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The notion of nature in chemistry

Joachim Schummer

Department of Philosophy, University of South Carolina, Columbia, SC 29208, USA

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Abstract

If nature is by definition the object of the natural sciences, then the dichotomy 'natural' versus 'chemical', held by both chemists and nonchemists, suggests an idiosyncrasy of chemistry. The first part of the paper presents a selective historical analysis of the main notions of nature in chemistry, as developed in early Christian views of chemical crafts, alchemy, iatrochemistry, mechanical philosophy, organic chemistry, and contemporary drug research. I argue that the dichotomy as well as quasi-moral judgments of chemistry have been based on static and teleological notions of nature throughout history and that chemists, unlike physicists, have neglected the dynamic notion of nature. The second part provides a philosophical criticism of the former notions and argues for the latter as well as for an explicit discourse about values in chemistry.

Keywords: History and philosophy of chemistry; Notion of nature; Alchemy; Mechanical philosophy; Synthetic organic chemistry; Contemporary drug research

1. Introduction

At first glance, talking about the notion of nature in chemistry appears to provoke contradictions, since ordinary language suggests a strict dichotomy between 'natural' and 'chemical'.[1] However, taking chemistry as a science of nature, as *physikê* in Greek, implies that nature is but the object of chemistry. Therefore, nobody should

E-mail address: js@hyle.org (J. Schummer).

[1] This is well documented in several empirical studies, e.g. Werth (1991) and the many references quoted therein. For a chemist's sensitive way to deal with that dichotomy, see Hoffmann (1990); Hoffmann (1995), chaps. 22–25; and Hoffmann & Leibowitz (1997), Chaps. 5 & 8.

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suggest a dichotomy between 'physical' and 'natural' or between 'biological' and 'natural', if only for etymological reasons. So, what is wrong with chemistry?

In this paper, I show that the ordinary language dichotomy, far from being only a temporary fashion, is deeply rooted in the history and prehistory of chemistry. The dichotomy depends on peculiar notions of nature, with strong normative implications, that were developed by opposing technology to nature and to God, whereby chemical crafts, alchemy, and chemistry were frequently the paradigm case of technology in pertinent debates. Inasmuch as chemists have adopted these notions, for which we still have evidence today, they define themselves in a peculiar way unknown in all other scientific disciplines and reminiscent rather of technicians than of scientists of nature.[2]

The first six sections provide a historical outline of what I regard as the most important phases and positions for shaping the notions of nature in chemistry: early Christian views of the chemical crafts (Sect. 1), alchemy (Sect. 2), iatrochemistry (Sect. 3), mechanical philosophy (Sect. 4), the rise of synthetic organic chemistry (Sect. 5), and contemporary drug research (Sect. 6). Since historians of philosophy have, strangely enough, neglected the notion of nature in virtually every aspect related to chemistry and alchemy, I mostly refer to historians of chemistry whenever possible.[3] The general history of the notion of nature is much too complex to be reviewed here, so besides occasional references, this study is only supplementary to the general history of ideas as it focuses on the special role the notion has played in chemistry. Furthermore, I exclude the essentialist meaning of 'nature' in the sense of 'the nature of something'.[4] Rather than presenting a complete narrative, the sections are to some degree systematically arranged in order to point out the development of the three major notions of nature—static, teleological, and dynamic notions—and their normative implications for judging chemical practice. In the final four sections, I argue for the dynamic notion in chemistry by criticizing the two others. The teleological notion, despite its being the major basis of public judgments of chemistry, arises from the arbitrary choice of plastic metaphors and is rooted at a subconscious level rather than in a reflected system of concepts (Sect. 7). Against the static notion of nature, I argue that the derived distinction between 'natural' and 'synthetic' substances, despite its wide use, has hardly any descriptive content (Sect. 8), and provides no sound criteria for preferring one over the other (Sect. 9). Finally, I argue that, because of the normative implications of the static and teleological notions, replacing them with the dynamic notion of nature as the object of chemistry

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[2] However, such self-definitions do not comply with standard characterizations of technology, see Schummer (1997c).

[3] A rare example that combines the history of chemistry and the history of philosophy with many references to the notion of nature is Bensaude-Vincent (1998). On a systematic–philosophical approach from a constructivist point of view, which tend to overlook the historically rooted peculiarities of the notion of nature in chemistry, see Janich (1996). Unlike the title of that book, all the other papers by philosophers do not refer to chemistry.

[4] For the difference between the essentialist and the dynamic notions of nature, see Note 79.

requires establishing an explicit discourse about the values and moral constraints of chemistry (Sect. 10).

2. Chemical crafts change divine creation: the static notion of nature

Once upon a time in heaven, 200 angels under the leadership of Semjasa were conspiring against the laws of God to make love with women on earth. Not only did they satisfy their lust; even worse, each of the fallen angels also taught secret arts to the women, such as magical cures, incantation, the use of medicinal herbs, and various crafts. When God heard about this misconduct from his archangels, he was more than angry and decided to destroy the whole earth. What enraged him particularly was that the angel Azazel had taught women 'the heavenly secrets from primeval times'. Thus, it was not Semjasa, the leader of the conspiracy, but Azazel who was held responsible for the worst evil, and consequently he alone received the hardest punishment, which is described in all its cruel details.

Let us look at what kind of 'heavenly secrets from primeval times' Azazel told the women that made God so furious. He first taught metallurgy, including the arts of forging and jewelry; he further instructed them in the preparation and use of colours for dyeing and cosmetics; and finally he initiated them into the arts of precious stones (which probably included the preparation of coloured glass). Metallurgy, dyeing, and the manufacturing of precious stones—these are exactly the chemical crafts from which alchemy arose in Alexandrian times.[5]

This story about the origin of technology is from the *Book of Enoch* (Chaps. 8–10), an apocryphal book of the Old Testament, originally written probably in Hebrew in the second century BC.[6] Compared to all the other myths about the divine origin of technology (such as those of Egypt, India, and ancient Greece), only the Christian myth makes it a case of fundamental evil. In the Egyptian story the celebrated god of wisdom, Thoth, gets all the credit, while the Christian story makes it a sin committed by fallen angels or satanic demons. That is the origin of the Satanism of technology, which in the Christian tradition occasionally arose in between periods of more favorable attitudes towards technology.[7] Moreover, among all the arts and crafts, the chemical crafts were condemned as by far the greatest evil.

What made the chemical crafts so special in the Christian view? Unlike all the other crafts, the chemical crafts change the fundamental qualities of matter. By so doing, they change the nature of God's creation, which was considered applying 'the

[5] See, e.g., Multhauf (1966), Chaps. I & V.

[6] For an English translation see Charles (1913). For the influence of the Book of Enoch on alchemy via Zosimus, see Partington (1962–1970), Vol. I, Pt. I, pp. 173–177; Patai (1994), p. 21.

[7] Favourable attitudes derived from man's likeness to (the technician-like) Creator; the instruction to dominate the Creation, as stated in the *Genesis*; and from particular forms of a working ethos. For the impact of such ideas on the medieval culture, see White (1962). The older idea that the Christian culture would have favoured advances in technology because of its rejection of slavery appears to be more than questionable in the face of the long and excessive history of western slavery.

heavenly secrets from primeval times', i.e. the secrets of Creation. There is an archaic ontology behind that, a distinction between essential and accidental properties. Let us compare the art of weaving with the art of dyeing. Both use wool cut from sheep. Weaving brings the woollen fibers only into a certain alignment, which was considered a secondary modification only. Dyeing, on the other hand, changes the colour of wool, considered an essential property of the material. Thus, dyeing, not weaving, interferes with God's creation and, thus, is a sin in the view of Christian fundamentalists.

The apparently 'innocent' case of dyeing is actually a model case of Christian criticism of technology. The standard argument was first formulated at the turn to the second century by Tertullian of Carthage (ca. 160–220)[8], one of the early Latin church fathers. As the premise, he maintained that God does not like anything that he did not create himself. If God had wanted human beings to wear purple cloths, he would have created purple sheep. Since he did not make purple sheep, dyeing of wool is against God's will and therefore a sin—an alliance with Satan, as Tertullian added. Note that the same argument is not applied to weaving, since that does not change the essence of the divine creation according to the archaic ontology.

Throughout the Christian tradition, the concept of nature has been defined in terms of God's creation which implies an ontological distinction between essential and accidental properties. That is the origin of the static notion of nature as both a descriptive and a normative concept: a given set of entities and processes that must not be changed on the level of essential properties. If the chemical crafts were condemned then it was because they pretended to change nature specifically at the level of essential properties.[9]

3. Alchemy imitates nature: the teleological notion of nature

In one of his famous books on natural history, Albert the Great (ca. 1200–1280) made the strange claim that, 'among all the arts, the alchemical art imitates nature best'.[10] How did this Christian philosopher arrive at the opposite view of alchemy: from changing the essence of nature to perfectly imitating nature?

For one thing, Latin alchemy was not the same as the chemical crafts. While the latter applied material changes of various sorts, alchemical transmutations were considered to be very specific changes, namely a stepwise material refinement towards the noblest state of matter. Secondly, starting with Albert, Christian philosophers adopted Aristotle's teleological concept of nature, according to which natural

[8] Tertullian (1844), Pt. I. 8.

[9] For instance, a ninth- or tenth-century *Canon Episcopi*, before the advent of Latin alchemy, says, 'whoever believes that anything created can be either mutated or transferred into another species or into another similitude, except by the creator Himself, is an infidel, and worse than a pagan' (quoted in Newman, 1989, p. 440).

[10] 'in arte alchimiae . . . quae inter omnes artes maxime naturam imitatur', *Liber mineralium*, III. 1, 2 (Albertus, 1890, p. 61).

things are driven towards their perfect state. Since antiquity that doctrine was considered to be exemplified by the natural ripening of ores in the mines, a stepwise process from base states, such as lead, towards the nobler states of silver and gold. Hence, the alchemical series of transmutation towards gold could be conceived as imitating the natural process of the ripening of ores. For those who, like Albert, believed in the possibility of alchemical transmutation, the imitation was even perfect compared to other arts, since for them artificial gold, if made correctly, was exactly the same substance as natural gold.[11] The teleological concept of nature has straightforward normative implications, since the natural tendency towards the noblest state defines which manipulation is in accordance with nature and allowed and which is not. In this sense, imitation of nature became a standard for judging alchemy in particular and technology in general,[12] to the effect that the phrase ‘alchemy imitates nature’ appeared in virtually every alchemical treatise from the thirteenth to the eighteenth centuries.

On a closer look, alchemists derived many variants from the phrase ‘imitating nature’ which served as a frame interpretation and justification of alchemy. As both William Newman and Barbara Obrist have recently pointed out,[13] alchemy challenged the received (Neoplatonic) dogma that technology is inferior to Nature, regarded as a quasi-personified agent.[14] Thus, the same practice, i.e. attempts at transmuting base metals into noble ones, was actually described in the following terms, frequently accumulated in one sentence in such a way as to appear contradictory without further explanations:[15]

1. Alchemy *imitates nature*, insofar as it refines metals along the natural pathway.
2. Alchemy *assists nature*, insofar as it accelerates the natural process of refining.
3. Alchemy *surpasses nature*, insofar as it performs material refining that is accidentally inhibited.
4. Alchemy *improves nature*, insofar as it refines the actual material state.
5. Alchemy *changes nature*, insofar as it changes the actual material state.
6. Alchemy *imitates the creation of nature*, insofar as alchemists imitate God.

[11] While Albert believed in a certain theory of transmutation (‘In his enim et ex virtutibus horum [elementorum] omnis metalli species inducitur’), he also thought that nearly all alchemists do wrong and are without doubt swindlers (‘procul dubios deceptores sunt’, *Liber mineralium* III. 1, 9).

[12] A good survey is Ogrinc (1980).

[13] The rest of this section draws on Newman (1989) and Obrist (1996). Both authors additionally point out a Neoplatonic conception of human intelligence using nature as instrument, which I exclude for brevity since it had only a temporary career in alchemy. The root of the Neoplatonic personification of Nature is probably Chalcidius’ fourth-century Christian commentary and Latin translation of Plato’s *Timaios*: ‘Omnia enim quae sunt vel dei opera sunt vel naturae vel naturam imitantis hominis artificis’ (quoted in Flasch, 1965, p 277).

[14] In the following, I use ‘Nature’ with a capital N to denote a quasi-personified agent.

[15] To provide at least one example of the puzzling accumulations of phrases, John Dastin wrote in the early fourteenth century, ‘Nam ars imitatur naturam et in quidam corrigit et superat eam, sicut mutatur natura infirma medicorum industria’ (quoted from Obrist, 1996, p. 254).

It is clear that these descriptions refer to different notions of nature that belong to two classes. I will briefly analyze the notions and their implications.

Descriptions 1–3, which were most frequently used, refer to a teleological notion of nature (what the scholastics called *natura naturans*). However, it is no longer the Aristotelian notion as a specific tendency or principle of motion of a certain piece of matter (*natura particularis*). Instead, they refer to one global agent active in all processes (*natura universalis*), a view that can be traced back to Neoplatonism, Stoicism, and Hermeticism. Once Nature has become personalized, a bundle of metaphors from the social sphere arose, which we meet again in nineteenth-century organic chemistry (Sect. 5): (1) Nature as a teacher or educator, (2) as a master to be served, or (3) as a rival in competition with art. Given the empirical equivalence, authors simply expressed their position in a general debate about the inferiority or superiority of art to Nature, by choosing or emphasizing one of these metaphorical descriptions. Thus, analyzing the use of these metaphors through history will provide a good measure of the estimation of technology in general and alchemy in particular against the received dogma.

Without going into details, it seems to me that, save a temporary emphasis on the power of technology at the turn of the fourteenth and in the early sixteenth and early seventeenth centuries, bowing to Nature by emphasizing descriptions (1) and (2) was the prevalent attitude of alchemists. Sometimes we also meet a conspicuously placatory tone, revealing that the struggle was ongoing, as for instance in Michael Maier's famous *Atalanta fugiens*:[16] 'Art, therefore, & Nature, do mutually join hands & officiate one for the other. Nevertheless, Nature is always the Mistress & art the Handmaid'. Furthermore, inasmuch as alchemy was involved in theological debates, the position of art had to be defined in relation to both Nature and God. To that end, alchemists pointed out that the art is a gift of God and that their work is essentially assisted by the supernatural, occasional and, therefore, unpredictable influence of God.[17] This, however, meant that understanding Nature by experimental means was impossible—a capitulation of whatever rudimentary form of science.

Descriptions 4–6 refer to a *static notion of nature* (what the scholastics called *natura naturata*). Though improvement (4) implies change (5), alchemists usually avoided speaking of change. The reason is simply that the static notion of nature relates to nature in the sense of divine creation; and any essential change of Creation could be accused of being against God's will. Similarly, description 6 is rare to find in Latin alchemy, although it directly derives from *Genesis* I. 26–27. A fourteenth-century example is Hortulanus' commentary on the *Emerald Table* where he claimed 'that the [alchemical] masterpiece should imitate the creation of the universe'.[18] However, for mainstream theology, comparing human capacities with God's power of creation was the sin of hubris.

A great deal of the medieval debate about alchemy was actually a purely theologi-

[16] Maier (1617), 2nd discourse.
[17] See Karpenko (1998).
[18] 'Caput XI: Quod magisterium imitetur creationem universi' (quoted from Ruska, 1926, p. 185).

cal debate about ordering the capacities of technology, Nature, and God that went deeply into the chemical interpretation of material change. Following Avicienna's influential *De congelatione et conglutinatione lapidum*,[19] opponents of alchemy employed the Aristotelian distinction between mixtures and compounds, which was frequently supported by atomistic stories: While only God can create real or natural compounds (atoms), the human capacity to manipulate matter is restricted to mere mixing.[20] At best, these mixtures can superficially resemble natural compounds, and as such they are only imperfect imitations of nature, the work of swindlers. In other words, what we would call a chemical interpretation of material change was an ontological answer to the theological question of how human activity can affect nature, that is, God's creation. Furthermore, since the static notion of nature is in conflict with the teleological notion, which presupposes material changes by Nature, an answer had to be given to how Nature, unlike technology, can change nature. To that end, Thomas Aquinas introduced a sort of astrological explanation, according to which the natural ripening of ores in the mines occurs through the influence of the sun in a way that cannot be imitated by technology.[21]

Overall, the normative implications of the notions of nature had disastrous effects on the status, methods, and scope of alchemy, compared to the way in which, for instance, Roger Bacon had conceived of alchemy as the basic natural science. They confined alchemical practice to the making of gold, either as perfect or imperfect imitations. On the other hand, impacts on widening the perspectives of alchemy beyond imitation should cause tensions and shifts of the notion of nature. Such impacts came in when chemical practice was applied to different ends, such as the preparation of medicines in Paracelsian iatrochemistry, to which we now turn.

4. Alchemy for the benefit of mankind: the growth of the dynamic notion of nature

As Vladimír Karpenko has pointed out,[22] even as late as the eighteenth century (al)chemists felt obliged to defend their transformations of materials against the theological accusation of destroying God's creation. The issue was particularly intricate whenever new substances were produced, like sulfuric acid, that could by no means be considered an imitation of nature. In general, alchemists only very hesitantly conceded that they were also producing things unknown in nature, either in the static or teleological sense.[23] That is surprising, since they could easily have drawn on non-

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[19] See Avicienna (1927).
[20] See Hooykaas (1948).
[21] See Newman (1989), p. 438.
[22] See Karpenko (1998).
[23] An early unambiguous position had Richardus Anglicus (probably early fourteenth century): 'In multis philosophorum datis per artem emendatur natura ultra suum motum, quem habuit in prima forma' (*Correctorium Fatuorum*. In: *Theatrum Chemicum*, Vol. 2, Straßburg 1659, p. 385; quoted from Ganzenmüller, 1956, p. 305).

Christian authorities such as Aristotle or Theophrastos in their original writings,[24] or on the ingenious Renaissance theologian Nicolaus Cusanus who pointed out that simple artifacts like spoons can by no means be considered imitations of nature.[25]

In the sixteenth and seventeenth centuries, when alchemy received a new utilitarian basis in Paracelsian iatrochemistry, conceptual conflicts increased tremendously. Medicines artificially prepared from minerals, although having a long tradition from early Roman medicine (Dioskorides) to Arabic alchemy (Rhazes) and the school of Salerno, were seen as innovations in early-modern Christian Europe and severely criticized on the basis of their 'unnaturalness'.[26] Paracelsus (1493–1541) and his followers responded by expanding the teleological notion of nature to the extent that utilitarian ends of humanity became included. Thus, his famous definition of alchemy says:[27]

> Nature is so subtle and sharp in her things that she does not want to be used without great art. She brings about nothing that would be perfect of its own, rather man must complete it. This perfection is called *Alchimia*. [. . .] Those who bring things, which grow out from Nature for the benefit of humanity, to the state prescribed by Nature are alchemists.

According to this view, using and chemically transforming materials for the benefit of humanity is prescribed by Nature, and inscribed by God.[28] The tacit presupposition is that human ends are by definition natural ends. The intellectual background of this view is Renaissance humanism, particularly the Italian *dignitas hominis* movement, which pointed out that humans are the ultimate end of God's creation, the rest of which is only instrumental to and to be governed by humans. Nonetheless, Paracelsus and his followers emphasized again and again that chemical processes must imitate Nature.[29] However, the phrase had lost any restrictive meaning and was sim-

[24] See Schummer (2001a).

[25] *Idiota de mente* II (1450); on Cusanus see Blumenberg (1957), one of the philosophical papers that in narrating a history of the notion of nature avoids reference to alchemy and chemistry.

[26] Such criticism of Paracelsian iatrochemistry continued in the seventeenth century. The Leipzig professor of medicine and anatomy, Joachim Tancke (d. 1610), published a significant defense, reminiscent of the earlier *dignitas hominis* movement and entitled 'Von der Alchimey würden und nutz' ('On the dignity and utility of alchemy') (Tancke, 1610).

[27] 'Dann die Natur ist so subtil und scharff in ihren dingen / das sie ohn grosse kunst nicht wil gebraucht werden: Dann sie gibt nichts an tag, das auff sein statt vollendet sey / sondern der Mensch muß es vollenden: Diese vollendung heisset *Alchimia*. Dass ein Alchimist ist der Becke in dem / so er Brodt bacht: der Rebman in dem, so er den Wein macht: Der Weber in dem / das er Tuch macht. Also was auß der Natur wachst dem Mensch zu nutz / derselbige der es dahin bringt / dahin es verordnet wirdt von der Natur, der ist ein Alchimist' (Paracelsus, 1589, Bk. III Pt. II, p. 61).

[28] For the physician Paracelsus, there is also a sense of nature as being expressed in the signatures of diseases, which the physician must be able to read and denominate correctly (see Kuhn, 1996). I owe this reference to one of the anonymous referees.

[29] For instance: 'Welcher also wil der Natur ein bereiter sein / der muß da herdurch / vnnd sonst ist er nur ein Sudelkoch vnnd Suppenwust / vnnd ein Auffspüler. Dann die Natur wil / das in allweg die bereittung bey dem Menschen sey / wie in Ihr: Das ist / das ihr nachgehandelt werde / vnnd nicht den tollen köpffen nach' (Paracelsus, 1589, Bk. III Pt. II, p. 68).

ply paying lip-service since every chemical transformation for medical purposes, including the production of new substances, could now be described as imitating Nature.

Inasmuch as the teleological notion of nature was broadened to include diverse ends, and thereby watered down, there was a shift of emphasis towards researching the hidden or subtle forces, virtues, or causes of Nature to be employed in medicine. For Paracelsus, revealing these forces of Nature and directing it according to human purposes defined the tasks of alchemy.[30] The idea was not new but was essential to all approaches of the so-called occult philosophy or natural magic since the fifteenth century, such as those of Pico della Mirandola and Agrippa of Nettesheim. The interesting point is that, along with the shift of emphasis, a new notion, the *dynamic notion of nature*, arose, according to which nature is the total of subtle forces, virtues, or tendencies of matter.[31] The dynamic notion, which should grow to the modern notion of nature, resembles the original Aristotelian notion, as applied to inorganic matters,[32] more than many contemporary philosophers are willing to admit. It results from cutting off the natural ends of the teleological notion. A force is a tendency towards a direction but without a definite inherent end, and as such can be subject to limited human control for human ends by changing contextual conditions skillfully. There is no definite demarcation line between both notions, as one could continue to speak teleologically and pose human ends as natural ends. Therefore, I find it impossible to name a 'founder' of the dynamic notion of nature.

Many metaphors were in use to describe chemical manipulation of matter with more or less clear reference to the dynamic notion of nature. Paracelsians commonly continued using the old alchemical images of completing, assisting, or collaborating with Nature. Others described it as 'outwitting Nature'. Statesman Francis Bacon (1561–1626), with his preference for militarily metaphors, said in his *Novum Organum* (NO), 'Nature is defeated only by obeying her'.[33] For Bacon, 'defeating nature' meant changing properties of individual bodies according to human needs, whereas 'obeying nature' meant doing that according to the laws that govern the activity of the bodies and which natural philosophers should study beforehand in order to be successful (NO, II. 2–3). Thus, if natural philosophers put bodies together or separate them in the right way, Nature completes the inner process of chemical transformation according to her laws (NO, I. 4).

[30] 'So nuhn so viel ligt in der Alchimey / dieselbige hie in der Arzney so wol zuerkennen / ist die vrsach der grossen verborgnen tugendt / so in den dingen ligt der Natur / die niemandt offenbar sind / allein es mache sie dann die Alchimey offenbar vn brings herfür' (Paracelsus, 1589, Bk. III Pt. II, p. 70).

[31] Note that 'dynamic' derives from Greek *dýnamis*: potentiality, force, or tendency, which is frequently confused with kinetic or kinematic, from Greek *kínesis*: movement.

[32] See Schummer (2001a).

[33] 'Natura enim non nisi parendo vincitur' (Bacon, 1620, I. 3). Note that the next paragraph describes the same process as collaboration between humans and Nature. Inspired by alchemical treatises as well as by the military and inquisitorial practices of his time, Bacon made great use of metaphors of nature in which the various notions of nature are mixed with literary virtuosity. For a one-sided survey, see Merchant (1980), Chap. 7, to which one may, to complete the picture, add metaphors like 'helping Nature', 'praising Nature', 'exalting Nature', and so on.

The fact that Bacon, besides employing the Aristotelian term 'form', used the juridical term 'law', which was occasionally used before in alchemy and astronomy[34] and then became so fashionable in mechanical philosophy (see Sect. 4), helped make dynamics appear predictable, controllable and accessible to the experimental method. It more clearly constrained both natural changes and the human capacities to change Nature to general dynamics according to the same laws of matter ('servatis legibus materiae', NO, I. 4), in such a way that the distinction between natural and artificial changes became obsolete. Since in this view human interventions could not alter the natural lawfulness of the process under investigation, Bacon could establish the experimental approach of alchemists as an epistemologically respectable method, for which Thomas Kuhn has credited him with being the founder of the 'Baconian sciences'.[35] Still centuries later, we find Kant, an adherent of what Kuhn has called the 'classical' or 'mathematical sciences', defining 'nature' as 'the being of things, insofar as it is determined by general laws'.[36] In principle, however, the talk of 'laws' (instead of virtues, forces, or tendencies) was just a change of metaphor which wiped out residual connotations of natural ends. However, as we will see in the next section, it helped introduce the idea of a legislator, and thereby a new form of teleology.

In its developed form, the dynamic notion of nature has no normative implications concerning the chemical manipulation of matter, because it is impossible to change, to work against, or even to do without the presupposed forces or 'laws'. Therefore, every real transformation is a natural process, whether it yields known substances or new ones, and whether it goes established pathways or not. In addition, the dynamic notion overcomes the restrictions of the static notion, since every substance is a natural one because it is the result of a natural process.

It should be noted that the dynamic notion of nature, in its rudimentary form, arose from chemical contexts and issues and has no specific relation to mechanics or mechanical philosophy, which came only later along with severe criticism of that notion. Strangely enough, however, in spite of being the most elegant solution to the confusions and theological problems, it could never gain a strong foothold in chemistry proper, unlike in the later mechanics. Before discussing the main reason for chemistry's regression to the static and teleological notion of nature in the nineteenth century, I will briefly consider the approach of mechanical philosophy.

5. Abolishing the 'received notion of nature': the mechanical approach

Though he could draw on many earlier remarks by Descartes, Robert Boyle (1627–1691) was the first mechanical philosopher who published an entire book on our

[34] The oldest allusion to laws of nature in the Christian tradition I could find is in the *Book of Enoch* (XVIII: 15), where seven stars (the planets with their irregular orbits?) are punished because they did not obey the command of the Lord: 'And the stars which roll over the fire are they which have transgressed the commandment of the Lord in the beginning of their rising, because they did not come forth at their appointed times'.

[35] Kuhn (1976); for the role of experiments in alchemy, see also Newman (1998).

[36] 'das Dasein der Dinge, sofern es nach allgemeinen Gesetzen bestimmt ist' (Kant, 1783, p. 294).

topic, *A free inquiry into the received notion of nature* (1682).[37] Together with other treatises, this book is a key to understanding the theological basis of mechanical philosophy. For Boyle, the 'received notion of nature', a teleological one, is how the contemporary 'school-philosophers', the 'Peripatetics', about whom Boyle was clear that they only loosely refer to Aristotle,[38] conceived of nature. According to that view, Nature is 'an intelligent and powerful Being, . . . continually watchful for the good of the universe in general, and of the particular bodies that compose it' (p. 164). On the one hand, Boyle made this view the target of severe philosophical criticism regarding conceptual ambiguities, ontological confusions, and epistemic inaccessibility. On the other, the main point throughout the book, he criticized it as grave theological aberration since it establishes Nature as a 'semi-deity' (p. 164): '. . . instead of the true God, they have substituted for us a kind of a goddess, with the title of nature; which as they look upon as the immediate agent and director, in all excellent productions, so they ascribe to her the praise and glory of them' (p. 191). Even worse, the received notion of nature undermines belief in the existence of God: 'if such a celebrated thing, as nature is commonly thought, be admitted, it will not be near so easy to prove the wisdom (and consequently the existence) of God by his work' (p. 202).

Nothing could have been more opposed to Boyle's own theological basis of the mechanical and experimental philosophy. What 'the school-philosophers ascribe to the agency of nature interposing according to emergencies, I ascribe to the wisdom of God in the first fabric of the universe, . . . according to us, it is like a rare clock . . ., where all things are so skilfully contrived, that the engine being once set a moving, all things proceed, according to the artificer's first design' (p. 163). Since for Boyle the corporeal world is 'nothing but matter and motion' (p. 164) once created *ex nihilo* and guided by the Laws of God (not of Nature!), the task of science is to reveal the wisdom and providence of God (not of Nature) by understanding the design of all corporeal things by experimental means and in mechanical terms. Hence, he suggested dropping the received notion because it was inconsistent with his own mechanico-theological project.

On closer inspection, however, the peculiarity of Boyle's approach is that it combines all three notions of nature in a certain manner. He retained the static notion of nature in his material corpuscles, once created by God and endowed with a fixed amount of impetus and then moving around unchanged, though capable of combining to form various textures. The teleological notion of nature, the one that he apparently harshly rejected, was only shifted from natural ends to divine providence, in such a way that the investigation of final causes remained a task of science.[39] The dynamic notion of nature seems to correspond to what Boyle called God's laws of motion which should direct all the movements of the corpuscles. Hence, what at first appears to be a radical criticism of the notion of nature—Boyle explicitly restricts his criti-

[37] Boyle (1772), Vol. 5, pp. 158–254.

[38] Indeed, that view is related rather to Stoicism, Neoplatonism, and Hermeticism than to Aristotle. For the historical background, though excluding alchemy and chemistry, see Nobis (1967).

[39] See his *A Disquisition about the final causes of natural things*, in Boyle (1772), vol. 5, pp. 392–444.

cism several times to what he called the 'received notion'—turns out to be a grand reconciliation of all former kinds.

On even closer inspection, Boyle, in his effort to abolish Nature as an agent, threw out the baby with the bathwater. As critics such as Leibniz soon realized,[40] Boyle not only excluded a personified Nature but also all forces, and thus dynamics in the proper sense. Corpuscles do not move and interact with each other because they are driven by inherent forces, such as inertia, repulsion, and attraction, but because they follow God's law-like imposition external to the bodies. Leibniz' point was that, in Boyle's view, dynamics is not inherent in matter but only imposed from outside. Putting it in a modern metaphor, corpuscles move like in a motion picture, not because of forces and interaction but because an operator arranges the individual pictures accordingly.[41] Hence, early mechanical philosophers like Boyle had not only serious difficulties with but even strong aversions against adopting a dynamic notion of nature. Dynamic approaches to mechanics, first suggested by Newton and Leibniz, only slowly gained acceptance among mechanical philosophers during the eighteenth century, so that we still find Kant emphatically arguing for such approaches in his *Metaphysische Anfangsgründe der Naturwissenschaft* (1786).

Furthermore, Boyle retained the teleological notion of nature in the form of God's providence, and thus dragged along normative implications. Now the distinction between externally imposed laws and inherent laws, between quasi-moral norms and natural necessity, becomes important. Human beings with free will and reason must be able to violate the divine laws and providence[42] in order to become subject to moral judgment. Therefore, they should also be able to transform matter and produce new substances by chemical means against God's law-like will. Thus, in Boyle's mechanical philosophy, chemists could still be accused of working against God's law, as the distinction between natural and artificial was reintroduced through the back door.[43] In sum, mechanical philosophy in its non-dynamic versions did not provide solutions for chemical issues because it rejected the dynamic notion of nature, nor had it much impact on chemistry.

Things were different in mechanics. For one thing, nobody has ever considered

[40] Leibniz (1875–1890), pp. 504ff.

[41] The movie metaphor is not so different from the way Descartes, to whom Boyle owed much, explained the duration of things (*Principia philosophiae*, I. 21; in Descartes, 1897–1913): Because the existence of things at one moment does not follow from their existence at the moment before, God must create all things at each moment anew (corresponding to the individual pictures), thereby producing the duration of things and the continuity of processes. Here, Descartes only repeated the medieval idea of *creatio continua*.

[42] Boyle explicitly excluded human action from God's law: 'all motions, where no intelligent spirit intervenes, are made according to . . . mechanical laws' (Boyle, 1772, Vol. 5, p. 208). Thus, while he pretended to give up the distinction between natural and violent movement, he actually excluded the only relevant cases of violent movement where an 'intelligent spirit intervenes', and thus reinforced the distinction.

[43] Therefore, I think Hooykaas was wrong to claim: 'With the triumph of the corpuscular theory the discrimination between Nature and Art in relation to the conception of chemical compound died out' (Hooykaas, 1948, p. 650).

the human lifting or throwing of a stone as being against God's will just because it is against the stone's tendency to drop. Moreover, as compared to the distinction between natural and artificial materials, the distinction between artificial and natural movement was much debated, and has received attention only in retrospect by modern historians of mechanics. The issue was rather that astronomical movements were regarded as different from movements on earth, according to the Peripatetics and Galileo. Only Newton's law of gravitation so united the two fields that the law, after temporary reluctance by mechanical philosophers, was regarded as universally valid. Since unification depended on a dynamic principle, gravitational force, it paved the way to a dynamic notion of nature in mechanical philosophy, on the basis of which the distinction between artificial and natural movement was given up only as a side effect. Thus, when modern physics emerged from philosophy of nature as an own independent discipline, and with Newtonian mechanics as its model, the term 'artificial' was cancelled since the objects of physics were, by definition, natural.

Although they had good reasons and earlier models, chemists never seriously took that step. The major reason, I suggest, is related to the rise of organic chemistry.

6. Reinforcing the static and teleological notions of nature: the rise of synthetic organic chemistry

The English term 'organic' goes back to the Greek term '*organon*' meaning tool or instrument. In the original meaning, the organs of a body are instrumentally well-adapted, i.e. organized, tools of the body as a whole. Thus, considering a part of the body to be organic is to employ a functional or teleological perspective. In Aristotelian doctrine, the principle of organization that guides the bodily tools towards achievement of the unified ends of the body is the vegetative soul. This he considered intimately related to the material element air (*pneuma*) in such a way that spontaneous generation of small animals out of mud and air was possible in his view.[44] The only difference between living and nonliving matter is whether or not it is organized by a vegetative soul, the principle of life. That is the basis of all sorts of vitalism until the twentieth century, which differ only as to whether the principle of life is a material (ponderable or imponderable) substance, a spiritual substance, or a force interacting among material substances; whether there are individual principles of life or one global soul; and how all that is related to God. It is fair to say that vitalism was prevalent, if not a matter of common sense, until at least the mid-nineteenth century in one or other version, since everybody denying a principle of life was in trouble to explain corporeal organization. Those who did deny vitalism, as did the mechanical philosophers Descartes and Boyle (unlike Newton), reintroduced it through the back door as God's organizational power and providence,

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[44] The classical passage is *On the generation of animals*, III, 11, where Aristotle discusses the possibly sponaneous generation of the unicellular (!) *testacea*. While modern historians of philosophy tend to overlook vitalism before the late eighteenth century, there is actually a continuous story that goes back to early antiquity. Still worth reading is Lippmann (1933).

whereas later mechanical philosophers tend to forget that. If one takes Justus Liebig (1803–1873) as a nineteenth-century authority in physiological chemistry, he rejected both what he called 'materialism' (neglecting any vital force) and 'vitalism' (neglecting physical and chemical forces in favor of vital forces) and argued until his death for accepting a vital force *in addition* to physical and chemical forces, i.e., vitalism.[45]

In the history of chemistry, vitalism played a pivotal role since it gave rise to the basic distinction between organic and inorganic substances according to the old Aristotelian distinction between the mineral kingdom and the vegetative and animal kingdoms of nature. It is well known that the term 'organic substances' gradually arose from 'substances extracted from organized bodies', i.e. from animals and vegetables.[46] It is perhaps less well known that the physician and chemist Georg Stahl, the founder of phlogiston theory and a defender of a strong version of vitalism,[47] provided an experimental meaning to the vitalist distinction of substances.[48] Besides their different origins, organic and inorganic substances also differ from each other in that only the latter can, after chemical manipulation, be restored by chemical means. Once taken apart, the organizational principle, the *vis vitalis*, of organic substances is definitely destroyed or removed, according to Stahl's explanation. The idea that substances isolated from animals and plants are organized through a force of life and therefore cannot be formed by chemical means, I call 'chemical vitalism'. This view was acknowledged by many prominent chemists in the eighteenth and early nineteenth centuries, such as Bergman, Gmelin, and Berzelius; others, including Liebig, Dumas, Murray, Prout, and many more, considered the formation of organic compound possible in principle or in future, whether they accepted the existence of a vital force or not.[49]

We have that wonderful myth that Wöhler refuted vitalism by his urea synthesis out of inorganic substances in 1828. However, thanks to many historians of chemistry and a recent review by Peter Ramberg (2000), we also know that the story originated in a rudimentary form as late as 1843–1847[50] and then, in the 1850s, became a founding myth of (paradoxically) both organic chemistry and the unity of inorganic and organic chemistry as well as a decisive part of the then growing criticism of

45 See Liebig (1878), particularly letters 22 & 23. Similar is Berzelius (1856), Vol. IV, pp. 5–6. For more details see Schummer (2003b).

46 For the etymological background of 'organic chemistry' and its roots in vitalism, see Lippmann (1953).

47 Stahl (1708); for a recent analysis see Gierer (1996).

48 See Brock (1992), pp. 82–83.

49 On Bergman and the early Gmelin, see Lippmann (1953), pp. 191–192; on Berzelius, Dumas, Murray, Prout, and Liebig, see Partington (1962–1970), Vol. IV, pp. 252ff., 314. For further examples, see Botsch (1997). It should be noted that opinions slowly changed with the preparation of organic substances, as did the definitions of 'chemical vitalism' with reference to the starting materials, which I ignore here. The 'triumphal march' of organic synthesis is documented in Berthelot (1860).

50 Ramberg (2000), following Rocke (1993), pp. 239–241, traced back the origin to H. Kopp's *Geschichte der Chemie*, Vol. 1 (1843), p. 442; vol. 4 (1847), p. 244. The myth was unmasked by McKie in 1944, followed by a series of papers quoted by Ramberg.

vitalism. It is true that Wöhler's urea synthesis challenged 'chemical vitalism' in the sense given above, although many were doubtful whether urea is really an organic substance rather than a waste product of organisms and whether Wöhler's starting materials were inorganic. But chemical vitalism was only one of the offspring of vitalism proper which was not at all affected thereby. Anyway, by the mid nineteenth century, anti-vitalism was gaining popularity, in Germany particularly in the form of sharp criticism of the radical form of vitalism of the Romantic *Naturphilosophie* in opposition to which also Liebig defined his own version of vitalism (see above). Since *Naturphilosophie* was most prominent in medicine, young physicians and physiologists like Hermann von Helmholtz, Emil du Bois-Reymond, Ernst von Brücke, Jacob Moleschott, and Ludwig Büchner attacked vitalism by propagating mechanical materialism.[51] In this period occurs the rise of synthetic organic chemistry, with Hermann Kolbe and Marcelin Berthelot as its major protagonists.

According to Ramberg (2000, p. 176), Kolbe formulated the 'prototype for nearly all textbook accounts of the Wöhler myth' in his *Lehrbuch der organischen Chemie* (1854), which he did in a strong anti-vitalist manner, mocking the 'quite mysterious inherent force exclusive to living nature, the so-called life force'. Berthelot, in a kind of exorcism, even regarded the refutation of vitalism as the purpose of his chemical work in order to establish the 'autonomy' of organic chemistry:[52]

> Banishing [the force of] life from all explanations regarding organic chemistry, that is the purpose of our studies. Only through that we will successfully establish a science complete and subsisting on her own . . .

The chemists' way to 'argue' against vitalism was by synthesizing organic compounds that they had isolated from animals or plants and characterized before; and they even put much emphasis on the condition that chemical syntheses should proceed from the elements, as Kolbe did with his synthesis of acetic acid from coal in 1845 and then, particularly, the prolific Berthelot.[53] In 1854, Adolph Strecker formulated what one could call the *synthesis credo* of organic chemists:[54] 'The artificial

[51] Strangely enough, their teachers in experimental physiology, Johannes Müller and Jacob Henle, were all vitalist at least in a weak sense, as were the French founders of experimental physiology from Xavier Bichat to Claude Bernard.

[52] 'Bannir la vie de toutes les explications relatives à la chimie organique, tel est le but de nos études. C'est ainsi seulement que nous réussirons à constituer une science complète et subsistant par elle-même . . .' (Berthelot, 1860, Vol. II, p. 656). Note that Berthelot's idea of a complete and self-subsisting science contradictorily means that all phenomena must be exclusively interpreted mechanically: 'les interpréter par des considérations exclusivement mécaniques' (ibid.).

[53] For Berthelot's synthetic project see also Russell (1987), pp. 176–179, and Bensaude-Vincent (1998), Chap. 2; on Kolbe, see Rocke (1993).

[54] 'Die künstliche Bildung der in der Natur sich findenden Stoffe kann man als das Ziel ansehen, nach welchem die organische Chemie strebt' (Strecker, 1854, p. 97). A bit more dramatic and programmatic was Schlossberger (1854, p. 27, emphasis in orginal): 'Die *künstliche Darstellung aus rein unorganischen Stoffen* müsste, wenn sie einmal in ausgedehnterem Masse gelingen würde, als der grösste Triumph des Chemikers angesehen werden; mit der damit ermöglichten Zusammensetzbarkeit (Synthese) der organischen Körper nach wissenschaftlichen Grundsätzen und nach Gutdünken, wäre für den Menschen das wichtigste Mittel geliefert, sich von der ihn umgebenden lebenden Natur materiell möglichst unabhän-

formation of substances in nature can be conceived as the goal that organic chemistry is striving for'. They were extremely successful. In the period from 1844 to 1870, the number of known organic substances grew from about 720 to 10,700 (i.e. it doubled every 6.5 years as compared to doubling times of some 13 years in the twentieth century), whereas the number of known inorganic substances only grew from about 3,250 to about 5,300 in that period.[55]

The chemical efforts to 'refute' vitalism did not stop in the 1870s. As Michael Engel (1999) has pointed out in a recent paper, the challenge of 'asymmetric synthesis', i.e. the impossibility of synthesizing asymmetric natural products from symmetric compounds, reinforced forms of chemical vitalism as well as anti-vitalist projects of chemical synthesis at least until the beginning of the twentieth century. When, for instance, Emil Fischer claimed in 1898, after his successful synthesis of sugars, that 'the difference between the natural and artificial synthesis is luckily removed',[56] opponents could rightly respond that he had in fact employed asymmetrical natural products in his synthesis. Furthermore, it has been suggested that in the heyday of natural product chemistry, in the mid-twentieth century, the 'long obsession with total synthesis may be due to a "psychological legacy of the concern with vitalism" '.[57]

Now, how does all this relate to the notion of nature in chemistry? I suggest that the rise of (synthetic) organic chemistry, in an effort to refute vitalism and thereby to prove the synthetic capacities of chemistry, hammered both the static and the teleological notion of nature into the minds of chemists until today—in a peculiar shape unknown in all other sciences, rather reminiscent of alchemy, and at the expense of the dynamic notion that thereby fell out of view.[58]

Chemists first isolated and characterized substances extracted from animals and plants on a large scale and then tried to reproduce these substances in the laboratory by chemical methods with the final claim of substance identity. The irony of this project is that, while it aims at abolishing the distinction between artificial and natural substances, it presupposes the static notion of nature in the sense of presupposing the existence of a given set of substances extractable from plants and animals, to be

gig zu machen; es wäre dann für alle Anwendungen der Chemie das ausserordentlichste Gebiet erschlossen'.

[55] See Schummer (1997a).

[56] Quoted from Engel (1999), p. 40.

[57] Ramberg (2000), p. 189, referring to Weininger (1972).

[58] It is fair to say that not all organic chemists have subscribed to the static and teleological notion of nature. A prominent early counter-example is Kekulé who, by stressing the necessity of studying the laws of chemical 'metamorphoses', among which his valence rules figured prominently, implicitly argued for a dynamical notion of nature: 'Hatte man früher, wo die Chemie doch eigentlich ein Theil der beschreibenden Naturwissenschaften ausmachte, mit Recht einen Unterschied, ja fast einen Gegensatz, gesehen zwischen Körpern aus dem Mineralreich und solchen aus dem Pflanzen- und Thierreich, also mit Recht in organisch und unorganisch getrennt, oder wenigstens unterschieden; so wurde jetzt, wo die Chemie als selbständige Wissenschaft aufzutreten begann, wo sie sich immer mehr ihrer eigentlichen Aufgabe: die Metamorphosen des Stoffes und die dabei stattfindenden Gesetze zu ermitteln, bewußt ward, eine Trennung der Körper einzig nach dem natürlichen Vorkommen widersinnig' (Kekulé 1861, Vol. I, p. 7). Similar views can be found in the philosophically well-informed A. W. Hofmann.

reproduced. Inasmuch as chemists compared and identified their synthetic products with natural products, they adopted the static notion of nature. And the more chemistry became dominated by the task of classifying the tremendously increasing number of substances, instead of comprehending general laws of material change, the more did they conceive of nature as a set of substances and the more did the dynamic notion of nature go out of view. In other words, the project of synthetic organic chemistry was grasping nature by means of imitation or reproduction—quite similarly to former alchemical projects. It should be noted that, for the static notion of nature, it does not make any essential difference whether the set of entities to be imitated consists of substances or processes as long as the entities are regarded as given or pre-existent and natural. Thus, later approaches of imitating certain *in vivo* processes of substance formation *in vitro*, so-called *biomimetic* methods, also subscribe to the static notion of nature, insofar as they regard these processes as pre-existent and natural.

Furthermore, inasmuch as chemists compared their own synthetic capacities to the synthetic capacity of 'Nature', they subscribed to a teleological notion of nature. Robert Boyle would turn in his grave if he could read how organic chemists have been ascribing agency, wisdom, and intentionality to a quasi-personified Nature. Whether they believed in a vital force or not, the teleological notion seems to have been a common agreement among chemists. It was already clearly expressed in Dumas and Liebig's seminal paper on the new radical theory:[59]

> The mysteries of vegetation, the mysteries of animal life were going to be unveiled to our eyes; . . . we were going to find the means of imitating them in our laboratories . . . Actually, to produce with three or four elements combinations as varied as and perhaps more varied than those which form the mineral kingdom, Nature has taken a course as simple as it was unexpected; for with the elements she has made compounds which manifest all the properties of elementary substances themselves. And that, we are convinced, is the whole secret of organic chemistry.

It was repeated numerous times also by anti-vitalists, such as Frankland and Kolbe:[60]

> Nature, who produces the various and innumerable products of the vegetative and animal life through the admirable combination of the few elements alone that are at her disposal, probably uses also the variety of properties of the compounded radicals in order to attain her great purposes.

[59] Dumas & Liebig (1837).

[60] 'Die Natur, welche die manichfaltigen und zahllosen Producte des vegetabilischen und animalischen Lebens allein durch die bewunderswürdige Combination der wenigen Elemente, worüber sie zu disponieren hat, hervorbringt, bedient sich vielleicht auch jener Vielseitigkeit der Eigenschaften der zusammengesetzten Radikale zur Erreichung ihrer großartigen Zwecke' (Frankland & Kolbe, 1848, p. 296).

When Berthelot, at the very end of his book, reformulated his synthetic program, he did it in terms of imitating the works and means of Nature:[61]

> I say, we can aspire to form anew all the materials that developed since the origin of things, to form them in the same condition, in virtue of the same laws, and by the same forces that Nature let contribute to their formation.

Since Aristotle, we well know that imitating nature presupposes a teleological notion of nature.[62] In order to imitate something by chemical laboratory activities, one first needs to suppose that this something is being analogous to human activities. That is to say, after projecting a sort of human activity (here, the chemist's own laboratory practice) onto 'nature', 'imitating nature' simply consists of retro-projecting the same image onto human affairs from where it originated. The mysterious personified Nature then turns out to be nothing other than a counterpart of the working chemist in the laboratory, like an imagined colleague. Whether knowingly or not, that is exactly what Berzelius suggested:[63]

> A living body, regarded as an object of chemical investigation, is a workshop in which a number of chemical processes occur, the final result of which is to produce all the phenomena that, as a whole, we call life know . . .

Strangely enough, in modern organic chemistry, the teleological notion of nature provoked the same phrases and metaphors that were already prevailing in alchemy. I refrain from presenting an extensive list of quotations and provide but one quote from organic chemist and historian of chemistry Paul Walden who accumulated in 1941 various pertinent metaphors with reference to many organic chemists:[64]

> Is not Nature both the model and the educator not only of the artist (painter, sculptor, etc.) but also of the chemist, of the latter even to a higher degree as he set

[61] 'Nous pouvons, dis-je, prétendre à former de nouveau toutes les matières qui se sont développées depuis l'origine des choses, à les former dans la mêmes conditions, en vertu des mêmes lois, par les mêmes forces que la nature fait concourir à leur formation' (Berthelot, 1860, Vol. II, p. 812).

[62] See Schummer (2001a).

[63] 'Ein lebender Körper, als Gegenstand einer chemischen Untersuchung betrachtet, ist eine Werkstätte, in welcher eine Menge chemischer Prozesse vorgehen, deren Endresultat ist, alle die Erscheinungen hervorzubringen, deren Gesamtheit wir Leben nennen . . .' (Berzelius, 1856, Vol. IV, p. 1).

[64] 'Ist nicht die Natur sowohl Vorbild als auch Erzieherin nicht allein des Künstlers (des Malers, des Bildhauers usw.), sondern auch des Chemikers, des letzteren in noch höherem Maße, da er sein Ziel weiter steckt? Durch seine Synthese will er die von der lebenden Natur erzeugten chemischen Verbindungen nachschaffen, er will aber auch ihren Bildungsmechanismus, den Werdegang dieser Körper in der lebenden Zelle erfassen und nachahmen, und weiterhin will und kann er die Natur ergänzen, indem er Stoffe schafft, die von der Natur nicht erzeugt werden . . . Die Chemie kann ja nur die Wissenschaft sein, welche die Natur nachahmt und mit ihr in der Erzeugung organischer Naturstoffe rivalisieren kann, wenn sie . . . daß die chemische Synthese über die natürlichen Vorbilder hinausgehen und hochwertige Kulturgüter künstlich erzeugen kann, die die Naturprodukte qualitativ nicht nur erreichen, sondern sogar übertreffen . . .' (Walden, 1941, pp. 5, 35, 37).

> himself higher goals? Through his synthesis, he wants to reproduce the chemical compounds created by living Nature; but he also wants to grasp and imitate their mechanism of formation, the development of these bodies in the living cell; and he further wants and is able to supplement Nature by producing substances not created by Nature . . .
>
> Chemistry can be the science that imitates and rivals Nature regarding the creation of organic substances, only if . . .
>
> chemical synthesis can go beyond the natural models and artificially create high-quality cultural goods that not only meet but even qualitatively surpass the products of Nature . . .

Once again there is the shift from imitating and learning from Nature to supplementing and surpassing Nature—from Nature as teacher to Nature as a rival—that pervaded alchemical discourse.[65]

What are these metaphors good for? As with alchemy, they give sense and orientation to chemical activity by providing accounts of its origin, its place in the universal history, and its future goals. Overall they suggest a stepwise progress of the discipline by comparing the chemists' capacities with that of an imagined personified agent called Nature, from apprenticeship through rivalry to independent mastery. If asked directly whether or not they believe in the existence of such a universal agency, most chemists would surely have denied it. Nonetheless, the fiction served powerfully as orientation, for some probably even as obsession. Furthermore, the metaphors were suitable to smooth out the instrumental concept of nature that chemists actually adopted in their experimental practice when employing, for instance, animals as chemical reactors.[66] After apprenticeship, rivalry, and mastery, the next step of chemical progress could consequently be described as the biblical 'domination over nature', to which Francis Bacon referred, or in Walden's concluding and programmatic words: 'directing, in accordance to its conditions, the processes in the living organism and designing them for the benefit of humanity'.[67]

In sum, the teleological notion of nature, in its metaphorically mediated form, has fostered a specific technological attitude of organic chemistry, which incidentally has been conferred via biochemistry to molecular biology. It has set free motivations of research through which chemists, and increasingly biologists, define themselves as engineers, in a peculiar way rather uncommon in traditional branches of engineering. However sloppily the metaphors were being used from a philosophical point of view,

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[65] See also Bensaude-Vincent (1998) for further parallels.

[66] Scanning the volumes of Liebig's *Annalen der Chemie und Pharmacie* of the 1840s and 1850s reveals that many organic chemists, as a standard procedure, fed animals with various substances and analyzed the urine afterwards; e.g. Wöhler (Vol. 65, p. 335), Schloßberger (Vol. 73, p. 212), and Hofmann (Vol. 74, p. 342) who also reported about self-experiments.

[67] '. . . die Vorgänge im lebenden Organismus den Bedingungen derselben entsprechend zu lenken und zum Wohl des Menschen zu gestalten' (Walden, 1941, p. 49).

they have shaped the way chemists define and distinguish themselves from physicists. The fact that the systematic study of reaction mechanisms in the 1940s, which made no reference to mechanics other than implicitly sharing with it a dynamic notion of nature, was assigned to *physical* organic chemistry illustrates how far the dynamic notion of nature has emigrated from chemistry to become a characteristic of physics.

7. Patterns of contemporary drug research

Although it is impossible to prove the impact of the metaphors on actual research without detailed psychological studies, one can at least provide indirect evidence by systematic analysis. In this section, I will analyze the major approaches of contemporary drug research in correspondence to the major metaphors about nature (Fig. 1).

When the ordinary language connotation of the term ‘chemical’ was at its worst, as opposed to the then favorably connoted terms ‘natural’ and ‘bio’, many chemical companies, along with restructuring their processes of research and development, tried to drop any associations to chemistry and called themselves ‘life sciences companies’ in the 1990s. Nonetheless, they continued their search for physiologically active substances on the basis of former research traditions and newly sophisticated methods of ‘target modeling’ with respect to both theoretical and material models. If, for instance, a decisive process of a disease is understood in biochemical terms of molecular components involved and their reactions (the target), a corresponding molecular model allows the derivation of specific features of active substances that might affect or hinder this process. From this idea, all major branches of contemporary drug research derive.

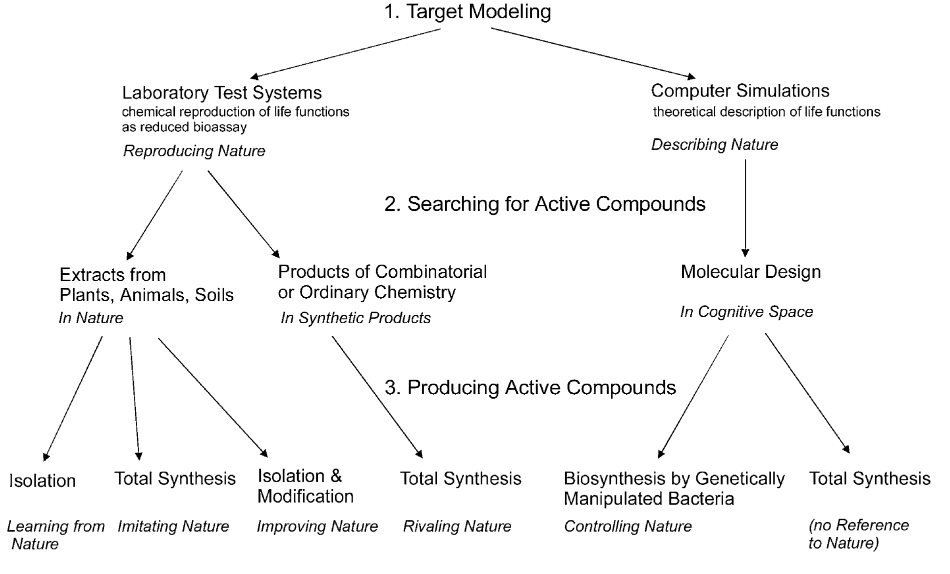

Fig. 1. Patterns of contemporary drug research.

Insofar as target modeling aims at producing laboratory test systems, the target model is a chemically reduced bioassay. The supposed essential biochemical component of a disease in a living cell is either isolated or synthesized and then chemically fixed on supports. It is a chemical reproduction of specific life functions, a surrogate of the cell or laboratory animal, an 'imitation of nature', so to speak. Next, a decision is made about what potential active substance resources will be used. According to one approach, exemplified by the penicillin story, the raw material is extracted from plants, animals, or soils as complex mixtures. In this approach, 'learning from nature' figures prominently, as the samples are carefully selected according to prior assumptions, either from traditional herb medicine or from biological models about how bacteria, moulds, etc., perform a 'struggle of life' by means of cytostatic or antibiotic substances. Once an active substance is found, isolated, and characterized, organic chemists try to modify the substance by chemical means. As an effort to 'improve nature'—the classical example is from ('natural') salicylic acid to ('synthetic') acetylsalicylic acid (Aspirin®)—they produce a large variety of 'derivatives' in order to find a physiologically more active substance. If the original or the derivative substance promises to meet all the criteria of a marketable substance, organic chemists develop a total synthesis according to the classical project of 'reproducing nature'. Finally, at the stage of production, there are two principal ways to produce the substance on a large scale, either by chemical synthesis ('imitating nature') or by isolation from 'nature'. Certainly, the decision as to whether the 'natural' or the synthetic way is preferable is based purely on economical reasons, but it is also a decision between two different research traditions and their relations to nature.

In recent times, automatized target test systems are also employed in a purely synthetic pathway. Instead of using extracts from plants, animals, or soils, chemists concoct their own mixtures by means of so-called combinatorial chemistry. Roughly speaking, two mixtures each of chemically similar compounds are combined in order to yield, by somewhat undefined reactions, a large spectrum of products. As with the extracts from 'nature', these products need not to be isolated and characterized before performing the target test with the entire mixture. Only if the test of a mixture is positive, chemists isolate and characterize the active substance and then work out a specific synthetic pathway. To be sure, the combinatorial approach is not completely uncontrolled as it is always guided by ideas about features of active compounds derived from the target molecule. However, it can be well distinguished from the specific design of active compounds (see below). The combinatorial chemistry approach rivals all the natural product approaches outlined above, and, on the metaphorical level, corresponds to the form of 'competing with or rivaling nature'.

Drug design, in the narrow sense, starts with a theoretical (not material) model of the target, usually a protein, and thus begins not with 'imitating' but 'describing nature'. On one or other level of semi-classical computer calculations, theoretical chemists simulate the shape, charge distribution, and dynamic properties of the target molecule, in order to derive the corresponding features of a molecule capable of inhibiting or affecting the target molecule in a specific way. Once these features are determined, they either search for a corresponding substance in so-called libraries of known substances or try to derive a suitable chemical configuration that serves as a blueprint for chemical synthesis. In this approach, there is no more reference to nature in the teleological sense either nature is not referred to at all or a dynamic notion of nature is tacitly adopted.

Since drug design is largely restricted to proteins, the organic chemists who synthesize proteins could be replaced with organisms, such as bacteria, that do the job of producing the desired proteins. For that purpose their DNA needs to be manipulated accordingly. At present, this approach is largely restricted to moving certain genetic sequences from one organism to another, e.g. the sequence corresponding to insulin from pigs to bacteria. However, it is conceivable that in the near future any synthetic genetic sequence corresponding to a designed protein can be inserted into the DNA of bacteria. If one wished to describe that on the metaphorical level, one would probably be forced to say that not a natural product but a natural agent (bacteria) is artificially changed or improved according to the chemical purpose of synthesis, i.e. ‘controlling or dominating nature’.

These are the major branches of contemporary drug research, separated from each other also by different research traditions.[68] The fact that we can so easily attribute the old metaphors to each of the branches—learning from Nature, imitating Nature, improving Nature, competing with Nature, and controlling Nature—is hardly pure chance. It is more likely that these metaphors have actually been effective in shaping research traditions until today. If that is true, the role of the notion of nature in shaping chemical research traditions has been tremendously underestimated.

8. The vulgar teleological notion of nature and the public image of chemistry

As has been mentioned already in Sect. 4, the teleological notion of nature in the original Aristotelian sense, if applied to particular inorganic matters, is not that different from the dynamic notion. For instance, in chemical thermodynamics, a piece of iron is said to have a tendency, a chemical potential or affinity, to corrode, i.e. to combine with oxygen in atmospheric environment. If we change atmospheric conditions or cover the piece of iron with a protective layer, it does not corrode but retains the potential to do so. Aristotle would not have objected to this description, nor would he have drawn the normative conclusion that we should not protect the piece of iron. As to the whole material world, the teleological notion of nature would claim that its development overall is governed by preexistent aims and ends. It is a matter of philosophical discussion whether or not reference to such ends may be employed in scientific explanations, and whether or not functional concepts such as the adaptation of species in evolution theory, or concepts in physics such as the principle of least action or selection rules actually refer to such ends.[69] All these serious philosophical issues around teleology should be well distinguished from the

[68] See, for instance, Drews (2000) and papers in the journal *Drug Discovery Today*.
[69] For a recent approach to teleological explanations in modern science, see Del Re (1992).

vulgar teleological notion of nature as a quasi-personalized agent with certain intentions and ends, which has accompanied chemistry since early alchemy.

Arguing philosophically against a quasi-personalized agent is like fighting windmills. Boyle put forward the major epistemological and ontological objections in the seventeenth century, but with little success. The reason is that the notion, rather than being part of a reflected system of concepts, is embedded on a subconscious level from which it set free various emotions, including motivations of research. Whether or not that orientates research towards acceptable directions depends on which research values one presupposes in a rational discourse and shall not be discussed here. In general, one can claim, however, that conformity is at best coincidental and rather depending on the plasticity of the metaphors.[70]

Personification of nature as a global agent through one of the various metaphors—between 'learning from Nature' and 'dominating Nature'—prompts quasi-moral judgments of research activity. If people conceive of Nature as a threat, say after a natural disaster, 'dominating Nature' is the preferred phrase in whatever context. If, on the other hand, people regard Nature as in danger, say after an environmental disaster caused by humans, 'dominating Nature' is percieved as the cause of evil. The changing attitudes of Western culture are nicely reflected in the history of aesthetics, particularly of horticulture, and can, in turn, be inspired by aesthetic fashions.

Inasmuch as chemists have publicly described their progress in metaphorical terms from 'learning from Nature' to 'controlling Nature', in a sense doing what alchemists were not allowed to do, they have defined their attitude towards Nature in a rather irreversible way and, thus, created their own public image. There were times, to be sure, when such control of nature was highly estimated in society and chemical companies could successfully base their advertisements on that attitude.[71] However, by the early 1970s at the latest, the public attitude reversed in the face of environmental pollution by chemicals. Not only were chemists made responsible for the pollution, but their attitude towards Nature was soon unmasked as the cause of all evils.[72]

The simple point I want to make is that the morally imbued notion of nature, the arbitrary fiction of a personified global agent, is the cornerstone on which the public image of chemistry is built, both by chemists in publicly promoting their research and by non-chemists in criticizing chemistry. It hinders both a rational judgment and a rational orientation of chemistry, as it prevents chemists from defining themselves

[70] Note that I do not argue against metaphors as such. Indeed one could claim, as many philosophers have done, that abstract reasoning is necessarily based on metaphors. Instead, I argue against the arbitrary choice of the plastic metaphors with normative implications, because it leads to arbitrary orientation and hinders a rational discourse about values.

[71] E.g., the famous slogan of Du Pont 'better things for better living through chemistry'; see Hounshell and Smith (1988); for the nineteenth-century background in the U.S., see also Friedel (1993).

[72] E.g., Merchant (1980, Chap. 7) identifies the evil with Bacon's prolific use of military and inquisitorial metaphors applied to (feminine) Nature. What a treasure would she have found in much earlier alchemical allegories, such as in the 'mortification' of mercury!

as scientists of nature in the modern sense. Thus, rather than inventing new or adjusting old metaphors, it would be wiser to drop the notion altogether.

9. What the distinction between natural and artificial substances is about

Both the teleological and the static notion of nature are the major obstacles to adopting the dynamic notion of nature as the object of science, the only one for which modern scientific methodology has been developed. While the teleological notion is rooted at a subconscious level, the static notion is not, since everybody, chemists as well as non-chemists, distinguishes between natural and artificial substances, suggesting that the distinction has a clearly defined meaning. In this section, I show that the meaning is far from being clear, and then, in the next section, I ask if there is any sense in which we can call natural substances better than artificial ones.

First, we should note that the distinction is usually meant to be about substances, not about material samples. Take two samples, one prepared in the laboratory, the other one found outside, 'in nature' so to speak, both of the same substance. Now, shall we regard that substance as natural or artificial? Our everyday attitude is already confused here. However, chemistry has clear identity criteria for chemical substances that force us to consider the same substance both natural and artificial.[73] If we want to avoid contradictions, we need to appeal to dispositional properties: from 'natural' versus 'artificial' to 'being isolable from natural resources' and 'being synthesizeable in the lab'. Only in this sense can the static notion of nature be held without contradiction.

Secondly, we should note that the distinction is usually meant to be about *pure* substances. Thus, 'isolation from nature', i.e. the operation of purification, is considered to preserve the natural status, just because substance identity is preserved. Chemical synthesis, on the other hand, is considered an operation that destroys the natural status because of a change of chemical substance identity. As a consequence, the whole distinction depends on the concepts of chemical substance identity defined in a highly sophisticated and specialized discourse, not free of conventional elements. If these concepts are modified—and the chemical community currently seems willing to do that[74]—then the distinction shifts. As another consequence, contrary to our everyday intuition, the natural status of a substance has nothing to do with its biological properties. Take, for instance, water. By purifying water its natural status is preserved by definition; from the biological point of view, however, that changes the substance from being an essential nutrient to a general poison.

Let us now consider how the two predicates 'isolable from natural resources' and 'synthesizeable' help us to describe the material world. We can distinguish between three possible cases: a substance can be (1) isolable from natural resources, or (2)

[73] See Schummer (2002).
[74] Ibid.

synthesizeable in the lab, or (3) both. It is clear that we have instances of case (3). The question is, do we really have any definite instance of cases (1) and (2)?

		Isolable from natural resources	
		yes	no
Synthesizeable	yes	+	No reliable statements
	no	(−)	−

Case 1: If a substance has been isolated from natural resources and characterized by chemical means, no chemist today would claim that the very same substance cannot be synthesized in the laboratory for reasons of principle. Usually, chemical characterization does already imply a way to produce that substance. Hence, unlike early nineteenth-century vitalism, today's chemistry rejects instances of Case 1.

Case 2: If a substance has been synthesized in the laboratory, can we make any reliable claim that the very same substance is not isolable from natural resources? To be sure, there were such claims, e.g. about chlorinated hydrocarbons, that turned out to be wrong. The problem is that we have almost no idea of what kind of substances might be isolable from natural resources. We even do not have the slightest idea about how many of these substances there are, were, or will be in the universe, because, unlike the tradition of natural history, recently renewed in bio-diversity projects, a systematic registration of all substances has never been established, nor even started.[75] Hence, chemical knowledge does not allow us to make any reliable statements about Case 2.

In sum, the distinction between natural and artificial substances turns out to be loose talk. It may help us to express some preliminary and vague ideas about resources for practical reasons. However, instead of making distinctions, the only thing we can definitely say on justified grounds is that there are substances that are both isolable from natural resources and synthesizeable in the laboratory. That is all, and it is virtually nothing.

[75] Pierre Laszlo has argued for such a project, a 'mission d'un organisme international d'isoler et de répertorier les substances naturelles', in the face of the dramatically rapid extinction of rain forests and other vegetable resources (Laszlo, 1995, p. 131).

10. Does naturalness matter?

If calling a substance natural means nothing other than that it can be isolated from natural resources without further chemical manipulation, the question arises if any normative implications of naturalness can be justified. Are substances that are isolable from natural resources better than those which, to our presently small knowledge, are not?

To answer this question, we first need to clarify what it means if we call a substance good or bad. 'Good' and 'bad' are commonly used in an instrumental sense.[76] A substance is good if it fulfils our needs well. In ordinary language, the instrumental view is so dominant that substances are classified and even named after one single property corresponding to our needs, such as food stuffs, building materials, dyes, adhesives, explosives, etc.[77] In this regard, many synthetic or chemically modified substances, e.g. non-fade dyes, are better than those isolated from natural resources. However, a substance can be both a good dye and poisonous, so that using it for dyeing is dangerous in practice. Despite it being a good dye in principle, it is a bad dye in practice. Thus, what counts is its practical usefulness in real contexts of human usage, instead of one theoretically isolated aspect of its usage.

How do we know about the usefulness of substances in real contexts? I claim that the most reliable way is through practical experience in the very same contexts of use. In order to substantiate this claim a few remarks about the epistemology of material properties are necessary.[78] Material properties are defined by certain kinds of behavior in certain contexts. Hence, our scientific (and nonscientific) concepts applied to substances are context dependent. Moreover, there are infinitely many properties according to infinitely many contexts, so that our knowledge about substances is always limited. We may have perfect, even theoretically substantiated, knowledge about a few properties of a substance, say about its colour, but there are always infinitely many properties about which we do not know. We know only those properties that we have experimentally tested before and to some extent theoretically predicted. As an instructive case, take chlorofluorocarbons (CFCs) with their nearly ideal properties for many applications. Thanks to their molecular simplicity, we knew a great many properties of CFCs in the early 1970s; but nobody knew about their ozone depletion potential, just because nobody had the idea of investigating that. Since real contexts of use are much too complex to be completely described by relatively simple scientific concepts, the simplicity of which are due to simplified experimental contexts, we are forced to study the behavior of substances in real contexts in order to draw reliable conclusions. And the more experience we have,

[76] The only examples where substances are considered intrinsically good or bad are probably aesthetic judgments. I believe that aesthetic judgments play an extremely important role in the distinction between natural and artifical substances. For reasons of brevity, however, I skip this topic here which has been dealt with in another paper (Schummer, 2003a).

[77] See Schummer (1996b).

[78] For more details and justification of the following epistemological remarks, see Schummer (1997b, 1998, 1999).

the more reliable are our claims about its usefulness in real contexts, i.e. whether a substance is good or bad.

Does the fact that a substance is isolable from natural resources say anything about its usefulness in real contexts of usage? In general, nothing. Using any substance isolated from a tree in the Brazilian rain forest as medicine can cause as big a surprise as using any other chemically produced organic substance. As long as we do not have extensive experience of its medical use, our evaluation is blind. In this regard, the metaphysically mediated familiarity with and preference for 'Nature' can be very dangerous. However, the analysis given above may help us to understand a subconsciously rooted preference for natural over artificial substances. Historically, many substances had been isolated from natural resources and used in certain contexts long before chemists produced new ones. For these substances and these contexts of use, we have culturally handed down experience that allows us to judge their overall usefulness and call them better substances than new ones. Thus, it is not 'Nature' but cultural history that provides us with criteria; and it is not the dichotomy between natural and artificial but the gradual distinction between more or less established substances on which sensible judgments are based. Moreover, if substances long established in certain contexts are used in completely new contexts, one should be aware that reliable judgements need new periods of trying and testing.

There is probably only one aspect in which substances isolated from plants and animals are preferable over chemically produced substances that are hitherto unknown in natural resources. If we include waste processing into the context of usage and its judgment, as we should do in my view, then substances isolable from plants and animals are advantageous because we definitely know about their biological decomposition. That definite knowledge is opposed to the little knowledge we have about the metabolism of other substances as well as to our uncertainty if these substances are really not isolable from natural resources (Sect. 8). Hence, the advantage of 'natural' substances arises from the lack of chemical knowledge.

11. The dynamic notion of nature in chemistry and explicit values

In the previous sections we have seen that both the vulgar teleological notion of nature in the form of plastic metaphors as well as the static notion with its alleged division of the world into natural and artificial substances are not very useful. If we abolish both notions in chemical discourses, will there be anything missing? To be sure, many chemists carefully avoid using the term 'nature', or use it only in the sense of 'essence' as in 'the nature of these things'. However, whenever a chemist tries to provide broad perspectives or new prospects of his or her science, particularly in addresses to a general audience or in papers of popular science magazines, references to Nature or nature soon show up. As we have seen, the two notions play a double role in combining descriptive and normative meanings. For instance, 'learning from Nature' means both that there is an object to be studied and that the knowledge thus gained has a higher value than other knowledge. Therefore, abolishing the two notions calls for substitution with regard to both the object of chemistry and its values.

With respect to the object of chemistry, I have already suggested that the dynamic notion of nature is the most elegant choice to avoid conceptual confusion and misleading normative implications.[79] According to the dynamic notion, nature in chemistry is neither a given set of substances nor a mysterious agent, but the chemical dynamics among all possible substances, their specific reactivities and changeabilities. In this sense, any real chemical reaction or transformation including its outcome is natural, whether it occurs inside or outside a laboratory. If nature, from a chemical point of view, coincides with chemical reality and possibility, then 'unnatural' simply means chemically impossible. Furthermore, 'studying nature' in chemistry means studying chemical dynamics. Note that I am not suggesting something completely new. I simply propose to use the term 'nature' for the object chemists have actually studied whenever they were pursuing chemical knowledge: on the empirical level of reactivity studies and substance classification according to chemical similarities, as well as on the theoretical level of reaction mechanisms. Apart from the millions of substances and the practical skills of syntheses, this has established the corpus of chemical knowledge. Adopting the dynamic notion of nature in chemistry by no means implies subscribing to physicalistic reduction, as it is open how chemical dynamics is to be interpreted theoretically. It simply puts chemistry on par with physics by defining the object of chemistry in such a way that the opposition 'chemical' versus 'natural' vanishes.

With respect to values, it is clear that the dynamic notion of nature does not confer any normative implications, as the static and teleological notions do in a premodern way. Therefore, values need to be established in an explicit discourse about the aims of chemistry and its moral constraints, instead of using the plastic metaphors. For instance, if 'learning from Nature' suggests that the resulting knowledge is somehow valuable, such implicit values need to be made explicit, without reference to Nature,

[79] One of the anonymous referees has made the two interesting points that what I call the dynamic notion of nature in chemistry was (i) clearly articulated in Spinoza's notion of *conatus*, and (ii) is closely connected with the essentialist notion of nature which I explicitly exclude in the Introduction. Even if one accepts that *conatus* is not a teleological concept, which not all Spinoza scholars do (e.g. Collins, 1984, p. 272), Spinoza's concept is inappropriate in the chemical context, because chemical substances do not have a tendency towards preserving their own reality (Spinoza: *Ethica*, III, Proposition 6) as psychological and mechanical entities might have, but, on the contrary, a tendency to change into other substances by chemical reactions. As to the essentialist notion of nature, I would argue that this is a much broader concept which, in the case of the nature of a substance, could also include nonchemical properties, depending on the point of view one is interested in. Furthermore, since chemical properties are context dependent and relational properties, any essentialist approach in chemistry would lead us astray (Schummer, 1997b). However, it makes sense to say that the essence, though not all, of chemistry as a science is the exploration of all possible combinations and reactions of substances (Schummer, 1998), and that, from a chemical point of view, these constitute the chemical nature of the material world. In other words, the epistemic object of chemistry (nature) is to some extent constrained by the epistemic perspective of chemistry, i.e. by what is considered essential as opposed to accidental. The distinction between the essentialist and the dynamic notion of nature only vanishes, in my view, if one adopts an idealist position by giving up the realist distinction between the epistemic perspective and the epistemic object, against which I have argued elsewhere in detail with reference to experimental sciences like chemistry (Schummer, 1996a).

and scrutinized for general agreement with the aims of chemistry. Similarly, if 'surpassing or controlling Nature' has any normative meaning, one needs to say what the corresponding actions are actually good or bad for. Instead of presenting metaphorical narratives, 'from learning from nature to controlling nature', the actual achievements need to be made explicit and judged on the basis of generally accepted values. If 'synthetic' is considered to have any advantage or disadvantage over 'natural', one needs to engage in a discourse about aesthetic values. Finally, since the dynamic notion includes no moral constraints about the chemical change of our material world, as the static and teleological notions do, such constraints must be found in a general moral discourse with reference to generally accepted values.[80] Because of chemists' reluctance to adopt the dynamic notion of nature, there is much to catch up on in these matters.

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[80] See Schummer (2001b).

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