



From Explanation to Understanding: Normativity Lost?

Henk W. de Regt¹

Published online: 16 September 2019
© The Author(s) 2019

Abstract

In recent years, scientific understanding has become a focus of attention in philosophy of science. Since understanding is typically associated with the pragmatic and psychological dimensions of explanation, shifting the focus from explanation to understanding may induce a shift from accounts that embody normative ideals to accounts that provide accurate descriptions of scientific practice. Not surprisingly, many ‘friends of understanding’ sympathize with a naturalistic approach to the philosophy of science. However, this raises the question of whether the proposed theories of understanding can still have normative power. In this paper I address this question by examining two theories of scientific understanding: Jan Faye’s pragmatic-rhetorical theory and my own contextual theory of scientific understanding. I argue that both theories leave room for normativity, despite their naturalistic tendencies. The normative power of my contextual theory is illustrated with a case study of the chemical revolution.

Keywords Chemical revolution · Intelligibility · Naturalism · Normativity · Scientific understanding · Explanation

1 Introduction

Since the turn of the millennium, the notion of understanding is a central topic of debate in the philosophy of science, and various philosophical theories of scientific understanding have been presented in the literature. Today, the idea that scientific explanations provide understanding, and the question of the nature of this understanding, is considered a legitimate subject for philosophical investigation. This contrasts starkly with the heydays of logical empiricism, when understanding was deemed a subjective, psychological phenomenon, which was perhaps of interest to empirical studies of science—such as the historiography and psychology of science—but not to the philosophy of science. The logical empiricists’ view was that philosophy of science should focus on the notion of explanation, to provide a logical analysis of this concept that may be used as a basis for normatively assessing prospective scientific explanations. In other words, they relegated understanding

✉ Henk W. de Regt
henk.deregt@ru.nl

¹ Institute for Science in Society, Radboud University, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands

to the descriptive context of discovery, while regarding explanation as part of the normative context of justification.

With the advent of naturalistic philosophy of science (Giere 1999, 151–173), this situation has changed radically. Today, many philosophers of science readily incorporate results of empirical studies of science, provided by historians of science, psychologists and cognitive scientists. This also applies to the philosophical debate about explanation and understanding: the growing attention for the role of understanding comes with an emphasis on analyzing how scientists achieve understanding in actual or historical practice, and on accounts that accurately describe these processes. As a result, the focus on understanding appears to lead to a shift from accounts that embody *normative ideals* to accounts that provide *accurate descriptions* of scientific practice. Thus, the question arises whether this naturalistic turn entails that normative appraisal, which after all remains an important aim of philosophical inquiry, becomes more difficult to achieve. Indeed, naturalism has often been associated with accounts that could not explain how normative epistemological statements can be justified without making the naturalistic fallacy.

In this paper I will argue that this fear is unfounded. I will not only show that naturalistic approaches can be consistent with the norms of scientific inquiry, but also argue that they help to uncover norms that are built into scientific practice, and that these norms cannot be revealed by the traditional and more formal approaches to explanation, in which understanding is regarded as merely a psychological phenomenon without philosophical significance. My aim in this paper is to disclose the norms of reasoning and behavior in the sciences that would not have been recognizable without a proper analysis of the notion of understanding. To achieve this, I will consider two recent philosophical theories of scientific understanding of a naturalistic kind: Jan Faye's pragmatic-rhetorical theory and my own contextual theory. I will argue that neither theory is normatively sterile. Although the aim of both theories is first and foremost descriptive and explanatory, they can also serve as a basis for normative assessment of scientists' actions.

The outline of the paper is as follows. Section 2 reviews the philosophical debate about scientific explanation and understanding with a focus on the tension between normative and descriptive aims of various philosophical theories. Section 3 zooms in on the normative dimension of Faye's theory of understanding and my own contextual theory. In Sect. 4 an in-depth case study of an episode in the history of chemistry illustrates the normative power of the contextual theory. Section 5 concludes.

2 Explanation, Understanding, and Normativity

In the 1950s and 1960s the notion of understanding was largely ignored by philosophers of scientific explanation. An exception was Michael Scriven, who in his paper 'Explanations, predictions, and laws' stated that "the request for an explanation presupposes that *something* is understood, and a complete answer is one that relates the object of inquiry to the realm of understanding in some comprehensible and appropriate way" (Scriven 1962, 202). In response, however, Carl Hempel argued that philosophers should be concerned with the logic of explanation only and ignore notions like 'understanding' and 'comprehensible' because these "refer to the psychological or pragmatic aspects of explanation" (Hempel 1965, 413). Hempel's point was that these aspects are irrelevant to the philosophical analysis of explanation because they are relative to the individuals who produce or receive the explanation. They may be interesting from a *descriptive, empirical* point of view (say, for

the psychologist of science) but not from a *normative, logical* perspective (for the philosopher of science). Hempel's sharp demarcation of the pragmatic and non-pragmatic dimensions of explanation shaped the philosophical debate about explanation for decades: though his covering-law model of scientific explanation was criticized from the 1960s onwards, for a long time the discussion remained within the boundaries drawn by Hempel. In his *Four Decades of Explanation*, Wesley Salmon relates this to the general climate in philosophy, observing that the 1950s and early 1960s witnessed a "strong opposition [...] between the Wittgensteinians, who practiced ordinary language analysis, and the logical empiricists, who might be characterized as artificial language analysts" (Salmon 1989, 35–36). Salmon's diagnosis reads:

It is easy to see why deep philosophical conflict arose in that situation. The ordinary language philosopher finds the logical empiricist insensitive to human needs and interests. The logical empiricist finds the ordinary language philosopher unappreciative of the objective features that determine whether a proffered explanation is a bona fide explanation. (Salmon 1989, 36)

Salmon's characterization of the situation suggests that part of the conflict was a disagreement about whether philosophy of science should provide a normative assessment or an accurate description of explanatory practice. The logical empiricists focused on objective norms for "bona fide" explanations, while the ordinary language philosophers described how actual explanations relate to pragmatic aspects like "human needs and interests".¹ With respect to scientific explanation Hempel's normative logical-empiricist approach carried the day, while for a long time Scriven's descriptive, pragmatic approach was largely neglected in mainstream philosophy of science.

It was only in the 1980s that the pragmatic approach to explanation returned on the scene, with Bas van Fraassen and Peter Achinstein as its most prominent advocates. But once again these theories of explanation were criticized for their alleged lack of normative power. The theory of van Fraassen is pragmatic because it asserts that not all scientifically relevant factors are explanatorily relevant to a particular explanation request: explanations single out 'salient factors' among the scientifically relevant factors, where the context determines what is explanatorily relevant. This idea was criticized by Philip Kitcher and Wesley Salmon for posing no restriction on the relevance relation (Salmon 1989, 141–146), and more recently by Michael Strevens (2008, 22), who classifies van Fraassen's approach to explanation as a relativist one. In a similar vein, Achinstein's pragmatic theory of explanation, in which the notion of understanding plays a central role, was criticized for allegedly failing to specify the objective relationship between a why-question and its correct answer, on which a sound explanation should be based (Salmon 1989, 148). In sum, the main objection to pragmatic approaches to explanation has been concerned with the lack of normativity, that is, the perceived failure to specify objective criteria for distinguishing between valid and invalid, or correct and incorrect, explanations.

Non-pragmatic theories of explanation such as Hempel's covering law model, the unificationist models of Friedman and Kitcher, and Salmon's causal-mechanical model of explanation are (at least implicitly) normative in the sense that they specify what counts as an *acceptable* or *good* scientific explanation. Still, they also aim at some descriptive

¹ Hempel (2001, 357–359) sees a comparable contrast between "the analytic-empiricist and the historic-sociological, or pragmatist, school", where the former offers a normative and the latter a descriptive construal of scientific rationality.

accuracy: proponents of these theories typically argue that their favored normative rules or principles for explanation align with the history and practice of science, and that generally accepted examples of good scientific explanations can be reconstructed in terms of their theory. Kitcher (1989, 437–448), for example, analyzes classical genetics, Darwinian evolutionary theory, and the theory of the chemical bond as being explanatory because they conform to his ideal of explanation by unification. Thus, the aim of these theories of explanation is first and foremost to provide *normative guidelines* for constructing and assessing explanations, but they also seek to *describe* actual cases of accepted scientific explanations.

Carl Craver, who defends a non-pragmatic theory of mechanistic explanation that is specifically suited for the neurosciences, addresses the issue of normative power versus descriptive accuracy explicitly in his *Explaining the Brain* (2007). In the preface he states that the goal of his project is both descriptive and normative, where the descriptive aim is to “characterize the mechanistic explanations in contemporary neuroscience and the standards by which neuroscientists evaluate them”, while the normative aim is “to clarify the distinction between good explanations and bad” (Craver 2007, vii–viii). He acknowledges that the normative does not follow directly from the descriptive (because scientists are sometimes mistaken and standards for explanation may change over time), but he argues that descriptive accuracy can help to reach the normative aim in the following way: a philosophical account should accommodate “the clear-cut and uncontroversial cases of successful and failed explanations”, and the “controversial cases can then be decided according to the account that best accommodates the central and uncontroversial cases” (Craver 2007, ix).² In Chapter 4, entitled “The norms of mechanistic explanation”, Craver presents his mechanistic account of explanation, guided by two normative distinctions: (1) the account should be able “to distinguish how-possibly models from how-actually models”; and (2) the account “should distinguish mechanism sketches from complete mechanistic models” (Craver 2007, 112–113). Craver concludes that progress in the development of mechanistic explanations “involves movement along both the possibly-plausibly-actually axis and along the sketch-schema-mechanism axis” (Craver 2007, 114). Craver’s norms for assessing mechanistic explanations are in line with the views of Hempel (1965, 423–424 and 428–431), who relegated how-possibly explanations and explanation sketches to the domain of pragmatics and argued that they fail to meet the standards for acceptable scientific explanation. It is therefore not surprising that Craver, like Hempel, also downplays the importance of understanding for scientific explanation, arguing that feelings of understanding are often misleading (Craver 2007, 21) and that one can have explanation without understanding (Craver 2007, 33–34).

In more recent years scientific understanding has become a focus of philosophical attention independently of explanation. Since the turn of the millennium the notion of understanding has been scrutinized from various perspectives, both in philosophy of science and in epistemology. For many philosophers of science, scientific understanding is now a central topic of investigation, and its pragmatic aspects are no longer routinely regarded as irrelevant from a philosophical perspective. Still, there appear to be two types of approaches to the analysis of (scientific) understanding, which roughly correspond to the two strands described above. On the one hand, one finds philosophers who emphasize that understanding should ultimately be grounded in objective explanations and/or knowledge (of, for example, causal relations). The understanding itself then consists in a ‘grasp’ of

² See also Craver (2007, 19–20): the model of explanation should be both descriptively adequate and function as a regulative ideal.

those explanations or causal relations, respectively (Grimm 2017; Strevens 2008; Khalifa 2017). Although they acknowledge that understanding involves a ‘grasp’, which is a cognitive achievement that relates to the psychology of the subject, they do not see this as sufficient for genuine understanding. Stephen Grimm, for example, adds an explicitly normative requirement when he states that “what seems needed *in addition to* an accurate, subjectively justified grasp of the world is some sort of reliable connection between one’s grasp and how the world is” (Grimm 2017, 218).

On the other hand, there are those who put the pragmatics of understanding center stage in their analysis. This typically leads to approaches to scientific understanding that invoke the results of empirical study by, for example, psychologists, historians, or sociologists of science. Thus, Faye (2014) bases his theory in part on results from cognitive science and evolutionary theory, while De Regt (2017) builds on historical studies of scientific development. Such approaches employ a *naturalistic* methodology, in the sense defined by Papineau: “Methodological naturalists see philosophy and science as engaged in essentially the same enterprise, pursuing similar ends and using similar methods” (Papineau 2016). Prominent philosophers of science taking a naturalistic approach are Ronald Giere (1999) and Joseph Rouse (2015).³ It should be emphasized, however, that methodological naturalism does not necessarily imply a radical scientism that aims to reduce philosophy completely to the empirical sciences, such as Quine advocated in his ‘Epistemology naturalized’. While Quine’s naturalism is purely descriptive and explanatory, leaving no room for normative philosophy at all, methodological naturalism may still be compatible with normative aims, as I will show below. Still, there are obstacles to reconciling naturalistic philosophies of science with normativity. The most fundamental one is Hume’s is/ought problem, also called the naturalistic fallacy, which asserts that it is impossible to derive normative claims from mere descriptions of how the world is. Giere (1999, 72–75 and 151–173), who favors a naturalistic approach to the philosophy of science, addresses this ‘argument from norms’ against naturalized philosophy of science, arguing that the norms of scientific rationality are not categorical but instrumental (and can be explained on an evolutionary basis).⁴

So far, our discussion has shown that the *prima facie* assumption that theories of explanation are normative while theories of understanding have descriptive aims has to be rejected. The difference is rather one of emphasis and degree: non-pragmatic theories of explanation place stronger emphasis on normative assessment, while pragmatic theories of explanation and naturalistic theories of understanding focus more on descriptive accuracy. When advocates of non-pragmatic theories of explanation describe cases from the history or practice of science, they typically do so in the form of a rational reconstruction, which also has a normative component. By contrast, the normative power of pragmatic and naturalistic theories is not immediately obvious. In the next section I will examine two naturalistically inclined accounts of understanding, Jan Faye’s pragmatic-rhetorical theory and

³ According to Rouse, “the most pressing challenge for naturalism today is to show how to account for our own capacities for understanding that could be understood scientifically” (Rouse 2015, 6–7). A naturalistic account of scientific understanding should show how our capacities for understanding “are a natural phenomenon, intelligibly part of the natural world as scientifically understood” (Rouse 2015, 345). Rouse adds that understanding is normative, which places constraints on the kind of account that is acceptable.

⁴ Compare the Kantian distinction between hypothetical and categorical imperatives. Laudan uses the distinction to defend a ‘normative naturalism’, based on the idea that the “normative rules of epistemology are best construed as hypothetical imperatives, linking means and ends; [and that] the soundness of such prudential imperatives depends on certain empirical claims about the connections between means and ends” (Laudan 1990, 46).

my own contextual theory, and investigate whether—and if so, to what extent and in which way—they are normative.

3 Two Naturalistic Theories of (Scientific) Understanding

In his book *The Nature of Scientific Thinking* (2014), Jan Faye presents a naturalistic account of science—and scientific understanding in particular—that is in part based on cognitive science and evolutionary theory. Faye aspires “to describe how our human cognitive capacities allow scientists to acquire an understanding of nature by means of representation, interpretation, and explanation”, where he assumes that these capacities are “a product of evolution and due to our adapting to our external environment” (Faye 2014, vii). This naturalistic approach is combined with a pragmatic view of science that emphasizes the context dependence of scientific explanation and understanding and allows for pluralism regarding representation and interpretation. As Faye explains, naturalism and pragmatism are two sides of the same coin: scientific thinking is part of human nature, but this implies that science rests on “human perspectives, cognitive limitations, and epistemic interests” (Faye 2014, 270).

In the preface to his book Faye writes that his account of science is “thoroughly descriptive” and adds that he does not aspire to provide a “normative ideal for evaluating better or worse acts of explaining or instances of understanding” (Faye 2014, ix). This appears to be in line with the general spirit of naturalistic analyses of science, which focus on describing and explaining science as a human activity, rather than on offering a framework for normative assessment of scientific activity and results. Faye’s non-normative stance emerges, for example, in his claims that understanding does not require knowledge (which is a normative concept), and that even false beliefs may lead to understanding.⁵ But is Faye’s theory indeed only descriptive, or does it include some (hidden) normative ideal of scientific understanding?

Faye (2014, 44–46) distinguishes between various levels and forms of understanding, which can be either embodied or reflective. While embodied understanding is non-representational and typically tacit, reflective understanding is representational and explicit.⁶ Here I will focus on the higher-level, reflective forms of understanding—such as explanatory, theoretical, and interpretive understanding—that are typical of scientific thinking. Faye regards understanding as an important aim of science, and in Chapter 2 of *The Nature of Scientific Thinking* he presents his own theory of scientific understanding, comparing it to two rival accounts, which he terms the ‘content view’ and the ‘ability view’. On the content view, understanding is a species of knowledge, namely knowledge of the (explanatory) content of our beliefs. On the ‘ability view’, by contrast, understanding is the cognitive skill that is needed to construct explanations. Faye rejects both views and presents an alternative, the ‘organization view’, on which understanding consists in “grasping how pieces of information relate to one another” (Faye 2014, 59). He presents the following characterization (U) of reflective understanding, which expresses his organization view in a more formal manner:

⁵ “A may truly claim to understand P, and therefore to assume that a belief regarding P is true, but not to know whether her belief is true” (Faye 2014, 54, original italics).

⁶ In line with his naturalism, Faye (2014, 46–48) observes a continuity between human and animal cognition, and argues that some lower-level, embodied forms of understanding can be had by animals as well.

(U) A human agent A understands a state of affairs, P, in a certain context, C, in the terms of a theory, T, if, and only if, A's belief regarding P connects (in the epistemically correct way for A; i.e., in accordance to A's epistemic norms, N, of understanding) with A's cognitive system, including A's background knowledge, beliefs, and assumptions (A's worldview). (Faye 2014, 54)

Faye proposes (U) as a descriptive characterization that fits all forms of understanding. To be sure, (U) refers to specific norms—namely, “A's epistemic norms of understanding”, but these norms vary with the context. Faye: “No single norm of objective understanding predominates in all sciences; rather the criteria for understanding vary according to the epistemic context in which scientific thinking takes place” (Faye 2014, 53). The norms of understanding vary across scientific disciplines, and sometimes also within a particular discipline. So (U) merely describes the role that particular context-dependent norms play in the achievement of scientific understanding. This is consistent with a naturalistic approach to understanding. In other words, there are no absolute, universal norms for understanding that transcend contextual epistemic norms, where the latter are ultimately social or conventional (2014, 53).

It seems to me, however, that (U) also expresses a demand for coherence as an overarching norm for understanding. (U) does appear to tell us something about how we *ought to* think in order to obtain scientific understanding; namely: if we want to understand P, we ought to connect our belief regarding P to our background knowledge, beliefs, and assumptions. In this respect, Faye's coherence theory of understanding does not differ from other coherence theories in epistemology (e.g. of truth or justification), which are clearly normative. That a coherentist view of understanding does not preclude but rather calls for a normative stance can be gleaned from Catherine Elgin's recent book, in which she develops an elaborate analysis of epistemic normativity to support her coherentist account of understanding (Elgin 2017, 63–121). Hence, it does not appear to be a problem that Faye is wrong in evaluating (U) as non-normative, on the contrary: an account of scientific understanding should have some normative power, as I will argue in more detail below.

So why would Faye emphasize the descriptive nature and downplay the role of normativity in his theory? This obviously has to do with his naturalistic objective. His approach is based on a distinction between universal cognitive standards of understanding, inherited in our thinking, and more local epistemic norms, which are socially constructed.⁷ Faye holds that norms are typically social, and characteristic of (communities of) beings that are capable of abstract, reflective thinking. By contrast, understanding by itself is a natural phenomenon and accordingly non-normative: the organizing principle (U) describes *how* humans understand; it does not present normative guidelines or rules for achieving understanding. I submit, however, that this assumes a too restrictive view of normativity. A broader interpretation should distinguish between two types of norms in relation to understanding:

- *Prescriptive norms*, which provide rules that scientists should follow if they want to achieve scientific understanding of phenomena.
- *Evaluative norms*, which can be used to assess whether or not a particular scientific result does in fact provide genuine understanding.

⁷ Jan Faye, personal communication.

On Faye's view, any prescriptive norms for understanding that we find in scientific practice are local, socially constructed, and context-dependent: these are A's epistemic norms N, cited in (U). Faye suggests that (U) itself does not specify a categorical norm that can be used in a *prescriptive* manner. However, it does at least offer a standard that can be used for *evaluating* claims to understanding: if someone claims to understand P, we can evaluate this claim on the basis of (U). So (U) at least allows for evaluative normativity, even if it does not allow for prescriptive normativity. What is more, we can use (U) for articulating instrumental rules for achieving understanding. Even if one wants to retain the idea that (U) in itself is non-normative (in the sense that it merely describes the nature of understanding), this characterization can be used to formulate an instrumental rule of the form 'If you want to understand P, do X', where X is the act of connecting your belief regarding P to your background knowledge, beliefs, and assumptions.⁸ I conclude that Faye's naturalistic account of scientific understanding contains more normativity than his writing suggests. For most philosophers of science this will be an asset rather than a disadvantage of Faye's theory.

My own theory of scientific understanding (De Regt 2017) has much in common with Faye's theory but also differs from it in important respects. Most importantly, it is an example of what Faye terms the 'ability view', on which understanding is the cognitive skill that is needed to construct explanations, a view that Faye rejects in favor of the 'organization view'. But like Faye's my approach is naturalistic in the sense defined in Sect. 2, and my theory is first and foremost a descriptive account of how scientists acquire understanding of phenomena in actual scientific practice. Thus, the same question arises: Does it have any normative force as well? In the remaining part of this section I will outline my theory with an eye on this question, and in the next section I illustrate it with a historical example, the Chemical Revolution. I will argue that my theory does not only describe this episode but can also give a normative assessment of it.

The contextual theory of scientific understanding is based on an analysis of examples from the history of science (esp. physics) and on recent insights that philosophers of science have derived from studying scientific practice. Its central idea is the thesis that scientists achieve understanding of a phenomenon P if they construct an appropriate model of P on the basis of a theory T, following the model-based account of explanation defended by Cartwright (1983, 143–162). More specifically, the contextual theory is built around the following criterion for scientific understanding:

CUP: A phenomenon *P* is understood scientifically if and only if there is an explanation of *P* that is based on an intelligible theory T and conforms to the basic epistemic values of empirical adequacy and internal consistency (De Regt 2017, 92).

The key term in this criterion is 'intelligible': understanding of phenomena requires an intelligible theory, where intelligibility is defined as:

Intelligibility: the value that scientists attribute to the cluster of qualities of a theory *T* (in one or more of its representations) that facilitate the use of *T* (De Regt 2017, 40).

⁸ (U) is an evaluative standard. 'Do X to achieve (U)' is a prescriptive norm, based on a valuation of understanding (U). See McMullin (1983, 5) for the distinction between valuation and evaluation.

Note that this definition entails that intelligibility is not an intrinsic property of theories, but a context-dependent value: whether or not a theory is intelligible to scientists depends on, for example, their skills and their background knowledge. Why do scientific theories need to be intelligible to the scientists who use them? My argument for this claim draws on the work of philosophers Nancy Cartwright (1983) and Margaret Morrison (1999, 60–64), who have highlighted the pivotal role of modelling in scientific practice, and in explanatory practices in particular. On the model-based account of scientific explanation scientists acquire understanding of the phenomena by constructing models, which ‘mediate’ between relevant theories and the phenomenon-to-be-explained. Constructing such mediating models involves pragmatic judgments and decisions, since models do not follow straightforwardly from theories (and neither do they follow from the empirical data). For example, suitable idealizations and approximations need to be made. I submit that the construction of such models—which provide explanatory understanding of phenomena—requires theories that are intelligible in the sense defined above. Only if scientists’ ability to work with the theory allows them to make suitable pragmatic judgments, will they succeed in constructing explanatory models. Consequently, the theory should be intelligible in the sense that scientists’ skills should match the qualities of the theory. In sum, understanding a phenomenon on the basis of T depends on an appropriate combination of skills of S and qualities of T .

An example of such a quality is visualizability. This is a theoretical quality that is widely valued, because for many scientists visualizable theories are more tractable and easier to work with (De Regt 2014). But the contextual theory does not imply that visualizability is a necessary condition for the intelligibility of scientific theories. Depending on the context, there may be alternative ways to render theories intelligible.⁹ A concrete example of model construction in which visualization plays a role is the explanation of gas phenomena on the basis of the kinetic theory of gases, as it was developed by James Clerk Maxwell and Ludwig Boltzmann in the nineteenth century. The kinetic theory represents gases as aggregates of particles in motion obeying the laws of Newtonian mechanics. Specific models of the particles and their structure have to be constructed in order to explain particular gas phenomena on the basis of the theory. For example, the kinetic explanation of Boyle’s law involves the construction of a model (the ideal gas model) that represents gas molecules such that Newton’s laws can be applied and a theoretical prediction of the relationship between pressure and volume can be derived. The ideal gas model does not follow deductively from the kinetic theory, as its construction involves idealizations and approximations. Specific features of the theory—its visualizability, but also its causal aspects—guaranteed its intelligibility to Maxwell and Boltzmann (and to physicists ever since).¹⁰ Subsequently, the construction of more specific molecular models, such as the van der Waals model and the dumbbell model for diatomic gases, yielded additional or more detailed understanding of gas phenomena (see De Regt 2017, 205–216).

One might object that my definition of intelligibility makes it a purely subjective notion that is thereby devoid of normative power. If valuing a theory as intelligible is merely a matter having a subjective preference for that theory, then it may seem that there can be no objective (normative) criteria for assessing whether or not a particular theory is intelligible. However, this does not follow. Although intelligibility criteria are contextual and will vary across scientific communities (and sometimes even within a community), there are ways of

⁹ See De Haro and De Regt (2018) for examples from current theoretical physics.

¹⁰ See De Regt (2017, 31–35 and 103–106) for an extensive discussion of this example.

objectively testing the intelligibility of a theory (for scientists in a particular context). Such an objective test is provided by the following Criterion for the Intelligibility of Theories:

CIT_i: A scientific theory T (in one or more of its representations) is intelligible for scientists (in context C) if they can recognize qualitatively characteristic consequences of T without performing exact calculations (De Regt 2017, 102).¹¹

The basic idea behind *CIT_i* is that its fulfilment indicates that the scientists have an ‘insight’ into the workings of the theory and are accordingly able to use the theory for the construction of models of the phenomena. If the resulting models are empirically adequate and internally consistent, they provide understanding of the phenomena in question. The conceptual tools—e.g. visualization—that scientists may use to recognize qualitative consequences of T are also the tools that will facilitate model construction.

4 Understanding (in) the Chemical Revolution

In this section I will apply the contextual theory of scientific understanding to a concrete historical case: the eighteenth-century revolution in chemistry, in which the phlogiston theory of combustion was replaced by Lavoisier’s oxygen theory.¹² The aim of this case study is to illustrate how analysis of the role of understanding in this episode from the history of science reveals the contextual norms of scientific reasoning in the sciences. In addition to showing how the contextual theory describes the historical case, I will address the question of whether it can also be used to give a normative appraisal of the development.

The transition from phlogiston theory to oxygen theory is a famous episode in the history of science.¹³ It was a revolution in chemistry, which involved radical conceptual changes that do not fit the picture of cumulative progress in which scientific understanding gradually increases. In particular, after the Chemical Revolution the existence of phlogiston—the principle of combustion—was denied; in its place, Lavoisier’s new theory postulated chemical elements such as oxygen and hydrogen. Lavoisier’s work marks the beginning of modern chemistry, and although there are important differences between his oxygen theory of combustion and today’s chemical theories, the way in which they explain chemical processes is basically the same. Accordingly, no one will deny that Lavoisier’s theory provides understanding of chemical phenomena. With phlogiston theory, on the other hand, the situation is less clear: because this theory is currently regarded as patently false, and phlogiston as a non-referring term, the claim that it can provide understanding of chemical phenomena is more controversial.¹⁴ However, historians of science have argued that with the phlogiston theory chemists were able to explain many (though not all) aspects of combustion, and they classified chemical substances and reactions in ways that bear

¹¹ N.B.: *CIT_i* is only one of many possible criteria (tests) for intelligibility. Accordingly, *CIT_i* is a sufficient condition for intelligibility, not a necessary one.

¹² Part of this section draws on De Regt and Gijsbers (2017), which presents the case in more detail.

¹³ See Hankins (1985, 8–112) for an overview, and Chang (2010, 2012) for an account that focuses on phlogiston theory.

¹⁴ De Regt and Gijsbers (2017) defend the claim that phlogiston theory can provide understanding despite the fact that today ‘phlogiston’ is considered a non-referring term.

close resemblance to our current understanding. Hence, there are reasons to argue that also phlogiston theory provided at least some degree of understanding.

Phlogiston theory was born in 1703, when Georg Stahl introduced the concept of phlogiston as the principle that accounts for the processes of combustion, respiration, and calcination of metals. Stahl identified phlogiston as the principle of inflammability, a fundamental substance that is present in all inflammable materials.¹⁵ He assumed that highly inflammable materials are rich in phlogiston, which escapes and is absorbed by the air in the process of combustion. Similarly, in the process of calcination metals are deprived of phlogiston and become “calx”. The presence of air is essential for the processes of combustion and calcination, and phlogiston theorists explained this by hypothesizing that the air is needed to absorb the released phlogiston. This hypothesis was supported by the observation that a candle that is placed in a closed vessel stops burning after a while, when the air is saturated with phlogiston and has turned into ‘phlogisticated air’.

Phlogiston theory provided a unifying explanation of the phenomena of combustion, respiration, calcination and the reduction of metals. It also explained common properties of metals, such as shininess, malleability, ductility, and electrical conductivity (Chang 2012, 21).¹⁶ Moreover, the theory led to fundamental experimental discoveries. In 1766, Henry Cavendish isolated hydrogen by dissolving metals in acid. Because it burned easily and explosively, he called it ‘inflammable air’ and identified it as ‘phlogisticated water’. In 1774, Joseph Priestley was the first to isolate oxygen, which he called ‘dephlogisticated air’. There was, however, one problem for phlogiston theory: calxes that result from calcination weigh more than the metals from which they are produced. There was no generally accepted explanation for this weight gain, but the problem was—at least for a long time—not considered fatal for phlogiston theory because, first, it was mainly restricted to calcination, and second, phlogiston chemists focused on qualitative rather than on quantitative features. Moreover, weight was regarded as a property of substances, not as a quantity of matter; and properties can change in chemical reactions. Here we see that norms for scientific understanding are context-specific: while in retrospect weight gain is often seen as fatal to phlogiston theory, it was not regarded as such in the eighteenth-century context.

The weight gain problem inspired Antoine Lavoisier to investigate the nature of combustion. In 1772 he learned that phosphorus gains weight in combustion and began to experiment with burning phosphorus. He found that in the combustion process air was absorbed and phosphoric acid produced. In his subsequent experiments and theorizing Lavoisier focused on the role of air in combustion and calcination. Assuming that air is not an element but rather a state that substances may achieve, he hypothesized that atmospheric air consists of several components, and that only one of these components (oxygen) is absorbed in the processes of combustion and calcination. The result was a radically new

¹⁵ To modern ears it may sound strange to call something both a principle and a substance. But the ontology of pre-Lavoisier chemistry distinguished between active and passive substances, where the former embody principles associated with particular properties. In line with the dominant approach in chemistry, the emphasis is on the property that the principle imparts on the passive substance. Thus, phlogiston is the active substance that makes, for example, wood a combustible.

¹⁶ This is a standard example of ‘Kuhn-loss’, since the explanation of this fact was lost in the Chemical Revolution. A new explanation appeared only at the end of the nineteenth century, with the electron theory of metals (Chang 2012, 44–45).

theory of combustion.¹⁷ In the late 1770s, Antoine Lavoisier repeated Priestley's experiments with dephlogisticated air and interpreted them in terms of his new oxygen theory.

Lavoisier successfully predicted the production of water in the process of burning inflammable air. He argued that water is not an element but a compound of inflammable air (hydrogen) and oxygen. The analysis of water is commonly regarded as the final victory of Lavoisier's oxygen theory over phlogiston theory, which assumed water to be an elementary substance. However, as Chang (2012, 6) argues, phlogiston theorists had a defensible account of the formation of water as well. Although they regarded water an element, this did not imply that it could not be modified: phlogiston could be added to it or taken from it, resulting in 'phlogisticated water' or 'dephlogisticated water'.

Let us see how the contextual theory of scientific understanding deals with this historical episode, whether it can give a descriptively adequate account and whether it allows for normative assessment. First, I will address the question of whether phlogiston theory provided understanding of chemical processes like combustion. That would be the case if CUP applies, that is, if phlogiston theory was an intelligible theory with which scientists constructed empirically adequate and internally consistent explanations of empirical phenomena. So, was phlogiston theory intelligible? Intelligibility is a contextual value: whether scientists value the qualities of a theory (as facilitating its use) depends on their skills and on other contextual factors. For eighteenth-century scientists phlogiston theory was plausibly intelligible, as it fitted the context in which chemistry was practiced. Eighteenth-century chemistry differed from modern chemistry in two important ways: first, it was predominantly qualitative rather than quantitative; and second, it focused on the properties of substances, not on their composition. The emphasis lay on explaining the properties of substances by means of principles. Thus, the scientific context changed fundamentally in the Chemical Revolution, involving a transition to a new approach in chemistry, which focused on the compositional analysis of substances and on quantitative research (exemplified by Lavoisier's emphasis on determining and explaining weight relations).¹⁸ Accordingly, it is reasonable to suppose that phlogiston theory was intelligible to chemists in the pre-Lavoisier era.

The qualities of phlogiston theory that facilitated the construction of explanations were: its ontology of principles, its qualitative nature, and its scope. So were the explanations that phlogistonists constructed using these qualities empirically successful? Above we have seen that phlogiston theory allowed eighteenth-century chemists to describe, predict and understand aspects of combustion, such as the escape of heat and light, as well as other chemical phenomena. Phlogiston theory provided a coherent, unifying account of combustion, calcination, reduction, and respiration, and made accurate predictions across a wide range of phenomena. Moreover, some phenomena could be understood on the basis of phlogiston theory but not on Lavoisier's oxygen theory (notably, the common properties of metals¹⁹), and the theory guided experimental chemistry and the discovery of new gases.

Still, Lavoisier won out in the end, and phlogiston theory was abandoned in favor of oxygen theory. So one might ask to what extent Lavoisier understood chemical phenomena, and whether he had more (or a higher degree of) understanding than phlogiston theorists such as Priestley. A comparative analysis by Hasok Chang (2012, 14–29) shows that both phlogiston theory and Lavoisier's oxygen theory had their merits and problems, and that

¹⁷ While Lavoisier abandoned phlogiston, he introduced a new invisible and weightless substance to account for the escape of heat in combustion processes: caloric. This is one important difference with modern oxygen theory.

¹⁸ This transition has been described as one from 'principlism' to 'compositionism' (Chang 2012).

¹⁹ For more examples, see Kuhn (2012, 156) and Chang (2012, 45).

there was no clear reason to favor one over the other at the end of the eighteenth century. Chang evaluates the merits of phlogiston theory and Lavoisier's oxygen theory by comparing the respective 'problem fields' they considered important and assessing how well they solved the problems in these fields. Of course, phlogistonists and oxygenists shared central problem fields (otherwise they wouldn't be rivals), but there were also differences. Chang (2012, 20) presents the following list of problem fields considered important:

- By both sides: combustion, calcination/reduction and respiration; theory of acids; constitution of various substances
- By phlogistonists only: properties of compounds in terms of properties of ingredients; mineralogy/geology; meteorology; nutrition/ecology
- By oxygenists only: theory of heat and changes of state; chemistry of salts

Assessing which side did better in solving problems is not an easy matter. Chang (2012, 22–29) suggests that in total the phlogistonists dealt with a larger number of problems. But he admits that the most important issue is which side did better in solving the shared problems. To answer this question, however, it should first be acknowledged that phlogistonists and oxygenists had different criteria for what counted as a good solution. In other words, they adhered to different epistemic values, associated with different norms for scientific understanding. Chang presents an elaborate analysis of the relevant differences in epistemic values. He notices three ways in which value judgments of phlogistonists and oxygenists diverged: completeness vs. simplicity, conservatism vs. novelty, and pluralism vs. absolutism (see Table 1).

Regarding completeness vs. simplicity, Lavoisier focused on explaining a relatively limited set of phenomena in an elegant way, while the phlogistonists advanced explanations for a wide range of phenomena, which were sometimes rather cumbersome. Moreover, even in cases where phlogistonists and oxygenists shared an epistemic value, they sometimes interpreted it differently. For example, while both parties valued unity and systematicity, they disagreed about what were instantiations of these values, and they accused each other of not respecting the values. Taking stock, Chang concludes that a clear verdict is impossible, because "there were different standards according to which one or the other was better supported by empirical evidence. [...] both systems were partially successful in their attempts to attain worthwhile goals, and [...] there was no reason to clearly favor one over the other" (Chang 2012, 29).

Chang's comparative analysis accords with the contextual theory of scientific understanding, as it assigns a crucial role to context-specific standards and epistemic values. CUP implies that whether or not a scientific theory can provide understanding of phenomena depends on its intelligibility, which in turn depends on the scientific, historical, and disciplinary context. We have seen above that phlogiston explanations provided understanding of phenomena in some domains. Phlogiston theory could achieve these successes because, in the context of eighteenth-century chemistry, it was an intelligible theory: it provided the tools for constructing models of the phenomena that were internally consistent and—from the perspective of the eighteenth-century chemists—empirically adequate to a sufficient extent. The development of Lavoisier's rival oxygen theory of combustion involved a radical change in chemical thinking, from qualitative to quantitative research and from principlism to compositionism, with a corresponding change in value judgments. This led to new intelligibility standards, which at least for Lavoisier himself opened the door to new explanations for known phenomena and to novel predictions of as yet unknown phenomena (e.g. the analysis of water). Chang's analysis makes it clear, however, that it is difficult to

say which theory provided more understanding. Accordingly, while the contextual theory allows for a positive normative evaluation of the understanding-providing power of the two individual theories within their respective contexts, it does not supply a context-independent normative rule for choosing between the two theories.

Some readers may find this type of normativity too weak. Since intelligibility is a context-relative notion implying that no theory is intrinsically unintelligible, CUP does not provide scientists with concrete normative guidelines. Hence, they might object, the demand for intelligibility does not seem to place any constraints on scientific activity. I admit that my theory can and does not provide concrete normative guidelines in the sense of categorically recommending the use of specific types of theories. However, this does not render the demand for intelligibility vacuous and CUP normatively sterile, as becomes clear if we invoke the distinction between *prescriptive* and *evaluative* norms, introduced in Sect. 3. It appears that CUP does not supply an unambiguous prescriptive norm for theory choice, at least not with respect to intelligibility.²⁰ It merely advises scientists to use intelligible theories, where the context determines which theory is intelligible. But while the normative power of the contextual theory is thus relatively weak if one is looking for prescriptive norms, the theory is well-equipped for (normatively) evaluating claims to understanding, that is, for assessing whether or not a model constructed to explain a particular phenomenon does in fact provide genuine understanding. Part of such an assessment is the evaluation of the intelligibility of the theory used in the construction of the model (e.g. using criterion CIT₁). Accordingly, in a specific context there is the possibility of assessing whether a theory is intelligible to a scientist or a group of scientists. Hence, the normative content of the contextual theory of scientific understanding is of the evaluative kind, rather than of the prescriptive kind.

It might be suggested that we should adopt the following prescriptive norm: ‘if theory T₁ is more intelligible than theory T₂ in context C, scientists in C should work with T₁’. However, although this may be a fruitful policy, it should never be turned into a normative rule. The case of phlogiston theory versus Lavoisier’s rival oxygen theory clearly shows that we cannot and should not proclaim that chemists, at any point in time in the late eighteenth century, should have used the one rather than the other theory. While it provides tools for assessing the (un)intelligibility of phlogiston and oxygen theory in their historical context, the contextual theory of understanding does not offer prescriptive norms. Its normative content is not of the prescriptive but of the evaluative kind. Evaluating the development of chemistry at the end of the eighteenth century leads to the conclusion that both Priestley and Lavoisier had some understanding of chemical phenomena such as combustion, and that it is difficult to determine whether Lavoisier had more.²¹ Today, however, the situation is different: it is fair to say that phlogiston theory has (de facto) become less intelligible than oxygen theory, because the scientific context has changed to such an extent

²⁰ Note that CUP includes the additional requirements of empirical adequacy and internal consistency, which do imply prescriptive norms, although also these values are to some extent context-relative (see De Regt 2017, 38–39).

²¹ A comparative evaluation of the understanding-providing merits of the various theories would be possible if we acknowledge that understanding comes in degrees. A precise analysis of the notion of degrees of understanding is beyond the scope of this paper, however. See Baumberger (2019) and Kelp (2017, 252–254) for attempts to explicate the notion of degrees of understanding.

Table 1 Opposing value judgments of phlogistonists and oxygenists

Phlogistonists	Oxygenists
Completeness	Simplicity (elegance)
Conservatism	Novelty (reform)
Pluralism	Absolutism (dogmatism)

that the framework in which phlogiston theory was embedded (qualitative chemistry on a principlist basis) has become completely foreign to present-day scientists. Moreover, in all contexts of application modern chemical theory (in contrast to Lavoisier's oxygen theory) is superior from a predictive and explanatory perspective.²²

5 Conclusion

In this paper, I have addressed the question of whether naturalistic theories of scientific understanding can have normative power, through an examination of two such theories: Jan Faye's pragmatic-rhetorical theory of understanding and my own contextual theory of scientific understanding. Although both theories focus first and foremost on the description and explanation of how understanding is achieved in the practice and history of science, I have shown that they are not normatively sterile. Faye's theory, which has been analyzed in Sect. 3, is basically a coherentist account of understanding, implying that coherence is a normative requirement for understanding. My own contextual theory of scientific understanding, also discussed in Sect. 3, is designed to describe the criteria for understanding employed in scientific practice and to explain their function and historical variation. But it can also serve as a basis for normative assessment of the understanding that scientific research delivers. Although it does not provide concrete normative prescriptions, the contextual theory allows for normative evaluation of concrete scientific practices, and of the intelligibility of the theories employed in these practices. The historical case study of the Chemical Revolution, presented in Sect. 4, illustrates how a naturalistic approach can uncover the contextual epistemic norms of understanding that are built into scientific practice. Using Chang's analysis of the competition between phlogiston theory and Lavoisier's oxygen theory, I have highlighted how local epistemic norms for intelligibility were conducive to understanding, where intelligibility itself functions as a universal norm for scientific progress.

To conclude, let me address a possible worry about the contextual theory of scientific understanding, namely that the definition of intelligibility is a vacuous notion without any normative bite. For it might be objected that associating intelligibility with the ability to make fruitful use of a scientific theory runs the risk of trivializing intelligibility, because it implies that *any* theory can become intelligible if only one succeeds in learning to use it in a fruitful way. But does this make the notion of intelligibility vacuous? Not at all. It is true that the demand that theories be intelligible does not pose *universal* restrictions on theories or theory choice, but it does entail that certain theories are preferable over others in

²² All phenomena that can be understood with phlogiston theory or with Lavoisier's theory can also be understood within modern chemistry. The commonalities of metals, for example, are understood in terms of the free electron theory of metals.

particular *local* contexts. Thus, for most chemists in the late eighteenth century phlogiston theory was plausibly more intelligible than, and thereby preferable to, Lavoisier's oxygen theory. However, no theory is intrinsically unintelligible, and there was no reason to suppose that oxygen theory could not become intelligible—which happened in due course.²³ The aim of the contextual theory is to describe and explain, historical developments like these, in which intelligibility standards may change. In addition, it offers a framework for normatively evaluating scientists' actions and results on the basis of local norms for scientific understanding.

Acknowledgement I wish to thank Jan Faye for his constructive comments and suggestions. Moreover, I thank two anonymous referees, the members of the research group Philosophy of Science and Technology (FWT) of the Department of Philosophy, Vrije Universiteit Amsterdam, the audience at the EPSA15 conference in Düsseldorf (September 2015), and the audience at the ALO meeting in Brussels (March 2018), esp. commentators Joachim Frans and Sven Delarivière, for helpful comments on earlier versions of this paper.

Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

References

- Baumberger, C. (2019). Explicating objectual understanding: Taking degrees seriously. *Journal for General Philosophy of Science* (this issue).
- Cartwright, N. (1983). *How the laws of physics lie*. Oxford: Clarendon Press.
- Chang, H. (2010). The hidden history of phlogiston. *Hyle*, 16(2), 47–79.
- Chang, H. (2012). *Is water H₂O?*. Dordrecht: Springer.
- Craver, C. F. (2007). *Explaining the brain. Mechanisms and the mosaic unity of neuroscience*. Oxford: Oxford University Press.
- De Haro, S., & de Regt, H. W. (2018). Interpreting theories without a spacetime. *European Journal for Philosophy of Science*, 8(3), 631–670.
- De Regt, H. W. (2014). Visualization as a tool for understanding. *Perspectives on Science*, 22(3), 377–396.
- De Regt, H. W. (2017). *Understanding scientific understanding*. New York: Oxford University Press.
- De Regt, H. W., & Gijsbers, V. (2017). How false theories can yield genuine understanding. In S. R. Grimm, C. Baumberger, & S. Ammon (Eds.), *Explaining understanding: New perspectives from epistemology and philosophy of science* (pp. 50–75). London: Routledge.
- Elgin, C. Z. (2017). *True enough*. Cambridge, MA: The MIT Press.
- Faye, J. (2014). *The nature of scientific thinking. On interpretation, explanation and understanding*. London: Palgrave Macmillan.
- Giere, R. N. (1999). *Science without laws*. Chicago: The University of Chicago Press.
- Grimm, S. R. (2017). Understanding and transparency. In S. Grimm, C. Baumberger, & S. Ammon (Eds.), *Explaining understanding: New perspectives from epistemology and philosophy of science* (pp. 212–229). New York: Routledge.
- Hankins, T. L. (1985). *Science and the enlightenment*. Cambridge: Cambridge University Press.
- Hempel, C. G. (1965). *Aspects of scientific explanation and other essays in the philosophy of science*. New York: The Free Press.
- Hempel, C. G. (2001). Scientific rationality: Normative versus descriptive construals. In J. Fetzer (Ed.), *The Philosophy of Carl G. Hempel. Studies in science, explanation, and rationality* (pp. 357–371). Oxford: Oxford University Press.

²³ Of course, it may turn out that some theories are de facto unintelligible; for example, because they are too complex to be comprehended by the human mind. See Nickles (2018) for a discussion of how the 'digital revolution' in science challenges human intelligibility.

- Kelp, C. (2017). Towards a knowledge-based account of understanding. In S. R. Grimm, C. Baumberger, & S. Ammon (Eds.), *Explaining understanding: New perspectives from epistemology and philosophy of science* (pp. 251–271). London: Routledge.
- Khalifa, K. (2017). *Understanding, explanation, and scientific knowledge*. Cambridge: Cambridge University Press.
- Kitcher, P. (1989). Explanatory unification and the causal structure of the world. In P. Kitcher & W. C. Salmon (Eds.), *Scientific explanation* (pp. 410–505). Minneapolis, MN: University of Minnesota Press.
- Kuhn, T. S. (2012). *The structure of scientific revolutions* (4th ed.). Chicago: The University of Chicago Press.
- Laudan, L. (1990). Normative naturalism. *Philosophy of Science*, 57(1), 44–59.
- McMullin, E. (1983). Values in science. In P. D. Asquith & T. Nickles (Eds.), *PSA 1982* (pp. 3–28). East Lansing: Philosophy of Science Association.
- Morrison, M. (1999). Models as autonomous agents. In M. S. Morgan & M. Morrison (Eds.), *Models as mediators* (pp. 38–65). Cambridge: Cambridge University Press.
- Nickles, T. (2018). Alien reasoning: Is a major change in scientific reasoning underway? *Topoi*. <https://doi.org/10.1007/s11245-018-9557-1>.
- Papineau, D. (2016). Naturalism. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Winter 2016 Edition). <https://plato.stanford.edu/archives/win2016/entries/naturalism/>.
- Rouse, J. (2015). *Articulating the world: Conceptual understanding and the scientific image*. Chicago: The University of Chicago Press.
- Salmon, W. C. (1989). *Four decades of scientific explanation*. Minneapolis, MN: University of Minnesota Press.
- Scriven, M. (1962). Explanations, predictions, and laws. In H. Feigl & G. Maxwell (Eds.), *Scientific explanation, space, and time* (pp. 170–230). Minneapolis, MN: University of Minnesota Press.
- Strevens, M. (2008). *Depth: An account of scientific explanation*. Cambridge, MA: Harvard University Press.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.