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van den Berg, H.

DOI
10.1016/j.shpsa.2024.05.003
Publication date
2024
Document Version
Final published version
Published in
Studies in history and philosophy of science

Studies in History and Philosophy of Science 105 (2024) 109–119

Contents lists available at ScienceDirect

Studies in History and Philosophy of Science

journal homepage: www.elsevier.com/locate/shpsa

Explanation, teleology, and analogy in natural history and comparative anatomy around 1800: Kant and Cuvier

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A R T I C L E I N F O

Keywords:
Kant
Cuvier
Science
Explanation
Teleology
Analogy

A B S T R A C T

This paper investigates conceptions of explanation, teleology, and analogy in the works of Immanuel Kant (1724–1804) and Georges Cuvier (1769–1832). Richards (2000, 2002) and Zammito (2006, 2012, 2018) have argued that Kant's philosophy provided an obstacle for the project of establishing biology as a proper science around 1800. By contrast, Russell (1916), Outram (1986), and Huneman (2006, 2008) have argued, similar to suggestions from Lenoir (1989), that Kant's philosophy influenced the influential naturalist Georges Cuvier. In this article, I wish to expand on and further the work of Russell, Outram, and Huneman by adopting a novel perspective on Cuvier and considering (a) the similar conceptions of proper science and explanation of Kant and Cuvier, and (b) the similar conceptions of the role of teleology and analogy in the works of Kant and Cuvier. The similarities between Kant and Cuvier show, contrary to the interpretation of Richards and Zammito, that some of Kant's philosophical ideas, whether they derived from him or not, were fruitfully applied by some life scientists who wished to transform life sciences into proper sciences around 1800. However, I also show that Cuvier, in contrast to Kant, had a workable strategy for transforming the life sciences into proper sciences, and that he departed from Kant's philosophy of science in crucial respects.

1. Introduction

In the eighteenth century, Kant articulated influential accounts of the nature of the natural sciences. In the *Metaphysical Foundations of Natural Science* (1786), Kant adopted a strict conception of proper natural science, which was exemplified by Newtonian physics (see Friedman, 1992; Plaass 1994; Sturm, 2009; van den Berg, 2014; Breitenbach, 2022; Friedman, 2022). Kant himself notes that chemistry in the eighteenth century was not (yet) a proper natural science (McNulty, 2014, 2015), and it is doubtful whether the life sciences could ever satisfy Kant's strictures on proper natural science. Consequently, authors such as Richards (2000, 2002) and Zammito (2003, 2006, 2012, 2018) have rejected the interpretation of Lenoir (1989), who argued that Kant's philosophy provided a methodological foundation for life sciences around 1800 and later. According to Richards and Zammito, Kant's philosophy and strict conception of science provided a significant obstacle for practicing life scientists at the end of the eighteenth century. The work of Richards and Zammito has given rise to diverse interpretations of Kant's philosophy of biology, which is now a flourishing field of research (Zuckert, 2007; Huneman, 2008; Breitenbach, 2009a; Cohen, 2009; Mensch, 2013; van den Berg, 2014; Goy & Watkins, 2014; Ginsborg, 2014; Goy, 2017; Geiger, 2022; Cooper, 2023).

Richards and Zammito's interpretation of Kant's philosophy of biology is popular, and the interpretation of Lenoir (1989) is often criticized. However, there are also criticisms of Richards and Zammito. van den Berg and Demarest (2020) argue that an axiomatic conception of science adopted by the likes of Wolff, Kant, and Schelling had a positive impact on some life scientists in the modern period, raising problems for Zammito's (2018) claim that the emergence of biology as a science in Germany was mainly due to the adoption of an anti-rationalist, anti-mathematical, and experimental conception of science. Beekman and Jochemsen (2022) revive Lenoir's interpretation insofar as they claim that Kant's philosophy and conception of mechanism influenced naturalists such as Müller, Virchow, and von Baer. Finally, we may note that many discussions on Kant and the history of biology focus on the alleged impact of Kant on German life scientists. However, Russell (1916), Outram (1986), and Huneman (2006, 2008) have argued, similar to a suggestion from Lenoir (1989) that Cuvier was close to accepting teleomechanism, that Kant's philosophy impacted the science of the influential French naturalist Georges Cuvier (1769–1832).

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https://doi.org/10.1016/j.shpsa.2024.05.003
Received 5 April 2023; Received in revised form 19 November 2023; Accepted 4 May 2024
Available online 17 May 2024

Russell, Outram, and Huneman mainly focus on the impact of Kant's conception of teleology on Cuvier's work in comparative anatomy, describing the role of teleology in Cuvier's account of his famous principles of 'the conditions of existence' and of the 'correlation of parts'. If this interpretation is correct, Kant's philosophy was more influential than Richards and Zammito acknowledge, since it impacted one of the main life scientists who attempted to establish biology as a science around 1800 (See for Zammito on Huneman, Zammito 2010). Indeed, according to Foucault's (1970) analysis in *The Order of Things*, Cuvier was one of the main figures involved in establishing biology as an autonomous science.

In this article, I wish to further the work of Russell, Outram, and Huneman and consider similarities between Kant's and Cuvier's views on the methodology of the life sciences. My aim is not to show the historical influence of Kant on Cuvier, which has already been established, but to show that Kantian philosophical ideas were fruitfully applied to the life sciences by Cuvier, whether they derived from Kant or not. I will, in contrast to Russell, Outram, and Huneman, not only focus on Kant's conception of teleology, but also investigate similarities between Kant's philosophy and methodology of science and Cuvier's conception of the methodology of science. More specifically, I adopt a novel perspective on Cuvier and show (a) similarities between Kant's and Cuvier's conceptions of proper science and explanation, and (b) the similarities between their conceptions of the role of teleology and analogy in science. I will argue specifically that both Kant and Cuvier conceived of science as a demonstrative system based on principles, and more specifically a system that *unifies* various phenomena, and had a similar conception of proper explanation and argued that *mechanical explanations* are ideal and proper explanations in the natural sciences. Moreover, I will argue that Kant and Cuvier had similar conceptions of organisms as purposive wholes which are studied in the life sciences, and that both claimed that the original organization of organisms cannot be explained mechanically. Kant's maxim that we should take the structure of organisms for granted and then explain as much of the functions of organisms mechanically was also adopted by Cuvier. Finally, I give a novel account of the role of teleology and analogy in the natural history and comparative anatomy of Cuvier, arguing that Cuvier's teleological and analogical reasoning was also in line with Kant's philosophy (Foucault, 1970 briefly notes the importance of analogy in Cuvier, but does not consider Kant). In contrast to existing literature on Cuvier, I give a precise explanation for why Cuvier, like Kant, adopted a *regulative* interpretation of teleology. This interpretation corrects early interpretations of Cuvier which ascribed to Cuvier the idea that explanations can be teleological and claimed that Cuvier did not accept Kant's regulative interpretation of teleology (Coleman, 1964; Ospovat, 1978). Moreover, I provide a novel account of analogy in Cuvier and its relation to Kant's views building on important work on analogy and homology by Balan (1979). In light of the similarities between the methodological views of Kant and Cuvier, we must critically reevaluate Richards and Zammito's claim that Kant's philosophy provided a significant obstacle for scientists around 1800 who wanted to establish biology as a science. However, Richards and Zammito are not completely wrong, for I show that Cuvier, in contrast to Kant, had a workable strategy for transforming life sciences into proper sciences, which involved an empiricist methodology and a rejection of philosophers of science who thought that science must be based on a priori metaphysical principles.

The paper is structured as follows. In the second section, I briefly describe Kant's views on (proper) science, teleology, and analogy in Kant's philosophy of the life sciences, mainly following the research of van den Berg, which provides a fruitful basis for comparing Kant and Cuvier. In section 3.1, I describe Cuvier's conception of science, explanation, and the method of natural history. I demonstrate many similarities between Kant and Cuvier which have so far have not been given due attention, while also highlighting some important differences between them. Section 3.2 contains an analysis of Cuvier's use of teleology and analogy in Cuvier's natural history and comparative anatomy, demonstrating continuities between Cuvier's research and Kant's accounts of teleology and analogy. Finally, I conclude in section four with remarks that show Kantian ideas were fruitfully applied by Cuvier, even if Cuvier also departed in important respects from Kant. This forms the basis for some methodological reflection of the study of biology around 1800.

2. Science, teleology, and analogy in Kant's philosophy of the life sciences

Kant's conception of proper natural science has been analyzed by several authors (see Plaass 1994, Falkenburg, 2000; Sturm, 2009; van den Berg, 2014; Breitenbach, 2022; Friedman, 2022). van den Berg (2014, 2021), whose work we shall follow here, argues that Kant's conception of proper science is a variety of a traditional axiomatic ideal of science captured by the so-called 'Classical Model of Science' of De Jong and Betti (2010) (see also De Jong, 2010; Zammito, 2017 also argues that the axiomatic ideal shaped Kant's conception of science). According to this ideal, a proper science has fundamental concepts and non-fundamental concepts are defined on the basis of these fundamental concepts. In addition, a proper science has fundamental judgments and non-fundamental judgments are demonstrated on the basis of these fundamental judgments (De Jong & Betti, 2010). For Kant, these fundamental judgments are the synthetic a priori judgments that constitute the principles of the natural sciences, principles proven by means of transcendental arguments (Watkins, 1998).

Van den Berg also argues that Kant's conception of scientific explanation is informed by this axiomatic conception of science. According to van den Berg (2013, 2014, chapters 2 and 3) a proper explanation in natural science is an instance of what Aristotelian medieval philosophers called a *demonstratio propter quid* (on this topic, Longuenesse, 1998, Watkins, 2019, and Watkins (forthcoming)). More specifically, a proper explanation in natural science is a valid deductive argument in which we (a) reason on the basis of true premises and (ii) reason from objective grounds (*causes* in natural science) to consequences (*effects* in natural science). For example, Newton's synthetic demonstration of Kepler's laws on the basis of the law of gravitation and other principles, which he provides in the *Principia* after his deduction of the law of gravity, is an example of an explanatory demonstration, insofar as Newton argues demonstratively from objective grounds (causes, such as gravity) to consequences or effects (e.g., the phenomena).

According to van den Berg (2013, 2014, chapter 3), the Aristotelian ideal of *demonstratio propter quid* shaped Kant's account of mechanical explanation (see on this topic McLaughlin, 1990; Ginsborg, 2004; Breitenbach, 2006; 2009a; Zuckert, 2007). Van den Berg construes mechanical explanations as explanatory demonstrations in which we reason deductively from more universal synthetic premises specifying objective grounds to more specific consequences. Such demonstrations can be construed as reasoning from the more universal (the part) to the more specific (the whole), and thus reason from part to whole, which is Kant's characterization of a mechanical explanation (see Geiger, 2022). These demonstrations can be found, for example, in Newton's *Principia* and eighteenth-century physics.

Kant construes mechanical explanations as ideal explanations of nature. In line with this view he denies that teleology is explanatory. Hence, teleology serves a *regulative function* (see McLaughlin, 2001; Zammito, 2006; Sloan, 2006; Huneman, 2008; van den Berg, 2014, chapter 4).[1] This means, first of all, that teleology serves a heuristic function in the search for causal mechanical causes. As Breitenbach

[1] Huneman (2008, p. 358) argues that the term 'regulative' in Kant is a relational concept. In the first *Critique*, Kant takes some principles of the transcendental analytic to be regulative and other principles to be constitutive of natural phenomena. However, all of these principles are constitutive regarding knowledge in the third *Critique*.

(2009b) explains, teleological language "can be understood as making heuristic assumptions for the study of causal laws of nature. It follows, therefore, that a teleological consideration of nature is *legitimate* if it is *useful* for the search of causal explanations." (p. 46). However, many interpreters, including Breitenbach, argue that Kant also assigns teleology a more substantive role than a mere heuristics (see Toepfer, 2004; Quarfood, 2006; Breitenbach, 2009a; van den Berg, 2014, chapter 5). According to his reading, which I also adopt, teleology plays a role in the identification and demarcation of the subject-matter of the life sciences: it is on the basis of teleology that we describe organisms as particular purposive objects and distinguish those objects, as studied in the life sciences, from non-living and non-purposive objects studied in other natural sciences.

What further role does teleology play, besides the heuristic role and the role in the demarcation of the domain of the life sciences? Ginsborg (2001) argues convincingly that Kant assigns a normative function to teleological judgments. To say, for example, that the purpose or function of the eye is to enable sight is to say that the eye *ought* to enable sight, referring to a form of normative lawlikeness. As an anonymous referee has argued, this type of function of teleology can also be taken to imply that teleology is key to biological relevance. This means, first of all, that we identify heuristically targets for mechanical explanations (a feature also stressed by Breitenbach and others). To give an example given by the anonymous referee, teleology allows you to ask 'why do we have hair?', which makes the mechanism of hair growth - which we can explain mechanistically - relevant for understanding the organism. Second, teleology allows us to distinguish mechanisms which are biologically relevant (such as the mechanism for hair growth) from mechanisms which are biologically irrelevant, such as the mechanism (to cite another example of the anonymous referee) of burning hair during volcano eruptions. This latter mechanism would never be the target of a teleological investigation, and hence is irrelevant biologically. Hence, teleology is of fundamental importance for investigations in the life sciences. However, it remains the case that teleology is not explanatory in the strict sense as mechanism is.

Given that proper explanations in natural science are mechanical explanations and that teleology is non-explanatory, and given that Kant believed that some features of organisms cannot be explained mechanically, it follows that Kant was skeptical about the possibility of providing proper explanations of several features of organisms. In this respect, Richards and Zammito are correct to argue that Kant's conception of the life sciences was difficult to reconcile with the project to establish biology as a proper science. To be sure, Kant did not deny that explanations in the life sciences are completely impossible, because he stressed that in the life sciences we must provide mechanical explanations as far as possible (Ginsborg, 2006; Breitenbach, 2009a; van den Berg, 2014; Geiger, 2022). More specifically, Kant argued that in the life sciences we take the organization of organisms as given, and then try to mechanically explain how certain organs or organisms can perform certain functions. For example, taking the structure of the human eye as a given, we use knowledge of anatomy and optics to explain how the human eye enables sight. However, Kant believed that the origin and purposive unity of organisms, features investigated by life scientists in Kant's time, could not be so explained. Hence, Kant was skeptical about the ambitions of many of his contemporary life scientists, insofar as key features of organisms are inexplicable.

This conclusion can also be reached if one investigates the role of analogy in Kant's philosophy and in the eighteenth-century life sciences (see Reill, 2005; Breitenbach, 2009a, 2014, Nassar, 2016; van den Berg, 2018). Breitenbach (2009a, 2014) and Nassar (2016) argue that Kant's philosophy of biology is fundamentally based on a particular conception of analogy. According to these authors, teleological judgments for Kant are not a mere heuristic for investigating organisms, but allow us to represent organisms as purposive. As such, teleology is, as we explained above, necessary for identifying and demarcating the subject-matter or domain of the life sciences. Both Breitenbach and Nassar stress that for Kant, teleological judgments concerning organisms are based on an *analogy* with human goal-directed action. Hence, analogy is fundamental to conceiving and identifying the subject-matter or domain of the life sciences.

van den Berg (2018), building on Breitenbach and Nassar, agrees that analogy fulfills this goal in Kant and also agrees that analogy was fundamental for the life sciences in the eighteenth century. He analyzes biological research in Kant and eighteenth-century life scientists, such as Buffon and Blumenbach, and distinguishes different roles of analogy in the sciences, among which (a) a heuristic role for the discovery of new knowledge, (b) a justificatory role in the justification of knowledge, and (c) a role in facilitating scientific understanding of scientific concepts and theories. Although Kant, according to van den Berg (2018), could assign analogy (a) a heuristic role and (c) a role in facilitating scientific understanding, he rejected the idea that analogy provides (b) justification of scientific knowledge, since he took the justification and explanation of knowledge of phenomena to consist in providing proper scientific demonstrations, i.e., strict and valid deductive (not inductive) demonstrations from principles. Hence, the fact that eighteenth-century life science was based on analogy and used analogy for the justification of knowledge provided one more reason for Kant to argue that the life sciences of his day were not proper sciences. In spite of Kant's denial of the explanatory function of analogy, the research of Breitenbach has convincingly shown that analogy was of vital importance for Kant's philosophy. As an anonymous referee has correctly stressed, for Kant analogy was of vital importance because analogy, among many other functions, underlies empirical concept formation according to Kant's arguments in the third *Critique*.

Kant's strict views on science and explanation allow us to understand, according to van den Berg (2014, chapters 2 and 8), why Kant thought that natural description and natural history were not proper sciences (see on natural description and natural history Sloan, 2006; Cooper, 2023. On race and racism in early modern natural history and Kant, see Lu-Adler, 2023). *Natural description*, the science of providing classifications of organisms based on their similarities, as provided for example by Linnaeus, does not specify objective grounds (causes) for why organisms are structured as they are and is thus not explanatory. It follows that natural description is not a science that conforms to Kant's definition of proper science as given in the *Metaphysical Foundations*. *Natural history* is understood by Kant in his 1788 essay on teleology as a discipline that investigates relations between present-day properties of organisms and their historical causes. As van den Berg (2014, p. 35) explains, building on Sloan, 2006, regularities that relate present-day effects to causes operative in the past are derived from the observation of forces that are active in the present and analogical inferences, the latter supporting the claim that such forces have also been operative in the past and have given rise to effects that are similar to effects that we observe in the present. Insofar as natural history aims at providing causal regularities, or more specifically aims to specify historical causes of present-day effects, it is an explanatory science. However, since natural history does not contain proper demonstrations but is based on probable analogical inferences and lacks a priori principles, it is, as Kant notes, an investigation that provides no certainty (van den Berg, 2018). Hence, again, it does not satisfy Kant's definition of proper science as given in the *Metaphysical Foundations*.

3. Cuvier's conception of science, natural history, and comparative anatomy

This paper wishes to establish that Kant and Cuvier had similar conceptions of proper science, scientific methodology, and explanation, thus demonstrating that aspects of Kantian philosophy provided a fruitful research programme for some naturalists. It is not mainly concerned with establishing historical influence. Nevertheless, we may start our analysis of Cuvier by noting some historical facts that support the interpretation that Kant influenced Cuvier. These facts have already been established by Outram (1986) and Huneman (2006). Outram, partly following the research of Lenoir, notes that Cuvier was educated in Stuttgart between 1784 and 1788, and that he was a lifelong correspondent of the German naturalist Kielmeyer, who was familiar with Kant. Cuvier, who explicitly references Kant in his work (see below), could have derived his knowledge of Kant through Kielmeyer. Huneman (2006) adds that throughout his life Cuvier also corresponded with Christian Heinrich Pfaff, a professor of medicine and chemistry. Given Cuvier's close involvement with German science, it could well be the case that he was quite familiar with Kant's philosophy.

With respect to the influence of Kant on Cuvier, (1800), Russell (1916) argued, presumably being the first, that Kant's conception of teleology, according to which we can only comprehend organisms by conceptualizing them as purposive wholes, impacted Cuvier's construal of organisms and teleological reasoning. Outram (1986), partly influenced by Lenoir, comes to basically the same conclusion, noting that Cuvier was attracted to Kant's conception of internal purposiveness. Huneman discusses Cuvier's so-called "principle of the conditions of existence" and "principle of the correlation of parts" and argues that they are to be understood, in line with Kant, as regulative teleological principles. I think all these interpretations are insightful and important. However, I will extend the work of the authors by arguing that according to the interpretations these authors give of Cuvier it is not quite clear how teleology is regulative. The reason is that Cuvier takes regularities based on teleological reasoning to have the status of laws, similar to laws in metaphysics and mathematics. How then can teleological reasoning be regulative? I will answer this question by looking very detailed at the logic of Cuvier's teleological reasoning. In this context, I will also provide a novel interpretation of Cuvier's use of analogy and analogical reasoning in comparative anatomy.

Cuvier's views on science have been most explicitly discussed by Outram (1986) and Appel (1987). Outram argues that Cuvier adopted an unstable position on the laws of organisms or life. Cuvier recognized that laws in science should in some sense follow from physical laws, yet Cuvier adopted, following Bichat, a definition of life that stressed that life could not be captured in terms of physical or chemical laws. Hence, Outram concludes, Cuvier viewed laws of organisms or life as at best approximations of laws in fields such as physics and chemistry. Appel (1987) describes Cuvier's empiricist methodology, which entailed taking generalizations to be collections of facts, and Cuvier's hostility towards philosophical systems and a priori reasoning. In addition, Appel construes Cuvier as a vitalist who opposed reductionism. Although Outram and Appel provide important insights into Cuvier's conception of science, I will argue that they have missed how some core Kantian insights were also adopted by Cuvier, namely: (i) that science is a system that should unify as many phenomena as possible, (ii) that only mechanical explanations are proper explanations in natural science, and (iii) that we should take the organization of organism as given in the life sciences and proceed to provide mechanical explanations of organisms as much as possible. My interpretation corrects early interpretations of Cuvier which ascribed to Cuvier the acceptance of teleological explanation and claimed that Cuvier did not accept Kant's regulative interpretation of teleology (Coleman, 1964; Ospovat, 1978). Lenoir (1989) claimed, even if Cuvier is not a major focus of his work and his analysis of Cuvier is very brief, that Cuvier came close to adopting what he calls teleomechanism, taking the organization of organisms as given, interpreting organisms teleologically and searching for a Newton of Nature. I think Lenoir's brief statements are exactly right and in the following I will further develop and substantiate this interpretation, providing, in contrast to Lenoir, a detailed analysis of the methodology, conception of science, and conception of mechanical explanation and regulative teleology and analogy of Cuvier.

Finally, it is important to stress that Kant was certainly not the only influence on Cuvier, a fact supported by the circumstance that Cuvier only refers to Kant in a few places, as an anonymous referee has stressed. The teleological and purposive conceptualization of organisms, which Cuvier sometimes does explicitly ascribe to Kant, could also be gathered by Cuvier from influential German life scientists, such as Blumenbach and his followers (see on the similarities between Kant and Blumenbach Lenoir, 1989), as well French naturalists who adopted such a conception, such as Bichat discussed by Outram, who we know influenced Cuvier. In general, I think the purposive conception of organisms was so widespread around 1800 that it is wrong to think this conception only derived from Kant. Moreover, as we shall see in the next section, Cuvier's research programme in the life sciences and rejection of speculative systems was heavily influenced by the French naturalist Félix Vicq d'Azyr (1748–1794). In line with his rejection of speculative systems, Cuvier, as we shall see, also rejected *Naturphilosophie* and the foundationalist aspects of Kant's philosophy. Hence, there were multiple lines of influence that led to Cuvier's research programme, and Kant was no doubt only a small part of this influence, whereas Cuvier also rejected parts of Kant's philosophy. Nevertheless, without a doubt Kant did influence Cuvier's research programme, and there are many similarities between Kant's and Cuvier's methodology of the life sciences. This establishes that what Lenoir christened Kant's teleomechanism was a research programme that was adopted by some influential life scientists around 1800, contrary to the interpretation of Richards and Zammito.

3.1. Cuvier on comparative anatomy, natural history, natural science, and explanation

As has been emphasized by Coleman (1964), Huneman (2006, 2008), and Schmitt (2009), an important influence on the research in comparative anatomy of Cuvier was the work of the French physician and naturalist Félix Vicq d'Azyr (1748–1794). As Schmitt (2009) explains, d'Azyr instituted a programme in which all studies on organisms and their functions are subordinated to comparative anatomy. Comparative anatomy was considered the foundation of exact knowledge of organisms. Understanding the function of the parts of organisms must be based on comparative anatomy, whereas physiological knowledge, knowledge of illness, and knowledge of mechanisms were also based on analysis in comparative anatomy. According to Schmitt (2009), d'Azyr rejected speculative science or systems of thought that were not based on solid data, and it was the task of comparative anatomy to supply such data. Finally, d'Azyr anticipated Cuvier by identifying through comparative research laws governing relations between the organization of different parts of the same animal. Huneman (2006, 2008) adds that Cuvier made extensive use of d'Azyr's idea that there is a constant conjunction between superficial organs and hidden vital organs, and of the claim that comparative anatomy must take viscera into account.

Having discussed some important historical context of Cuvier's research, we may turn to his views on natural history, science and explanation. Cuvier's conception of natural history, proper science and explanation are discussed in the little studied works *Tableau élémentaire de l'histoire naturelle des animaux* (1797–1798) and the *Histoire des progrès des sciences naturelles depuis 1789 jusqu'à ce jour* (1826–1836).[2] In these works, I will argue, we find a coherent conception of natural history, science, and explanation, which is in several respects quite similar to Kant's conception of science and explanation. After studying these works, we can find similar conceptions of methodology in Cuvier's lectures on comparative anatomy.

In his *Tableau* (1800 [1797–1798], pp. 1–2), Cuvier defines natural science as the science of moveable extended objects which we call bodies. As parts of natural science Cuvier mentions disciplines such as dynamics, which deals with general laws of (the communication of) motion and force, and chemistry. Importantly, Cuvier argues that in science we often deal with natural bodies and *apply* the general doctrines

[2] I have consulted the German translations of both and compared and checked these with the French works. I refer to the German translations.

of natural science. This is the case for what Cuvier calls the particular doctrine of nature, also called natural history (p. 2). Hence, in natural history we apply general laws pertaining to natural science such as dynamics or chemistry. In line with this view, Cuvier argues that we have two types of cognition in natural science: (a) knowledge of that which we obtain through the senses, such as the quantity and structure of bodies, and (b) the *explanation* of phenomena and empirical objects and events, which is defined as a *demonstration* of consequences based on general laws of the physical and mathematical sciences (ibid). On this basis Cuvier infers that natural history must involve not only the description of bodies, their structure and their parts, but also the *explanation* of all that is described in natural history (pp. 3–4).

Our analysis of Cuvier's *Tableau* shows that Cuvier, very similar to Kant, saw explanation in science as a demonstrative inference on the basis of physical or mathematical laws. In other words, Cuvier stressed that *mechanical explanations* are proper and ideal explanations in science and natural history. This conception of explanation led Cuvier to argue that natural history should ideally be an explanatory science, in which we provide mechanical explanations of phenomena. Hence, for Cuvier natural history was more than what Kant calls natural description. For Cuvier natural history should aim to achieve the same status as other explanatory sciences in physics, such as for example Newtonian physics.

A very similar conception of natural history and explanation can be found in Cuvier's *Histoire des progrès des sciences* (1826–1836). In this text, Cuvier begins by giving a general account of natural science and its methods. Cuvier notes that natural science, which is construed as a non-mathematical science, cannot attain the same level of *certainty* as the mathematical sciences. Characteristic of natural science is that we strive to collect a large number of *facts*, which allow us to derive more and more universal statements that *unify* a large number of phenomena (1828, p. 2). Hence, Cuvier sees unification as a central ideal of natural science. In this respect, Cuvier again adopted an ideal of science that was very close to Kant. As van den Berg (2021) shows, extending Falkenburg's (2000) analysis of Kant's logical ideals of science, Kant adopted as a logical ideal of scientific knowledge that science should be based upon a minimum of principles that allows to give a *unified* explanation of a maximum amount of phenomena. Hence, both Kant and Cuvier stressed the importance of unification as an ideal or virtue of science, even if, as we shall see below, they differed in their conception of the certainty of empirical science.

In line with his conception of explanation in the *Tableau*, Cuvier, in the *Histoire des progrès des sciences*, notes that we properly explain phenomena in natural science if we explain phenomena as a consequence of fundamental causes (1828, p. 2). On the basis of this conception of explanation, Cuvier sketches a (somewhat hypothetical) programme of mechanical explanatory unification in natural science. He argues that what he calls general (Newtonian) attraction is well established, and can be taken to be also operative between parts of matter that constitute earthly substances. This microscopic form of attraction can then, presumably with other assumptions, be taken to explain phenomena such as cohesion and chemical phenomena. Finally, chemical laws can in turn be taken to explain the formation of minerals and changes in the atmosphere, and ideally chemical laws are also used to explain phenomena of living bodies, although here Cuvier stresses our ignorance and difficulties with achieving this task (p. 3). In short, Cuvier adopted a view of science as a hierarchical system of statements in which general laws and causes are used to explain more specific consequences in order to provide (as far as possible) mechanical explanations of natural phenomena. This conception of science and explanation was shared by Kant.

To be sure, Cuvier remarks that the idea of a unified and systematic science is an ideal of science that is not yet achieved. He recognized that, as he puts it himself, the *rational principles* of natural science have often not yet been found, and that natural science at present mainly consists in a collection of empirical facts (1828, p. 5). In this context, Cuvier, as has also been observed by Outram, 1984, 1986; Appel, 1987, objected to the attempt of metaphysicians and philosophically inclined scientists to provide metaphysical and a priori principles of science speculatively. This speculative mode of science often leads to a neglect of facts and provides dubious modes of explanation, Cuvier argues (p. 6). We must, therefore, stick to empirical facts and to what Cuvier calls the certainty that can be obtained on the basis of empirical facts (p. 7). In adopting this empiricist methodology, Cuvier certainly departed from Kant's philosophy of science, even if Kant need not be the main target of Cuvier's criticisms of speculative science and it is more likely that he criticized *Naturphilosophie* (on Cuvier's aversion to *Naturphilosophie*, see Outram, 1984, chapter 6). We will return to this difference and explain its importance for Cuvier's philosophy of science below.

In his account of natural history in *Histoire des progrès des sciences*, Cuvier again notes that natural history should strive for *mechanical explanations* of nature. Thus, he writes that the final goal of natural history is to use the universal laws of mechanics, physics, and chemistry in order to explain particular phenomena of natural bodies in natural history (1828, p. 120). This is also true for the life sciences, even if such mechanical explanations constitute an ideal that is difficult to establish. Thus, Cuvier remarks, for example, that the physiologist in explaining the phenomena of life in plants and animals must necessarily base herself on physical laws that play a role in the phenomena of life (p. 122).

We can appreciate how Cuvier applied the ideal of mechanical explanation if we describe his historical account of the theory of nutrition and other vital phenomena around 1800, as given in his *Histoire des progrès des sciences*. Cuvier took nutrition, in line with the views of many eighteenth-century naturalists, to be a defining feature of organisms (1828, p. 164). According to Cuvier, one must investigate nutrition on the basis of three research programmes. First, one must investigate which materials organisms take up and which they secrete, which is (a) the *chemical* investigation of nutrition (ibid.). Then, one must describe the trajectories that materials follow throughout an organism, which is (b) the *anatomical* investigation of nutrition (p. 165). Finally, one must investigate the forces by which materials are taken up as nutrition, i.e., the forces that govern nutrition, which is (c) the *dynamical* or *physiological* part of the investigation. With respect to (a) Cuvier notes that the chemical investigation of nutrition in plants has been largely solved, insofar as we know, due to the research of Lavoisier, Senebier, and others, that plants use water and carbon dioxide or carbonic acid, which they decompose using sunlight, in order to form nutrition (p. 165). Hence, in this domain mechanical explanations are possible. With respect to (b) Cuvier notes that the anatomical investigation of nutrition in animals, i.e., of the trajectories that materials and nutrients take in animals, has also been solved, mentioning his own work but also other work, such as William Harvey on the circulation of the blood (p. 170). Finally, with respect to the (c) physiological investigation of nutrition and of living phenomena more generally, Cuvier notes that physiologists have often assumed the existence of *vital forces* in organisms. He argues with respect to vital forces that so far it has not been possible to explain vital forces and their effects in terms of mechanical forces or chemical forces (1828, p. 184). Hence, a mechanical explanation of vital phenomena, such as the irritability of muscles, which he mentions in this context, is so far only an ideal. As a consequence, Cuvier says that in order to further the progress of physiology we should provisionally take vital phenomena to be inexplicable and take vital phenomena such as irritability as *principles* on the basis of which we try to provide unified explanations of other vital phenomena in physiology. Here, we see Cuvier's pragmatic stance toward science: if we cannot proceed further with providing the causes of irritability and sensibility we should at least provide the best unified explanation of phenomena in terms of principles we have established. However, taking this pragmatic stance does not mean that we rest content with not providing mechanical explanations of vital phenomena. For Cuvier, the ideal of explanation remains that of mechanical explanation. Hence, he remarks when discussing the phenomena of irritability and sensibility, investigated by Haller, that the fate of physiology depends on combining the investigations of irritability and sensibility with the new discoveries in anatomy and chemistry, which will hopefully result in proper natural or as Kant would put it mechanical explanations of vital phenomena (p. 191).

As an anonymous referee has stressed, Cuvier's *Histoire des progrès des sciences* (1826–1836) obey a quite institutional form of writing. Hence, it is also important to consider his explanatory practices when arguing that mechanical explanations are ideal explanations of nature. To this end, we can consider Cuvier's *Leçons d'anatomie comparée* (1800–1805). In this work, Cuvier also argues that we must try to provide mechanical explanations of nature, i.e., explanations of wholes in terms of their parts and composition. As Cuvier puts the point:

> Unable to ascend to the origin of living bodies, there remains then within our reach no source of information respecting the real nature of the powers which animate them, except the examination of the composition of those bodies, that is to say, of their texture, and the composition of their elements [...] (Cuvier, 1802, p. 7)

Cuvier acknowledges that our knowledge of the mechanisms of living bodies is limited, insofar as "this composition of living bodies is too imperfectly known to enable us to deduce clearly from it the effects they exhibit" (p. 8), but mechanical explanation remains an ideal nonetheless. Thus, for example, in discussing the structure of the organs of animals, Cuvier provides mechanical accounts of the muscles to explain how they move animals:

> Their force, the point of their insertion, and the length and weight of the parts attached to the lever they have to move, determine the velocity and the duration of the motion they are capable of producing. On these different circumstances depend the force of leaping, the extent of flight, the rapidity of the race, and the prehensile power possessed by the different species of animals (Cuvier, 1802, p. 24).

Finally, Cuvier clearly took mechanical explanations to be an integral part of comparative anatomy, and, like Vicq d'Azyr, took comparative anatomy to contribute to knowledge of mechanisms of organic phenomena. This is clear, for example, from Cuvier's discussion of the circulation of the blood in different animals (1810, pp. 1–5). There, Cuvier attempts to specify, as he also says himself, the *mechanism* of this circulation, noting that explaining circulation requires an account of the organs and trajectories of the blood involved, i.e., an explanation of a complex whole in terms of its interacting parts. Providing such a mechanical explanation is helped by discussing different forms of circulation in different animals.

Hence, very much like Kant, Cuvier adopted the ideal of mechanical explanation in science and natural history and stressed that we should always strive to provide mechanical explanations of organisms and organic phenomena as much as possible. This was the meaning of Kant's regulative maxim of mechanism articulated in the third *Critique*, and our study of Cuvier showed that Cuvier consistently followed (perhaps unconsciously) this maxim. Now, of course, Kant argued that there are limits to our mechanical explanations of organisms and organic phenomena: we cannot mechanically explain the origin and purposive structure of organisms. Accordingly, he argued that we must take some purposive structure of organisms as given, e.g., the purposive structure of the human eye, and then explain functions of such structures mechanically, e.g., explain how the laws of optics and the organization of the parts of the eye make sight possible. Interestingly, in his *Histoire des progrès des sciences*, Cuvier adopted precisely this methodology. Thus, while discussing natural history, he remarks that for living bodies we must assume the general form of these bodies as given data (p. 163), given that we cannot explain the origin and generation of organic bodies. Hence, Cuvier, again like Kant, argued that we take the organization of organisms as a given and inexplicable principle on which we base explanations in the life sciences.

We have stressed the similarities between Kant's conception of mechanical explanation and that of Cuvier, arguing that Cuvier adopted Kant's teleomechanism. It is important to also stress, however, that Cuvier adopted alternative modes of explanation in the sciences, including life sciences, when mechanical explanations were not available. This was the case, for example, in his investigations in paleontology, a science in which, as an anonymous referee has stressed, mechanical explanations were not possible. We can finish our analysis of science and explanation in this section by briefly analyzing Cuvier's research practice in paleontology, which demonstrates his flexible conception of scientific method.

According to Cuvier, comparative anatomy was vital to research in zoology and geology, although the research field Cuvier engaged himself with would now also be called paleontology. In a *Memoir on the Species of 'Elephants, both Living and Fossil* (Cuvier 1997 [1796]), Cuvier remarked that comparative anatomy could *with certainty* establish for one elephant from Ceylon and for one elephant from the Cape of Good Hope that they do not belong to the same species (p. 19). Comparative anatomy also provided improvement in the (mere) conjectures of *geology*, defined as a science dealing with the historical structure and history and monuments of physical earth, insofar as comparative anatomy proves that the mammoth and the elephant are not of the same species and gives support to the conjecture that the earth has undergone revolutions or catastrophes, which has rendered some animals extinct (p. 24). Here, we thus see how comparative anatomy can yield both certainty and give support conjectures in zoology and geology without providing mechanical explanations of phenomena.

In his *Extract from a memoir of an animal of which the bones are found in the plaster stone around Paris, and which appears no longer to exist alive today* (Cuvier 1997 [1798]), Cuvier articulated a research programme for paleontology. Here, he once again noted that comparative anatomy was essential to geology or what we now call paleontology. He famously remarked, as he did in other places, that through comparative anatomy one can reconstruct the class and sometimes even the genus of the animal after observing one bone. This is because organisms constitute functional wholes, so that one can infer every bone of an animal after observing just a single bone (p. 36). Cuvier illustrated this teleological reasoning by noting, as we shall discuss in more detail below, that if we observe the teeth of animals as allowing for the consumption of fresh flesh, we can be sure that the system of digestion is appropriate for digesting such food, that its whole skeleton and locomotive organs allow for catching prey, and so forth. Cuvier did remark, however, that such inferences were often probable and not with certainty (p. 37). Cuvier applied his methodological maxims by reconstructing the entire skeleton of a fossilized animal to which they belong, and argued that it belonged to the same class as pigs, tapirs, hippopotamus, and other thick-skinned herbivores, that it is extinct, while finally reconstructing the forms of muscles attached to the bones and of the skin, thus obtaining an image of the entire animal. In this way, comparative anatomy provided probable knowledge of paleontology without providing certainty or mechanical explanations.

3.2. *Teleology and analogy in Cuvier's natural history and comparative anatomy*

We have seen that Cuvier shared with Kant ideas an ideal of mechanical explanation and also adopted the method of taking the original organization of organisms as a given in the life sciences. In this section, we will investigate the role of teleology and analogy in the scientific works of Cuvier. I will argue that Cuvier, similar to Kant, took teleology to have a role in the definition of organic or living beings, and thus attributed to teleology a role in the demarcation of the subject-matter or domain of natural history. In addition, I will, furthering the work of Russell (1916), Outram (1986), and Huneman (2006, 2008), explain why Cuvier's so-called "principle of the conditions of existence" and "principle of the correlation of parts" are to be viewed as regulative teleological principles, in line with Kant's interpretation of teleological principles. Throughout my analysis of Cuvier, I also describe very precisely the role that analogy plays in Cuvier's reasoning.

3.2.1. Kant and Cuvier

In our description of Kant, we have seen that according to many commentators Kant attributes an identificatory function to teleology: it is on the basis of teleology that we identify organisms as purposive wholes and delimit the domain of organic bodies from non-organic bodies, i.e., delimit the domain or subject-matter of the life sciences (see section 2). Cuvier also attributes such a function to teleology, a feature of Cuvier's thought that is seldom noticed. According to Kant's teleological definition of organisms, as is well known, the whole is the (ideal) cause of the parts, and the parts thus depend on the whole, while in turn the parts are the cause of the whole. In addition, Kant takes the parts of organisms to be reciprocally dependent upon each other. In his *Tableau élémentaire de l'histoire naturelle des animaux* (1800 [1797–1798], p. 6), Cuvier gives a similar teleological definition of organized beings while characterizing the domain or subject-matter of natural history. Thus, he defines organisms as beings with a multitude of parts, in which the parts are reciprocally dependent and in which every part contributes to a general goal or function, namely the support of life (ibid.). He subsequently delimits organisms from non-organized beings by noting that organisms are generated, grow, nourish themselves and die. In his *Leçons d'anatomie comparée* (1800–1805), Cuvier gives a similar teleological definition of organisms, and explicitly attributes this definition to Kant. He says, characterizing organisms (1802, p.6), that "according to the expression of Kant, the mode of existence of each part of inanimate bodies belongs to itself, but in living bodies it resides in the whole". Thus, the parts of an organism are dependent on the whole. It is by adopting this teleological definition of organisms that Cuvier delimits the domain or subject-matter of the life sciences. He continues in his *Leçons* by noting, again, that organized beings or living beings are characterized by generation, nutrition and death, and he notes that we identify other beings in natural history as animals by analogy to ourselves. Thus, Cuvier argues that we know the faculties of sensation and of voluntary motion exist in ourselves, and that we then ascribe these faculties *by analogy* to other beings, which we call animals (1802, p. 11). Hence, to conclude, Cuvier uses teleology as a means to identify and demarcate the domain or subject matter of natural history, and analogy plays a role in the identification of a class of the objects studied in natural history, namely animals. We will return to the use of analogy in Cuvier's scientific writings below.

We may now turn to the similarities between Kant's regulative conception of teleology and Cuvier's conception of teleology, turning our attention to Cuvier's so-called "principle of the conditions of existence", a principle of natural history that according to Russell (1916), Outram (1986), and Huneman (2006) was influenced by Kant's teleology. Huneman (2006, p. 659) gives a nice account of the general idea behind Cuvier's "principle of the conditions of existence", noting that Cuvier also calls it a principle of final causes. According to this principle all organs of an animal have a common purpose, namely the existence of the animal in its milieu. Russell (1916) explains the principle with reference to the opening sections of Cuvier's *Leçons d'anatomie comparée*. There, Cuvier often infers the structure of organs and organisms from functions. Cuvier begins by specifying that organisms have the functions of generation and nutrition, and that animals constitute a subclass of organisms (1802, pp. 10–11). He then notes that in animals the idea of sensation is included in the idea of voluntary motion, since "we cannot conceive volition without desire, and unaccompanied by the sentiment of pleasure or pain" (p. 11). In this way, Cuvier thus shows how different functions of animals are *dependent* upon one another. From the fact that animals have functions such as sensation, i.e., can experience pleasure and pain, Cuvier in turn infers that animals must have the power of avoiding one and procuring the other. On this basis, Cuvier extends his analysis, showing on the one hand how functions are dependent on one another and also how structures can be inferred from functions. For example, from the fact that animals can change their place, Cuvier infers that they can transport nutritional substances, must have an internal cavity for storing these substances, should have instruments for dividing those substances, and so forth (p. 13). This example shows how Cuvier applies the principle of the conditions of existence: it is the inference of dependent functions and structures from more primary functions. As such, it is a clear instance of teleological reasoning.

Cuvier's reasoning based on the "principle of the conditions of existence" is a clear instance of reasoning in a regulative fashion as Kant would understand it. We adopt a teleological principle as given and subsequently infer functions and structures from given functions in organisms, e.g., from the motion of animals we infer that they must have an internal cavity for storing nutritional substances, instruments for dividing such substances, etc. Hence, we can already say, as an anonymous referee has stressed, that teleological principles provide a *heuristic* for empirical research, which is precisely the heuristic use of teleological principles that was implied by Kant's regulative (and hence heuristic) teleology. This practical use of teleology was central for Cuvier's research practices, but we have also seen that Cuvier, like Kant, also used teleology to demarcate the domain or subject matter of the life sciences. Hence, teleology, for both Kant and Cuvier, has a foundational function for the life sciences. This is, as an anonymous referee has stressed, a second and *different* meaning of the idea of a regulative teleology. Here, however, the impact of Kant may have been limited. As van den Berg (2014) has shown, many life scientists in the eighteenth century, including Blumenbach and his followers, used the language of purposiveness to demarcate the subject matter or domain of the life sciences. Having made these preliminary remarks, we will continue the investigation of the regulative status of teleology and analogy in Kant and Cuvier in the next section.

3.2.2. Regulative teleology, analogy, function, and structure in Cuvier

Huneman seems to take the principle of the conditions of existence and the corresponding "principle of the correlation of parts" (which we discuss below, and which is really one more variety of the principle of existence), as regulative teleological principles (Huneman calls the principle of the correlation of parts regulative and is silent about the principle of the conditions of existence, but generally notes Cuvier follows Kant). But it is not clear exactly why the principle of the conditions of existence is regulative. Russell (1916), who similarly argued for the influence of Kant's teleology on Cuvier, also took the principle of the conditions of existence to be regulative and non-explanatory. However, he simultaneously called similar principles explanatory. Thus, Russell contradicts himself. The idea that a teleological principle is explanatory is problematic, since as we have seen in section 2, many commentators of Kant, who I follow, do not take teleology to be explanatory. Russell and Huneman do not properly explain why Cuvier's principle of the conditions of existence is a regulative teleological principle. Nevertheless, I will argue that Russell's and Huneman's interpretations are correct. In order to understand why the principle of the conditions of existence is regulative, in line with Kant's views on teleology, we must take a closer look at how Cuvier applies this principle in his research and in his *Leçons d'anatomie comparée*, while also looking into the way analogical reasoning figures in Cuvier's comparative anatomy.

We have seen that Kant assigns teleology a regulative function within the life sciences. This implies that teleology for Kant has a heuristic function, although many commentators agree that teleology in Kant is not merely heuristic. The heuristic function of teleology corresponds to the heuristic function that Kant assigns to analogy, although again analogy does not have a merely heuristic function. van den Berg (2018, pp. 68–69) explains the heuristic function that Kant assigns to analogy with reference to the Wolffian philosopher Eberhard (1778). According to Eberhard (1778, pp. 21–22), and Kant agrees, analogies provide probable, tentative, and provisional knowledge that can later become certain by being corroborated by observation or demonstration. Eberhard gives the example of an analogy between moss and other plants in order to hypothesize that moss reproduces through seeds. This inference illustrates the heuristic function of analogy: it provides us with tentative knowledge of objects that must later be confirmed by other means. According to Eberhard, the conclusion concerning the reproduction of moss later became certain when it was corroborated by observation. Teleology can be taken to be heuristic in the same sense. Thus, for example, Kant would argue that teleological assumptions allow us to conceive of organs and organisms, such as the human eye, as purposive, on the basis of which we subsequently try to provide mechanical explanations of the functioning of organs and organisms, e.g., of optical processes in the human eye. In this example, teleology again points us to certain facts and regularities concerning organisms and organs which are later (partly) explained by proper mechanical explanations, which are true explanations. Hence, teleology has a regulative function, as Kant argues. Cuvier, as I will argue below, assigns both teleology and analogy a similar heuristic function. Before discussing teleology and analogy in Cuvier, however, we may briefly discuss the historical context of the use of the concept of analogy in comparative anatomy.

As an anonymous referee has stressed, the concept of analogy was key to natural history and comparative anatomy. In particular, the concept pair analogy/homology was central to comparative anatomy, and during the eighteenth-century the distinction between analogy and homology was not typically made. From our modern perspective, we strictly distinguish homology and analogy: a homology in biology signifies a similarity of structure or physiology due to common evolutionary descent, whereas an analogy is a functional similarity not due to common evolutionary descent. As Schmitt (2009, pp. 164–167) has stressed (see on the history of the concept of homology also Schmitt, 2004), Aristotle described an *analogia* or similarity between the parts of different types of organisms. Buffon later invoked the idea of a common type, again a form of analogy or similarity, noting the same organization between man and animals and introducing the idea of an original design of animals. It was, according to Schmitt, Vicq d'Azyr who transformed the idea of a common type from an abstract idea to a law of nature which could be discovered by comparative anatomy. Huneman (2006) notes that Kant, in the third *Critique*, describes what he calls a form of archeology of nature where we note *analogies of form* described by comparative anatomy, which include homologies, and subsequently adopt the idea of an original form or "parenthood of nature "that would mean a mechanistic derivation of the entire living realm" (p. 661), an idea of which Kant was critical. Kant himself spoke of a common schema of many genera of animals, which yields the idea of a common archetype, and of an analogy of forms. As such, Kant did not distinguish the concepts of analogy and homology. Kant's idea of an archeology of nature was taken up, according to Huneman, by Goethe and Geoffroy.

In his L'*ordre et le Temps* (1979),Bernard Balan sketches the importance of the concept pair analogy/homology in the history of comparative anatomy. Balan remarks (p. 180) that the first applications of the concept homology designated the repetition of organs in individual organisms. From 1838, the concept of homology referred to a comparison of organs of different organisms, a meaning of the term of homology commonly associated with Owen (see also Schmitt, 2004). The concept of homology was, according to Balan and as we have seen, associated with the idea of a unity of plan or (common) type of organisms, and was related to the concept of analogy. In 1833, Balan notes, MacLeay defined an analogy as a correspondence between certain parts of the organization of two animals which differ in their overall structure (p. 186). In 1843, Owen defined a homology as the same organ in different animals and under all varieties of form and function, thus providing a precise concept of homology (p. 190). In contrast, an analogy was defined by Owen as a part or organ which possesses the same function as another part or organ in a different animal (ibid). Cuvier did not yet distinguish analogies and homologies strictly, and no doubt treated many homologies as analogies. Huneman (2008, p. 343) argues that for Cuvier comparative anatomy was fundamentally an analogical science, insofar as a function was considered by Cuvier as an operation common to different classes of organisms, requiring different organs to be carried out. Hence, Huneman explains, attention to function implies attention to different (analogous parts of) animals.

Analogy also played a role in determining the relation between function and structure, which is central to the research in comparative anatomy of Cuvier (see on this topic also Schmitt, 2004). Throughout his lectures on comparative anatomy, Cuvier constantly reasons from function to structure on the basis of the principle of the conditions of existence and analogy, as an anonymous referee has stressed, often provides a set of specific structure-function relations. This is clear if we look at some instances of analogical reasoning in Cuvier. For example, Cuvier provides an analogy between all organized bodies, which according to the analogy require some kind of combustion to live, to argue that some animals have lungs which facilitate this combustion (1802, pp. 16–17). Here, we see how analogy guides the inference from function to structure and how it provides us with structure-function relationships (e.g., the function of the lungs to respire). Similarly, Cuvier notes that animals and plants or vegetables have an *analogy of function* with respect to generation, i.e., both animals and plants share in the analogous function of generation. However, since animals have the capacity (function) for motion and advancing toward one another, while plants have not, the spermatic fluid of animals is transmitted directly to the ova, whereas plants must reproduce differently with the help of pollen and stamina (1802, pp. 17–18). Here, we see how analogy guides the inference from function to structure, and how it allows us to describe how a function is *differently* obtained by different structures in animals and plants. As such, analogy again provides us with specific structure-function relations.

Having provided a general description of the use of teleology and analogy in the research of Cuvier, we may return to our question whether Cuvier took teleology and analogy to be regulative in Kant's sense. We may first note that Cuvier's teleological inferences are regulative and heuristic in the sense that they allow us to *discover* dependency relations between functions and between functions and structures. Thus, his inferences, described above, that animals having the function of motion must be able to transport nutrition, must therefore have a cavity for storing nutrition, and instruments for dividing nutritional substances, and so forth, are rule-based teleological inferences that enable us to identify, discover, and construct different relations between functions and between functions and structures.

Analogy and teleology have similar functions for Cuvier. Importantly, analogy also allows Cuvier to describe and identify certain organisms with certain structures. This resembles the identificatory and descriptive function Kant assigned to teleology. It is on the basis of analogy that Cuvier has a guideline for the empirical description of different animals and their structures. For example, Cuvier notes that all organisms are analogous in the sense that in all organisms there is some form of respiration, and all organisms must have thus analogue organs facilitating this process (1802, pp. 16–17). He then continues to describe disanalogies between organisms, noting that some plants and animals respire throughout the whole of their surface, while other animals respire by a particular organ.

These examples elucidate that analogy provides us with similarities on the basis of which Cuvier describes and identifies groups of organisms, which form a starting point for empirically describing these organisms and their differences. The centrality of analogy for Cuvier also shows itself in that Cuvier uses analogy to define the subject-matter or domain of comparative anatomy. Thus, he notes that organs of different animals often only resemble each other in the effects they produce, i.e., there is an analogy of function between the different organs. The task of comparative anatomy is then conceptualized as the minute description of the different structures of different organs of different classes of animals that nevertheless constitute a unity in the sense that they have analogue or similar functions (1802, p. 35). Thus, for example, it is on the basis of analogy that we can view different organs with different structures as organs that facilitate *respiration* as similar organs, and the task of comparative anatomy is then to chart these different organs and structures, ultimately hopefully helping in the discovery of explanations of how these different organs and structures make respiration possible. In this sense, as aids for explanation, analogy also has a heuristic role for Cuvier.

The question that confronts us now is how Cuvier conceives of the knowledge of organisms that we obtain by means of teleological and analogical reasoning as described above. He describes knowledge of the dependencies of functions or of the dependency of structure on function as *laws*, which suggests that Cuvier actually thinks we have knowledge in the strict scientific sense of organisms and which may then be difficult to square with a regulative reading of Cuvier's use of teleology and analogy. Thus, Cuvier writes:

> It is on this mutual dependence of functions, and the aid they reciprocally yield to one another, that the laws which determine the relations of their organs are founded - laws which have their origin in a necessity equal to that of metaphysical or mathematical laws, for it is evident that suitable harmony between organs which act on one another, is a necessary condition of the existence of the being to which they belong (1802, pp. 47–48).

Hence, Cuvier grants the regularities concerning the relations of organs obtained by teleological and analogical reasoning the same epistemic status as laws in metaphysics or mathematics. How can we reconcile this with a regulative reading of Cuvier's use of teleology and analogy? The answer to this question emerges if we understand, as we have already seen above, that Cuvier still thinks that we have not yet properly explained these empirical regularities concerning the relations of organs so-long as we have not yet provided a mechanical explanation of these regularities. Like in his other works, in the *Leçons d'anatomie comparée* mechanical explanations are treated as ideal explanations of nature. Thus, Cuvier notes that although we have as of yet not succeeded in explaining the phenomena of living bodies in terms of the general laws of nature, it would be wrong to conclude that these phenomena are of a different kind. Indeed, we should strive to provide mechanical explanations, and so long as this is not possible, we should put our effort in providing a (non-explanatory) "empirical exposition, instead of a rational system" (1802, p. 9). This is a claim of positivistic humility, highlighting Cuvier's empiricist methodology and his aversion to speculative systems and *Naturphilosophie*, an aversion which we have seen Cuvier shared with Vicq d'Azyr.

In addition, Cuvier thinks, in line with the regulative conception of teleology and analogy that we have sketched above, that regularities obtained by teleological and analogical reasoning must be supported by observation and/or experiment in order to make them certain. This fact, which has escaped many commentators, becomes clear if we look at Cuvier's analysis of respiration. Dealing with this topic, Cuvier first notes that "the mode of respiration" depends on the manner in which "the motion of the nutritive fluid is performed" (p. 48). Thus, in animals that have a heart and vessels, this fluid is collected in a central reservoir, comes from the heart, and can be exposed to the action of the air at its source, and passes through lungs or branchiae to be subject to that action (ibid.). However, this fact does not hold for animals, like insects, which have no heart or vessels. Their nutritive fluid does not depart from a common source, and hence they have a different mode of respiration.

In this way, Cuvier again uses reasoning to deduce certain organic laws. However, he is quite clear that these laws need to be supported, as the above laws are, by observation, noting that after laws are deduced by reasoning they are confirmed by observation (p. 57). Moreover, in developing his account of respiration, Cuvier refers to the *experimental finding* that "one of the principal uses of respiration is to reanimate the muscular force, by restoring to the fibre its exhausted irritability (p. 50). This experimental finding is then used, together with observational support, to explain regularities such as that birds and mammalia "not only always live in air, and move in it with greater force than the other red-blooded animals, but each of those classes enjoys the faculty of motion precisely in a degree corresponding to its quantity of respiration" (p. 50). Hence, we can conclude that Cuvier indeed uses teleological and analogical reasoning in discovering regularities concerning organic phenomena, but that these inferences are regulative and heuristic in the sense that (a) proper explanations are always causal (mechanical) explanations, and (b) the discovered regularities are only certain if after have being inferred they are corroborated by observation and experiment. In this sense, Cuvier can certainly be said to follow Kant's regulative conception of teleology and analogy.

3.2.3. Cuvier and the principle of the correlation of parts

We may now turn our attention to Cuvier's principle of the correlation of parts, which is, as I will argue, regulative in the same sense as the principle of the conditions of existence. In the *Discourse préliminaire* (1812), Cuvier describes the principle of the correlation of parts, according to which one can infer the existence of all parts of an organism from a single part, as resulting from his teleological (Kantian) definition of organisms:

> Every organized being forms a whole, a unique and closed system, in which all the parts correspond mutually, and contribute to the same definitive action by a reciprocal reaction. None of its parts can change without the others changing too; and consequently each of them, taken separately, indicates and gives all the others (1997 [1812], p. 217)

Thus, for example, Cuvier shows the application of this principle, which is really just another application of the principle of coexistence, by noting that animals with intestines that only eat fresh flesh, must have jaws for devouring prey, claws for seizing and tearing prey, teeth for cutting flesh, the entire system of locomotive organs, and so forth (ibid.). Now, Cuvier suggests that sometimes we can arrive at these conclusions through pure a priori reasoning. However, he still always thinks, as we have seen above, that a proper explanation of the coexistence of organs must be a causal explanation, even if we are unable to give one, and also argues that in general such regularities arrived at through teleological reasoning must be based on empirical support. Thus, Cuvier states:

> In a general sense, this principle is sufficiently clear in itself not to need any demonstration. But when it comes to applying it, there is a large number of cases in which our theoretical knowledge of the relationships of the forms would be insufficient, if they were not founded on observation (1997 [1812], p. 219)

Hence, teleological reasoning allows us to infer different parts and organs of an organism on the basis of knowledge of a single part or organ, but that these inferences are actually correct and that the regularities that we infer teleologically actually obtain in the world, must be established by observation. Thus, for example, Cuvier notes that although we can use a priori teleological reasoning to guess that hoofed mammals are herbivores, since they cannot seize prey, observation is required to determine that all ruminants have a cloven hoof. In all these cases, we can use teleological reasoning or empirical observation to establish relations between parts or organs of organisms. Cuvier remarks, however, that since we often do not know the cause of these relations, we must rely on observation in order to establish empirical laws in comparative anatomy and natural history:

> Nevertheless, since these relations are constant, they must have a sufficient cause. But as we do not know it, where theory fails observation must provide. It establishes empirical laws that become almost as certain as rational ones, when they are based on sufficiently repeated observations (1997 [1812], p. 220).

Hence, the principle of the correlation of the parts is properly called a regulative teleological principle. It is not properly explanatory, because only a causal explanation would be, but it allows us to use teleological reasoning to *discover* all the parts of an organism on the basis of knowledge of a single or some parts. Hence, the principle is regulative in the sense of providing us a heuristic for reconstructing relations between parts of organisms. Moreover, the principle is also regulative in that by itself the relations of coexistence of parts of organisms it establishes by teleological reasoning are not certain. Rather, these relations of coexistence must be, after we infer them teleologically, also be supported by repeated empirical observations. Hence, teleological reasoning must ultimately be supported by empirical data, as was the case for the principle of the conditions of existence, although of course the teleological principles themselves are not justified by empirical data.

4. Comparing Kant and Cuvier: transforming the life sciences into proper sciences

I have argued that Kant and Cuvier shared various views on methodology in the life sciences: they shared (i) the idea of science as a system that unifies various phenomena, (ii) the idea that only mechanical explanations are proper explanations in natural science, (iii) the idea that in the life sciences we must assume as given the original organization of organisms, and (iv) the idea of teleology as providing *regulative* principles for research in the life sciences. As such, the continuity between Kant and Cuvier is much greater than has so far been recognized. However, what does this mean for our assessment of the relevance of Kant for the emergence of the science of biology around 1800?

My study of Kant and Cuvier shows that we must maybe critically reevaluate the interpretation of Richards and Zammito of the relevance of Kant for the emergence of biology as a science around 1800. It shows, similar to what Lenoir once suggested, that some Kantian philosophical ideas were employed as a research programme by at least some influential naturalists. Contrary to what Richards and Zammito suggest, practicing and influential life scientists, such as Cuvier, actually employed Kantian conceptions of science, explanation, and teleology. However, it must also be stressed, in line with Richards and Zammito's interpretation, that Cuvier had a workable pragmatic research programme for transforming the life sciences into proper sciences, whereas Kant did not. As we have seen, in the absence of causal and mechanical explanations of organic phenomena, Cuvier adopted an empiricist and observational research programme for the life sciences, according to which we can ascribe the status of laws to organic regularities to empirically and inductively supported regularities. Moreover, he sketched a programme for working towards mechanical explanations of many organic regularities, even if he like Kant restricted the scope of mechanical explanations, taking teleology and analogy as heuristic guides that allows us to search for future causal and mechanical explanations. Kant had a more normative conception of proper science, and focused on the justification of empirical laws. In the *Metaphysical Foundations*, Kant argued that empirical laws must be derived from a priori principles. As we have seen, Cuvier rejected precisely this type of metaphysical and a priori foundationalist philosophers of science. It was, moreover, Kant's idea of a priori justification which made him skeptical of the scientific status of disciplines such as chemistry and biology: whereas we could give a priori principles of Newtonian physics and laws like the law of gravity, there was, as Friedman (1992) has observed, an explanatory gap between Kant's a priori metaphysical foundations of natural science and disciplines such as chemistry and biology. Hence, Kant's foundationalist philosophy resulted in his skeptical attitude towards sciences such as chemistry and biology. Cuvier rejected this type of foundationalism, and accordingly provided an empirical research programme that allowed researchers to establish genuine biological laws. In this sense, Cuvier is an example of an empirical and experimental researcher who along with similar empirical and experimental researchers were responsible for establishing biology as a science (Zammito, 2018).

We may end by providing the methodological reflection that historical research of biology around 1800 and later has failed to yield a comprehensive historical model or scheme that can provide a unified interpretation of all life scientists working in this period. Lenoir provided his interpretation of teleomechanism in the 1980s, but Lenoir's interpretation has been shown to be inadequate for authors such as Blumenbach, Reil and others by Richards and Zammito. However, as this paper shows, there were individual life scientists, such as Cuvier, who again fitted the description of Kantian teleomechanism, and who were highly critical of *Naturphilosophie*. The emergence of biology as a science around 1800 thus remains a fruitful field of historical investigation, and in the absence of generally valid historical accounts and narratives of this period in the history of biology, it remains useful to focus more on detailed case studies of individual life scientists, which can perhaps form the basis for a more general historical narrative in the future.

5. Conclusion

The relevance of Kant's philosophy for the emergence of biology as a science around 1800 remains a hotly debated topic. The dominant current interpretation, articulated by Richards and Zammito, is that Kant's strict conception of science and regulative teleology provide a significant obstacle for the emergence of biology as a science. However, there are also critics of the interpretation of Richards and Zammito. In this paper, I demonstrate continuities between Kant's and Cuvier's conceptions of the methodology of the life sciences. I have shown that Kant and Cuvier shared (i) a conception of science as a system that provides a unified account of many phenomena, (ii) the idea that mechanical explanations are proper and ideal explanations of nature, (iii) the idea that in the life sciences we must presuppose the original organization of organisms, and (iv) the idea that teleology and analogy have a regulative function in the life sciences. As such, parts of Kant's philosophy, contrary to the interpretation of Richards and Zammito, are shown to articulate a research programme that at least some influential life scientists around 1800 adopted, even if I also show, in line with Richards and Zammito, that Cuvier rejected Kant's metaphysical foundationalism and articulated an empiricist and experimental research programme for establishing biology as a science.

Funding

Hein van den Berg is supported by The Netherlands Organisation for Scientific Research under project no. 277-20-007.

CRediT authorship contribution statement

Hein van den Berg: Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing.

Acknowledgments

I wish to thank the anonymous referees and Boris Demarest and Jeroen Smid for comments. Thanks also to the *Concepts in Motion Group* for continued support. I also wish to thank participants of the conference "Analogie und Wissenschaft in Kants Kritik der Urteilskraft" (Villa Vigoni, November 2023).

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