. Yet clearly, the eel's capacity to numb is maintained under water. This problem was addressed by naturalist philosopher Henry Cavendish, who designed an artificial torpedo. Powered by many lowly charged Leyden jar, this artificial torpedo could produce numbing sensations under water, without visible sparks (Walsh 1773).

With this in mind, let us consider again Trout's warning that "By prioritizing the phenomenology of understanding, philosophers of science risk a fundamentally psychological notion of explanation, thereby threatening its objectivity" (Trout 2005, 199). Does accepting phenomenological understanding undermine the objectivity of scientific explanation? Hardly. The epistemic role of phenomenological understanding is to point us to a certain hypothesis. It does not in any way replace objective, third-person understanding procured by experiments, but rather invites us to procure such understanding in order to confirm or disconfirm our hypothesis. It is perfectly possible to acknowledge this role of phenomenological understanding without 'prioritizing it': I am sure that other types of understanding are also important. Of course, the phenomenological evidence obtained by researchers like van 's Gravensande could be mistaken, and as we have seen, the hypothesis was backed up by evidence obtained from intervention experiments. As such, I do not employ a 'fundamentally psychological' notion of explanation. Phenomenological and theoretical understanding worked complementary in explaining the eel's capacity to numb. Far from being a 'terrible indicator of understanding', or 'threatening the objectivity of science', first-person experience can play an important role in the process of mechanism discovery. Rather than threatening objectivity, the fact that the evidence comes from different domains, ranging from the phenomenological to intervention experiments, might be seen to lend to the electricity hypothesis what Heather Douglas (2009, 120) calls 'convergent objectivity', or multiple strands of evidence obtained by independent techniques confirming the same hypothesis.

Conclusion

In this article, I have argued that phenomenological understanding should not be restricted to merely the feeling of satisfaction one gets after grasping an explanation. This restriction makes us overlook other possible types of phenomenological understanding that can play an important part in the process of scientific explanation. The phenomenological understanding that guided the discovery of the mechanism responsible for electric eels to stun, constitutes an example of this.

If we put ourselves in van 's Gravensande's position, it is hard to deny that the phenomenological similarity of his two experiences, although not infallible, constituted an extremely powerful incentive to accept or at least pursue this particular hypothesis – a hypothesis that proved to be true. Therefore, although I readily acknowledge the dangers of bias when it comes to phenomenological experience, I believe that this case study shows that there is more to phenomenological understanding than just the 'aha' experience.

REFERENCES

Allemand, J. N. S. 1756. Kort verhaal van de uitwerkzelen, welke een Americaanse vis veroorzaakt op de geenen die hem aanraaken. *Verhandelingen Hollandsche Maatschappye der Weetenschappen Haarlem* 2: 372-379.

Bechtel, W. 2011. Mechanisms and Biological Explanation. *Philosophy of Science* 78: 533-557.

Bechtel, W. and A. Abrahamsen. 2005. Explanation: A Mechanist alternative. *Studies in History and Philosophy of Biological and Biomedical Sciences* 36: 421-441.

Borelli, Giovanni Alfonso. 1680-1681. *De Motu Animalium*. 2 vols. Roma: Bernabo.

Craver, C. F. 2006. When mechanistic models explain. *Synthese* 153: 355-376.

Craver, C. F. 2007. *Explaining the Brain*. New York: Oxford University Press.

Cushing, J. T. 1994. *Quantum Mechanics. Historical Contingency and the Copenhagen Hegemony*. Chicago: The University of Chicago Press.

Darden, L. 2009. Discovering mechanisms in molecular biology. Finding and fixing incompleteness and incorrectness. In J. Meheus & T. Nickles, *Models of Discovery and Creativity*. Dordrecht, Springer: 34-55.

Díez, J. 2014. Scientific w-explanation as ampliative, specialized embedding: A neo-Hempelian account. *Erkenntnis* 79: 1413-1443.

de Regt, H. W. 2004. Discussion note: Making sense of understanding. *Philosophy of Science* 71: 98-109.

de Regt, H. W. 2009. Understanding and scientific explanation. In H. W. de Regt, S. Leonelli, & K. Eigner (eds.), *Scientific Understanding: Philosophical Perspectives*. Pittsburgh: University of Pittsburgh Press, 21-42.

de Regt, H. W. and D. Dieks. 2005. A contextual approach to scientific understanding. *Synthese* 144: 137-170.

Douglas, H. 2009. *Science, Policy and the Value-Free Ideal*. Pittsburgh: University of Pittsburgh Press.

Gopnik, A. 1998. Explanation as orgasm. *Minds and Machines* 8: 101-118.

Grimm, S. 2009. Reliability and the sense of understanding. In H. W. de Regt, S. Leonelli, & K. Eigner (eds.), *Scientific Understanding: Philosophical Perspectives.* Pittsburgh: University of Pittsburgh Press, 83-99.

Gronov, L. T. 1758. Brief van D. Laurens Theodorus Gronovius aan C. N. over niew-ontdekte zeediertjes en byzonderheden van den siddervis of beef-aal (Leide October 1758). *Uitgezogte Verhandelingen uit de Nieuwste Werken van de Societeiten der Wetenschappen in Europa en van Andere Geleerde Mannen* 3: 464-478.

Hempel, C. G. 1965. *Aspects of Scientific Explanation. New York*: Free Press.

Koehler, P. J., S. Finger, and M. Piccolino. 2009. The eels of South-America: Mid-18th century Dutch contributions to the theory of animal electricity. *Journal of the History of Biology* 42: 715-763.

Lorenzini, S. 1678. *Osservazioni intorno alle torpedini*. Firenze: Onofri.

Machamer, P., L. Darden, and C. F. Craver. 2000. Thinking about mechanisms. *Philosophy of Science* 67: 1-25.

Richer, J. 1679. Observations astronomiques et physiques faites en l'Isle de Caienne. En Divers authors (1678-1693). *Recueil d'observations faites en plusieurs voyages par ordre de sa majesté, pour perfectionner l'astronomie et la geographie*. Paris: Imprimerie Royale.

Salmon, W. C. 1984. *Scientific Explanation and the Causal Structure of the World*. Princeton: Princeton University Press.

Salmon, W. C. 1998. *Causality and Explanation*. New York: Oxford University Press.

Schurz, G. and K. Lambert. 1994. Outline for a theory of scientific understanding. *Synthese* 101: 65-120.

Trout, J. D. 2002. Scientific explanation and the sense of understanding. *Philosophy of Science* 69: 212-233.

Trout, J. D. 2005. Paying the price for a theory of explanation: de Regt's discussion of trout. *Philosophy of Science* 72: 198-208.

Trout, J. D. 2007. The psychology of explanation. *Philosophy Compass* 2, 564:596.

Walsh, J. 1773. On the electric property of Torpedo. In a letter to Ben Franklin. *Philosophical Transactions of the Royal Society* 63: 478-489.

Weber, E. 1996. Explanation, Understanding and Scientific Theories. *Erkenntnis* 44: 1-23.

Weiskopf, D. A. 2011. Models and mechanisms in psychological explanation. *Synthese* 183: 313-338.

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