Chemical versus Biological Explanations

Interdisciplinarity and Reductionism in the 19th Century Life Sciences

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ABSTRACT: This paper analyzes four controversies in the 19th century life sciences: the nature of fermentation, the nature of infectious diseases, the generation of life from inanimate matter, and vitalism. All these controversies appear to concern chemical versus biological explanations, suggesting that reduction of biology to chemistry was the common underlying issue. My analysis rejects such interpretations, including the labels for explanation, and instead points out sophisticated forms of interdisciplinarity between chemistry, medicine, and biology in the first three debates. I argue that the philosophically favored perspective on reductionism, historically induced by a few physicians in the fourth debate, leads us astray from understanding interdisciplinary research.

KEYWORDS: interdisciplinarity; reductionism; 19th century life sciences; fermentation; infectious diseases; generation of life; vitalism

INTRODUCTION

Nowadays, the disciplinary structure of the sciences established in the 19th century is increasingly undermined by goal-oriented interdisciplinary research. From biomedical research through materials science to nanoscale science and technology, chemical concepts, theories, and methods play a pivotal role in most of these research fields, even if the term "chemistry" is usually avoided. Historians, and especially philosophers of science, are challenged to leave their disciplinary focus behind if they wish to contribute to an understanding of recent research. Moreover, philosophers of science—with their focus on the conceptual and epistemological structures of each of the sciences—may encounter difficulties in understanding interdisciplinary relations other than asymmetric logical relations, such as the various forms of reduction or supervenience. What we need is a broader perspective.

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In this paper I analyze interdisciplinarity in the 19th century life science. Then, discipline formation was still in progress—scholars from various young disciplines worked together, or struggled with each other on similar issues. The advantage of considering this period is that the landscape of the life sciences was far less complex than it is nowadays, while the major disciplines then involved, that is, chemistry, medicine, and biology, were roughly the same as they are today. I use the term "scientific discipline" in the sense of a social institution with effective means for research, communication, and teaching, including self-reproduction—and with individuals involved who share a common area of problems, methods, concepts, and knowledge. This usage so combines sociological and cognitive aspects. Taking this broad perspective, I aim at a better understanding of forms of interdisciplinarity, which, as I will argue, is disguised by the perspective on reductionism favored by philosophers.

Let us first take a brief look at the general historical context. Starting around 1810 in the German states, universities changed from secondary teaching institutions to tertiary teaching *and* research institutions. Moreover, their faculties of philosophy upgraded from merely providing preliminary teaching service to having equal rank with the higher faculties of theology, law, and medicine. Philosophy faculties offered an increasing range of scientific studies when chemistry and natural history moved in from the medical faculties. Although the philosophical faculties became the home of the formation of most modern disciplines, the medical faculties continued to be important to the life sciences.[1,2] Here too, radical changes took place, including a new research orientation in large part modeled on experimental research in chemistry. Apart from experimental pathology, hygiene, diagnostics, therapy (pharmacology), and so on, it was particularly the new physiology that shaped the scientific-experimental image of medicine. However, many fields that we today assign to biology remained under the umbrella of medicine, such as embryology, cytology, and bacteriology. Although chemistry could incorporate important parts of the life sciences (i.e., organic chemistry, chemistry of plants and animals, and then biochemistry), subjects like physiological chemistry remained with medicine, notwithstanding considerable overlap.

By mid-19th century, there was a freshly marked out multidisciplinary field of the life sciences, consisting of (organic) chemistry, biology, and medicine, still full of disciplinary dynamics and mutual overlap. At that time, researchers of the several new disciplines engaged in four controversies, all being about the same general issue —whether a certain field of phenomena could (or should) be explained by reference to inanimate or animate matter. Historians of science frequently present these stories as competitions between "chemical" and "biological" explanations, which suggests that the common underlying issue was the reduction of biology to chemistry.

In the following, I first sketch the four controversies very concisely (interested readers may find more details in the references[3–18]), with just enough detail to point out some analogies. Although these analogies might suggest the adequacy of the labels for explanations and reductionism as the underlying issue, I raise serious doubts about that in the DISCUSSION section. My emphasis is rather on interdisciplinarity—in this respect, three of the four cases show interesting common features. I argue that focus on the issue of reductionism, although favored by recent philosophy and suggested by the fourth controversy, leads us astray from understanding much more intricate relationships between the sciences.

TABLE 1. Opponents in the debate on fermentation

	Substance theory ("chemical explanation")	Microbe theory ("biological explanation")
Chemists	Joseph L. Gay-Lussac Justus Liebig Marcelin Berthelot Eduard Buchner	Louis J. Thenard Christian F.P. Erxleben? Friedrich Kützing (pharmacist) Pierre J.A. Béchamp Louis Pasteur
Physiologists, biologists	Wilhelm Kühne	Theodor Schwann
Engineers		Charles Cagniard de Latour

FOUR CONTROVERSIES IN THE 19TH CENTURY LIFE SCIENCES

Fermentation

The first controversy I deal with involved the nature of fermentation and ferments (TABLE 1). Fermentation is a transformation of substances that requires the presence of a component, the ferment, which is not transformed in the process. A typical example, which was also in the focus of the controversy, is the transformation of sugar to alcohol and carbon dioxide in the presence of yeast. A kind of substance transformation, fermentation had long been a subject matter of chemistry, but also of physiology because most steps of digestion had been taken as fermentation. Up to the early 19th century, there was broad agreement that ferments like yeast were more or less homogeneous inanimate materials.

In the 1830s, mainly supported by microscopic studies based on the newly developed achromatic lens systems, that classical view began to be doubted because yeast showed a globular structure, and seemed to grow like a living being in the course of fermentation. According to the new theory, the life processes of microorganisms, the ferments proper, caused fermentation. Opposed to that, Justus von Liebig (1803–1873) developed a complex theory of (auto-) catalysis, claiming that yeast, as inanimate matter, was both a waste product and a catalyst of fermentation. At first, this so-called "chemical explanation" had many followers, particularly among chemists. By the 1840s, further studies, particularly microscopy and chemical investigations of metabolism, increasingly convinced researchers (and finally Liebig himself) that yeast was a living organism. Thus, the "biological explanation" appeared to be the winner of the controversy—but that was only the prelude.

The main controversy developed over the question of whether the cause of fermentation, the "ferment proper," was the entire living organism itself ("biological explanation") or an inanimate substance that might be isolated from the yeast organism ("chemical explanation"). The main opponents were two chemists, Justus von Liebig and Louis Pasteur (1822–1895). Since the particular issue of brewer's yeast evaded experimental clarification, the controversy was soon put on a general level to include all kinds of fermentation. Pasteur investigated various species of yeast and argued that each had its own particular fermentation effect—dependent on its particular metabolism—which he tried to clarify by chemical analysis. Liebig referred to apparently inanimate ferments, such as pepsin, which the physiologist Theodor Schwann (1810–1882) had isolated from gastric juice shortly before, and argued that finding the ferment proper was only a matter of skilful experimental isolation. Pasteur responded by excluding such cases from "fermentation proper," which, according to his definition, necessarily involved a living organism.

Although the methodological agreement on the validity of experimental proofs (here, chemical isolation) favored Liebig's view to some degree, the debate on fermentation reached a state that evaded a general decision on experimental grounds. Provided an open set of yet to be discovered fermentations, it is logically impossible to prove or disprove by experimental means that there exists at least one kind of fermentation that resists isolation of a specific substance as the ferment proper. The particular issue of brewer's yeast turned out to be extremely difficult. Indeed, the successful isolation of the ferment proper (then called enzyme, from Greek *zyme*, "yeast") was not achieved before 1896. Eduard Buchner (1860–1917) received the Nobel Prize for chemistry in 1906 for this achievement.

Since fermentation is a kind of chemical substance transformation, we may properly call it a chemical issue. However, the controversy, which almost ran through the whole 19th century, also involved physicians, physiologists, biologists, engineers, and pharmacists. They applied a broad scope of experimental and observational technologies, each from their own disciplinary background—such as chemical analysis, chemical investigation of metabolism, microscopy, the breeding and cultivating of microorganisms, taxonomic distinctions of species, and so on. Regardless of their disciplinary background or position in the controversy, researchers accepted and used these various methods and their conceptual and theoretical bases as valid tools of argumentation. Moreover, there is no correlation between disciplinary background and view defended in the controversy (TABLE 1). Therefore, unlike the opposition "chemical versus biological explanation" suggests, the controversy was truly interdisciplinary—both with respect to the researchers involved and to the methods and conceptual bases accepted.

Infectious Diseases

My second instance of controversies in the 19th century life sciences was about a typical issue of medicine or pathology, the nature of infectious diseases, followed-up by debates on the mechanisms of vaccination and the immune system (TABLE 2). According to the dominating view since antiquity, those diseases were transmitted and caused by poisonous substances (in Latin also called *virus*, "toxic slime"). Opinions differed only as to whether these poisons came from the environment (the miasmatic theory, with malaria as its paradigm) or from other infected persons (the contagion theory, with syphilis as its paradigm). A serious alternative came up only in the mid-19th century, again supported by microscopy. According to this view, the proper transmitters of diseases were microorganisms or microbes. Despite the different set of issues, there were many obvious analogies to the controversy on fermentation; also, some persons were involved in both debates.

Growing empirical evidence (e.g., from microscopy, cultivation of microbes, controlled infection of test animals) supported the *microbe theory*, so that defenders of

TABLE 2. Opponents in the debate on infectious diseases aand vaccines

	Poison theory/Serum theory ("chemical explanation")	Microbe theory/Cell theory ("biological explanation")
Chemists	Justus Liebig	Louis Pasteur
Physiologists, physicians, biologists	Max Pettenkofer Jean-Joseph Henri Toussaint Emile Roux Alexandre Yersin Robert Koch Emil Behring Shibasaburo Kitasato	Jacob Henle Robert Koch (prelude only) Ilya Metchnikoff

the *poison theory* increasingly accepted the involvement of microbes (e.g., cholera bacteria). Again, that was only the prelude, after which the camps divided anew. Proponents of the revised poison theory argued that, while microbes were undoubtedly involved, the disease-causing agent proper was a poison that might be isolated from microbes. The main proponents of that view, which historians of medicine are accustomed to call "the chemical explanation," were the physician Robert Koch (1843–1910) and his school. The leader of the camp of the so-called "biological explanation," according to which entire living microbes are necessarily involved, was again Louis Pasteur, a chemist. Contrary to Pasteur's original assumption, researchers successfully isolated a toxin from diphtheria bacteria, which, upon injection into test animals, caused the typical symptoms of diphtheria. That made adherents to the poison theory claim that every infectious disease could finally be reduced to toxins, if the analyses were only performed with sufficient rigor. Defenders of the microbe theory rejected such instances as diphtheria and claimed that infectious diseases proper involved (by definition) a living organism. (Still, nowadays, malaria might be a case in point.) Once more, the controversy reached a level of generality where definite decisions on experimental grounds became impossible.

The medical controversy on infectious diseases initiated at least two other related controversies, for each of which historians of medicine have assigned the labels of "chemical" and "biological" explanations. Followers of the microbe theory believed that all vaccines for infectious diseases must contain living or "moderated" cells, and they explained the mechanism of the immune system by the effects of corporeal cells ("cytophages" or later "leukocytes"). Proponents of the poison theory picked up the old idea of antidotes. They tried to isolate vaccines from the cell-free blood serum of infected animals, and explained the immune system by the effects of natural antidotes. Both parties collected sufficient evidence for their views, such that we still have two kinds of vaccines nowadays—and a historically rooted divide of the immune system into a cellular and a humoral branch.

Despite its being a distinct issue of medicine, the controversy on infectious diseases once more shows the characteristics of interdisciplinarity mentioned previously. Besides a majority of physicians, also chemists and biologists were involved, all of whom brought in their own disciplinary concepts and methods, each accepted or even used by others, regardless of disciplinary background or position in the debate.

TABLE 3. Opponents in the debate on the generation of life

	Abiogenesis ("chemical explanation")	Preformation theory ("biological explanation")
Chemists		Joseph Priestley Justus Liebig Louis Pasteur John Buchanan John Tyndall Svante Arrhenius
Physiologists, physicians	"Naturphilosophen" (e.g. Oken, R. Treviranus, Burdach) Max Schultze Henry Charles Bastian	Eduard Pflüger Rudolf Virchow
Biologists, naturalists	George-Louis de Buffon (18th c.) Erasmus Darwin Jean-Baptiste de Lamarck Felix Pouchet Ernst Haeckel Thomas H. Huxley	Charles Bonnet (18th c.) George Cuvier Ferdinand Cohn
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Generation of Life

The third controversy that I briefly deal with is about a core issue of biology, already discussed at book-length by Aristotle, that is, the generation of living beings. Although some critical views were advanced already in the 17th and 18th centuries, the prevailing view up to mid-19th century was that some primitive living beings could more or less spontaneously arise from inanimate matter by abiogenesis (or self-organization, as chemists would probably call it nowadays). People found support of abiogenesis not only in the Bible and Aristotle, but also in ample everyday life evidence—for instance, when worms suddenly crept out of feces or putrefying meat, or when swarms of small animals appeared in rotting water. Indeed, spontaneous generation of life, which incidentally also implied the possibility of artificial creation of life, was a triviality, both for learned and uneducated people—and it was in accordance with, if not part of, most philosophies of nature.

By the mid-19th century, however, the counter-position gained extraordinary strength (TABLE 3). According to that view, which was defended already by Leibniz, all life arose from life—or is at least preformed in germs, eggs, semen, or spores (the preformation theory). Again, historians of science have used the labels "biological" and "chemical" for the opposing views, such that the two main opponents in mid-19th-century France seemed to act in changed roles: the biologists Felix Pouchet defended the "chemical" view, whereas the chemist Pasteur held to the "biological" view.

As compared to the former controversies, the debate over abiogenesis had strong theological and metaphysical overtones, and it was closely connected to many other biological issues of the time, such as systematics, evolution theory, and embryology. Nonetheless, opponents on both sides used (and accepted) arguments based on an experimentally sophisticated level. For instance, proponents of abiogenesis tried to prove by infusion experiments that primitive life forms arose from inanimate matter, such as dried grass, water, and oxygen. They heated some grass at 300 °C in oxygen-free atmosphere and infused it under mercury into a disinfected flask that contained nothing but oxygen and freshly synthesized water. Opponents of abiogenesis, like Pasteur, sought indirect experimental evidence by showing, for instance, that disinfection was imperfect or that spores, much too small to be observed through microscopes then, could enter a flask despite all care. Notwithstanding the sophisticated experimentation, that controversy was also impossible to settle on experimental grounds because of the generalized level of the claims on both sides.

By the end of the 19th century, the debate reached a new dimension when biologists like Ernst Haeckel (1834–1919) and Thomas H. Huxley (1825–1895) rejected the cell theory of Theodor Schwann, according to which the cell was the smallest unit of life. Some biologists believed they had found the "essence of life" in colloid cell juices (protoplasm) or so-called "life molecules"—which were assumed to emerge spontaneously from inanimate matter. Such views increased the gap between biologists and biochemists for some time well into the 20th century. Biochemists, on the one hand, dived into the complexities of molecular processes within the cell, which they tried to grasp by dynamic systems approaches, always facing the limits of chemical understanding. Biologists and physiologists, on the other hand, sought for a simple molecular "essence of life." (Today's pop-science view—according to which the essence of life is the DNA molecule—is probably a late echo of that simplistic essentialism of life.) Their belief in abiogenesis gave biologists much more trust in chemical explanation than chemists who, faced with chemical complexities, mostly denied the possibility of abiogenesis. Strangely enough, the controversy on spontaneous generation of life reveals once more that biologists tended to favor the "chemical" view, whereas chemists were inclined to the "biological" view.

Nonetheless, we have a debate on a biological issue here that, save for an intermediary period, shows again the characteristics of interdisciplinarity with respect to researchers, concepts, and methods involved, and which greatly worked for the benefit of biology.

Vitalism

The fourth controversy I briefly discuss concerned vitalism (TABLE 4). Unlike the former issues, vitalism evades the simple assignment to one or more scientific disciplines and belongs rather to metaphysics or speculative philosophy of nature. The general issue was, whether there was a substantial difference between animate and inanimate matter, such that the explanation of life phenomena required reference to particular factors not required for explanations of nonlife phenomena. Anti-vitalists rejected that, whereas vitalists answered in the affirmative (strong vitalism) or at least allowed for the possibility (weak vitalism). Historians of science and philoso-

TABLE 4. Opponents in the debate on vitalism

	Anti-vitalism ("chemical-mechanical explanation")	Vitalism (weak and strong) ("biological explanation")
Chemists	Marcelin Berthelot Garrit Jan Mulder	Jöns J. Berzelius Leopold Gmelin William Prout Justus Liebig Franz Döbereiner Louis Pasteur
Physiologists, physicians, biologists	Emil du Bois-Reymond Ernst von Brücke Hermann von Helmholtz Carl Ludwig Karl Vogt Jacob Moleschott Ludwig Büchner	Johannes Müller Jacob Henle Rudolf Virchow Xavier Bichat (François Magendi) Claude Bernard

phy frequently narrate the controversy in terms of an opposition between physical-chemical explanation and biological explanation, or as a debate over the issue of whether biology can be reduced to chemistry (and ultimately to mechanics).

Apart from Cartesianism and some radical forms of materialism in the French Enlightenment, virtually all natural philosophies with a significant impact on medicine had included vitalism in one or the other form (e.g., Aristotle, Galen, Avicenna, Paracelsus, van Helmont, Stahl, Haller, Schelling, and so on). They differed, however, as to whether the particular factors were (i) particular (ponderable or imponderable) substances; (ii) particular forces attached to certain substances; or (iii) matter-independent (transcendent) mental or psychological principles. In the first half of the 19th century, almost all organic chemists as well as the founders of experimental physiology in the German states (Müller, Henle, Virchow) and France (Bichat, Magendie, Bernard) were vitalists at least in the weak sense. It is true that they all tried to explain life phenomena as far as possible without reference to particular factors. However, they met with considerable barriers to understanding and explaining life phenomena, including barriers to synthesizing organic substances. Thus, they did not exclude *a priori* the possibility of particular life substances, or forces attached to certain substances, such as magnetic forces appearing only at certain substances. In so doing, they were also in strong opposition to the *Naturphilosophie* of Schelling and his followers, which was extremely influential on German medicine then and which came under the label of "vitalism" too. According to that view, a transcendent "principle of life" governed "nature" overall, with various manifestations on different levels such as mechanical force, life, and mind. For most experimental scientists, both the metaphysical existence claim of a transcendent principle and the *a priori* negation of life forces or substances were beyond the standards of scientific argumentation. When they referred to particular life factors, they did that frequently in a provisional manner to mark the limits of knowledge of the time. And when they explicitly confessed to strong vitalism, by claiming the existence of life forces or substances, they did that mostly outside the scientific discourse proper—in popular lectures or books.

TABLE 5. Biographical dates of the major anti-vitalists

Name	Dates	Doctorate	Full professor in physiology (first app.)	Teacher in physiology	Education by chemists
Emil du Bois-Reymond	1818–96	Dr. med. 1843 (Berlin)	1858, Berlin	Joh. Müller	Mitscherlich, G. Magnus
Ernst von Brücke	1819–92	Dr. med. 1842 (Berlin)	1849, Wien	Joh. Müller	Mitscherlich, G. Magnus
Hermann von Helmholtz	1821–94	Dr. med. 1843 (Berlin)	1849, Königsberg	Joh. Müller	Mitscherlich, (G. Magnus)
Carl Ludwig	1816–95	Dr. med. 1840 (Marburg)	1849, Zürich	Ludwig Fick	Assistant to Bunsen in Marburg
Karl Vogt	1817–95	Dr. Med. 1839 (Bern)	1847, Giessen	K. Vogt, senior	First study under Liebig in Giessen
Ludwig Büchner	1824–99	Dr. med 1848 (Tübingen)	(1854, PD in Tübingen)	?	First study under Liebig in Giessen
Jacob Moleschott	1822–93	Dr. med. 1845 (Heidelberg)	1856, Zürich	Jacob Henle	Assistant to Mulder in Utrecht

By mid-19th century, the debate on vitalism in the German states grew to unparalleled dimensions when seven young physicians, all in their early twenties and with many obvious biographical parallels (TABLE 5), entered the stage to proclaim anti-vitalism or mechanical materialism and to sharply denounce any talk of life forces, substances, or principles. They were very active in giving public speeches, writing manifestos (including the foundation manifesto of the first German "physical society"), and popular philosophy texts, such as Ludwig Büchner's *Kraft und Stoff* ('Force and Matter') which probably topped any other philosophical text of the time regarding circulation and number of editions. Although these physicians indirectly criticized also the weak vitalism of their influential physiology teachers (e.g., Müller and Henle), their target was rather the *Naturphilosophie* tradition in medicine. For, with the help of their teachers, all of them made a rapid academic rise and obtained most of the new chairs of physiology in the German-speaking countries. Of the powerful people in physiology then, only Liebig, a strong vitalist, called the anti-vitalists "*dilletanti* in the sciences" because of their naive claims to the omnipotence of chemical and mechanical explanation.[19] (Note that they proclaimed mechanical explanation of physiological phenomena when chemical structure theory was not even developed.) Not surprisingly, when they became leading physiologists, they were unable to translate their metaphysical ideas into successful research programs, as they failed to provide any mechanical explanation of a life phenomenon. However, they were extremely successful in applying and developing further experimental approaches to physiology and in ousting the influence of *Naturphilosophie*.

Overall, the debate on vitalism had little to no impact on experimental research that was comparable to the other controversies discussed previously. Rather, it was primarily as a struggle within the medical faculties, articulated in philosophical terms: metaphysically as materialism versus idealism, and methodologically as experimental research versus speculative *Naturphilosophie*. In addition, like the late 18th century French physicians La Mettrie and Cabanis, it was related to atheism and republicanism, such that three of the seven physicians were so much involved in the political quarrels in the German states in 1848 that they emigrated to Switzerland afterwards.

DISCUSSION

Interdisciplinarity on Disciplinary Issues

Behind all of the four controversies, there is the common general issue as to whether some field of phenomena can (or should) be explained with reference to animate or inanimate matter. The first three controversies show further common features, all of which are missing in the debate on vitalism.

(1) All opponents, no matter of which disciplinary background, presupposed that there was a substantial difference between animate and inanimate matter; otherwise there would have been nothing to debate. (For an anti-vitalist who, as defined above, rejected the distinction between animate and inanimate matter, there was, strictly speaking, no controversy.)

(2) All of the three controversies were interdisciplinary in the sense that researchers of different disciplines were involved who, regardless of their disciplinary background, used and accepted the experimental methods of different disciplinary origin as valid elements in scientific discourse. Thus, in each controversy, an interdisciplinary consensus on scientific methods developed, or, as Hans-Jörg Rheinberger has called it, a common "experimental culture."[20]

(3) All of the three controversies went through several steps of stating views more precisely, refining experimental approaches, and generalizing theses up to a level that they evaded decision on experimental grounds, which nonetheless fostered further experimental research.

(4) All of the three controversies were related to each other in such a way that ideas in one area could be used to support views in others. For instance, in the fermentation controversy, defenders of the "chemical" explanation explained the growth of yeast as a secondary effect (not the cause) of fermentation by spontaneous generation ("biological" explanation).

(5) In spite of structural similarities and their interdisciplinary characteristics, each of the three controversies was about a certain issue that is clearly related to a single discipline, which also benefited most from the debates: (*a*) a kind of substance transformation, fermentation belongs to the classical issues of chemistry; (*b*) a kind of disease, infectious diseases belong to the classical issues of medicine; (*c*) a kind of generation of life, abiogenesis belongs to the classical issues of biology.

In sum, the controversies prove that interdisciplinarity is possible even if the issues under debate are clearly related to a single discipline. They further prove that researchers from different disciplines can struggle with each other on a common methodological basis that defines how arguments are to be generated and applied properly. In addition, they illustrate that the disciplinary background does not imply a bias with respect to the views under debate, as the labels “chemical” and “biological” explanations suggest.

The Special Role of the Debate on Vitalism, Reductionism, and the Labels for Explanations

The debate on vitalism plays a special role among the controversies discussed in this paper because it shows none of the characteristics of interdisciplinarity, nor does the issue clearly belong to any of the scientific disciplines. Further, the debate stood rather outside of the 19th century scientific discourse because it did not keep the conceptual, methodological, and argumentation standards established in the experimental sciences then. Both the negation and the affirmation of the existence of some life forces, substances, or principles, without compelling experimental evidence, were metaphysical statements of the sort which the 19th century experimental sciences had successfully overcome. Similarly, bold claims regarding the omnipotence of certain explanatory approaches, without providing ample evidence by instances of successful explanations, were relicts of 17th century speculations about nature which no longer had a place in the 19th century experimental sciences. Weak vitalism, leaving it open to future research whether particular factors are required for the explanation of life phenomena or not, was the only rational view then, if any was.

The particular attention that 20th century philosophers have paid to the debate on vitalism suggests that the issue belongs to philosophy. Let us consider the arguments in favor of that.

First, one might say that, because 20th century philosophers have dealt with vitalism, albeit mostly from a historical point of view, it is a genuine topic of philosophy. Back to the 19th century, however, it was a handful of physicians who picked the quarrel as an attempt, I assume, to reform medicine. Professional philosophers, such as Albert Lange (1828–1875)[21]—if they were not philosopher-turned-physician, as was Hermann Lotze (1817–1881)—entered the scene only later. However, they had much more general concerns, carefully avoided making bold claims, and approached the topic from an epistemological point of view. If philosophy were about making bold claims that modern sciences had banned from their discourses for methodological reasons, it would simply be an anachronistic way of doing “science.”

Second, one might argue that, because the issue of vitalism was connected to metaphysical and theological issues and could not be decided by scientific means, it qualifies as a genuine philosophical topic. Yet, the same is also true of the issues of the other three controversies which we can nonetheless clearly assign to scientific disciplines. For instance, the issue of abiogenesis was closely related to theological issues of creation; Lamarck favored abiogenesis because it was in accordance with his teleological view of evolution, whereas Cuvier rejected abiogenesis because it did not fit his teleologically based systematics; and so on. Furthermore, as I have argued above, all three controversies were pushed to a level of generality that evaded decision by experimental means. Therefore, the relation to metaphysics and its experimental indecisiveness does not as such make an issue a genuine philosophical one.

Third, strong vitalism and strong anti-vitalism, in the sense of stating and negating the existence of an extra-factor to be considered in the explanation of life phenomena, could be translated into methodological norms, for instance: “Seek/avoid reference to animate matter in scientific explanations of life phenomena!”

From the point of view of methodology, the debate on vitalism then appears as a methodological meta-discourse on science that governed all the three other controversies and urged participants in the debates to take either side. In each case, methodological anti-vitalism would recommend what has been called the "chemical" explanation, whereas methodological vitalism favored the "biological" explanation. Further, as strong anti-vitalism implies ontological reduction of life phenomena to phenomena of inanimate matter, methodological anti-vitalism recommends reductionist approaches to life phenomena, and vice versa. Now, if one takes biology as the science of life phenomena and chemistry as the science of inanimate matter, anti-vitalism corresponds to the reductionism of biology to chemistry. I assume that this is why philosophers have paid particular attention to the debate on vitalism and why historians have chosen the labels of "chemical" and "biological" explanations.

Let us finally consider why the idea of a methodological meta-discourse is a misleading fiction, both from historical and philosophical points of view.

(1) Historically, the scientists involved in various debates did not match the simplistic polarization. For instance, Liebig advanced good reasons to take fermentation and infection as processes of inanimate matter ("chemical explanations"), but he was skeptical about abiogenesis and a defender of strong vitalism ("biological explanations"), as were most of his colleagues in organic chemistry then. If we adopt the attitude of normative methodology suggested above, we would have to call most scientists irrational, although their scientific arguments are perfectly understandable.

(2) The opposition between biology/physiology as the sciences of life phenomena and chemistry as the science of inanimate matter is an anti-modern fiction that lacks any historical evidence. If it were correct, there would never have been any of the interdisciplinary controversies I have discussed. Interdisciplinarity requires overlap where different disciplines deal with the same subject matter and use the same concepts although their methods and perspectives might differ to some degree. In fact, concepts of inanimate matter have belonged to biology and physiology as much as concepts of animate or organized matter to chemistry.

(3) Consequently, labeling explanations as "chemical" or "biological" based on whether references are made to inanimate matter or not would lack any historical and philosophical justification and lead us to absurdities. Note that these labels refer neither to disciplines (as sociological entities) nor to issues, methods, particular concepts, theories, and subject matter of certain research fields. If, for instance, a trained biologist suggests an explanation for a biological issue based on applying biological methods, we would have to call it a "chemical" explanation whenever the explanation refers only to inanimate matter. Furthermore, the controversies I have discussed above would urge us to conclude that biologists and physiologists favored "chemical" explanation, whereas chemists favored "biological" explanation. If one needs disciplinary labels for explanations, I would suggest referring to disciplinary *issues*, such that every explanation related to a biological issue is by definition a biological explanation.

(4) If philosophers adopt the idea of a methodological meta-discourse about chemical versus biological explanation, anti-vitalism versus vitalism, or reductionism versus anti-reductionism, they would not only be at odds with the history of science, but also use arbitrary definitions for the sciences and invent strange labels for explanations. Such simplistic dichotomies also prevent us from understanding the complex relationships between the actual sciences. Interdisciplinarity evades dichot-

omies, such as the reductionism issue, which makes us blind for analyzing the intricate forms of interdisciplinarity. The three 19th century cases I have briefly discussed in this paper are only simple examples without much reference to theories, as compared to the complex forms of interdisciplinary research nowadays. Here is a field of growing importance for philosophers of science.

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