notly disputed; above all, the analysis of water into oxygen and another gaseous element, and the complementary synthesis of these gases to generate water. Along with doubts about the accuracy of the authors' etymology, such controversial chemical questions became the focus of the criticisms of the reform, while the *Méthode*'s own principal justification, as forcefully presented by Lavoisier, remained Condillacian philosophy. Lavoisier saw Condillac's methodology as providing him with the authority of nature, a twist that would prevent this reform from being just another option among several proposed chemical nomenclatures. Nevertheless, this deployment of nature's authority, however compelling it might have been for Lavoisier as a disciple of Condillac, was unlikely to win over a chemical audience with its more practical concerns. Thus, although it is hard to interpret silences, I would suggest that the silence that greeted the Condillacian philosophy in the reception of the *Méthode* has an opposite meaning to the silence around the Academy's role in the reform. While the latter was a silence expressing a profound comprehension of the dominant place of the Academy in French science, the former was a silence of incomprehension when faced with a novel application of Enlightenment philosophy to chemistry.

AMBIX, Vol. 49, Part 3, November 2002

Looking for an Order of Things: Textbooks and Chemical Classifications in Nineteenth Century France

JOSÉ RAMON BERTOMEU-SÁNCHEZ
University of Valencia

ANTONIO GARCIA-BELMAR
University of Alicante

and BERNADETTE BENSAUDE-VINCENT
Paris X University

ABSTRACT

The purpose of this paper is to reconsider the issue of the creativity of textbook writing by exploring the links between nineteenth-century French textbooks and the quest for a classification of elements. The first section presents the elegant combination of didactic and chemical constraints invented by eighteenth-century chemists: the order of learning — from the known to the unknown — and the order of things — from the simple to the complex — were one and the same. In section two we argue that the alleged coincidence did not help the authors of elementary textbooks required for the new schools set up by the French revolution. Hence the variety of classifications adopted in the early nineteenth century. A debate between natural and artificial classifications raised a tension in the 1830s without really dividing the chemical community. Rather it ended up with the adoption of a hybrid classification, combining the rival natural and artificial systems.

Introduction

Textbooks are closely associated to the history of classifications in chemistry by one success story, at least. Mendeleev discovered the periodic law while he was striving to order the chapters of a general chemistry textbook, intended for his students at St Petersburg University.[1] Yet to our knowledge no-one has seriously considered the relationship between classification and textbook writing. Given the current view of textbooks as repetitive and uninspired literature, Mendeleev's discovery can be considered as the one exception confirming the general rule. Only in the hands of a creative scientist like Mendeleev did the enterprise of textbook writing provide an opportunity for the discovery of a natural law. Most textbooks authors are not really innovative and consequently disappear from the memory of scientific communities

[1] See J. W. van Spronsen, *The Periodic System of Chemical Elements: A History of the First Hundred Years* (Amsterdam and London: Elsevier, 1969), 125, 133; B. Bensaude-Vincent, "Mendeleev's Periodic System of Chemical Elements," *British Journal for the History of Science* 19 (1986): 3-17; N. M. Brooks, "Dimitrii I. Mendeleev's *Principles of Chemistry* and the Periodic Law of the Elements," in *Communicating Chemistry: Textbooks and Their Audiences, 1789-1939*, ed. A. Lundgren and B. Bensaude-Vincent (Canton, Mass.: Science History Publications, 2000), 295-311; M. D. Gordin, "The Ordered Society and Its Enemies: D. I. Mendeleev and the Russian Empire, 1861-1905" (Ph.D. diss., Harvard University, 2001), chap. 2.

whatever the commercial success of their books in their contexts. Mendeleev's textbook remains an anecdote that does not question the established division of labour between the creative writing of researchers and the paradigm-driven textbook literature aimed at reinforcing the paradigm.

The purpose of this paper is to reconsider the issue of the creativity of textbook writing by exploring the links between textbook writing and classifications. To what extent did textbooks act as a driving force in the quest for a classification of chemical elements? In his pioneering study of early chemistry textbooks, Owen Hannaway pointed out the heuristic power of didactic writing. Andreas Libavius, he argued, attempted a classification of chemical recipes and processes in order to organise the chapters of his *Alchemia* (1597). This attempt raised problems that others — readers and colleagues — would solve through new hypotheses and experiments. Libavius thus initiated a process of confrontation between organising principles and chemical data that gradually transformed a collection of empirical recipes into a teachable knowledge organised in a rational way.[2] In the rich tradition of chemistry textbooks published in the seventeenth and eighteenth centuries, various organising principles were adopted. However the classification of chemical elements was not an issue until the number of chemical elements increased from four or five to several dozens.

Two major reasons lead to focus on nineteenth century. On the one hand, in the long history of chemistry, the nineteenth century is distinguished by an expanding number of chemical substances that made the urge for a classification more and more pressing. Without considering here the inflation of organic compounds, the number of elements more than doubled in the nineteenth century: 33 elements were listed by Lavoisier at the end of the eighteenth century; 24 were isolated between 1800 and 1850 thanks to the powerful electrolytic techniques; 24 additional elements were identified between 1850 and 1899 through spectroscopy.[3] In the nineteenth century, due to the large number of chapters dealing with the properties of chemical substances, the success of a chemistry textbook largely depended on the solution to this problem. How was a teacher to present beginners with the knowledge accumulated about the innumerable compounds formed by so many elements? Even an elementary exposition of chemistry was in danger of becoming something like a random collection of short descriptions of elements and their various compounds, or at best a collection of entries following the alphabetical order of a dictionary. How to guide students into the chaos of materials whose individual properties matter for chemists? The

[2] See Owen Hannaway, *The Chemist and the Word: The Didactic Origins of Chemistry* (Baltimore: Johns Hopkins University Press, 1975); Hélène Metzger, *Les Doctrines Chimiques en France du Début du XVIIe à la Fin du XVIIIe Siècle* (1923; Paris: A. Blanchard, 1969); Allen G. Debus, *The French Paracelsians: The Chemical Challenge to Medical and Scientific Tradition in Early Modern France* (Cambridge: Cambridge University Press, 1991).

[3] See A. Massain, *Chimie et Chimistes* (Paris: Magnard, 1952), 235; Joachim Schummer, "Scientometric Studies on Chemistry: The Exponential Growth of Chemical Substances, 1800-1995," *Scientometrics* 39 (1997): 107-123.

author of a textbook has to decide upon a sequence of the chapters in view of the expectations of the targeted readers and the constraints of educational policy. A powerful organisation for a general chemistry textbook should meet at least two requirements: 1. to provide a picture of the material world of chemical substances as objective and faithful as possible; and 2. to facilitate the learning of chemistry by the targeted audience. In more general terms, writers of chemistry textbooks — or people in charge of designing school curricula — have to determine the optimal combination between the "order of things" and the "order of learning."

On the other hand, cognitive and didactic concerns became more and more entangled in the nineteenth century. As chemistry chairs were created in various universities all over Europe, most active chemists were professors. Professors in higher education were expected to teach a particular discipline and to contribute to the advancement of knowledge in this area. It was in this period that the term "discipline" acquired its current dual meaning as a department of learning and as a coherent research area. Textbooks authors such as Thomas Thomson, Jōns Jakob Berzelius or Louis-Jacques Thenard, tried to combine research and didactic imperatives, and thus played a key rôle in the reorganisation of the discipline.[4]

The case of nineteenth century France is of special interest because the question — how to design a classification combining the chemical and the didactic constraints — was openly debated by textbook writers. Far from being confined to the circle of the leading chemists, authors of high education treatises, those debates involved more obscure chemistry teachers who authored textbooks for lower educational levels.

Quite surprisingly, the problem of finding the best organising principle had been solved before it was re-opened and debated. As we will see in the first section, eighteenth century chemists provided an elegant solution: they assumed that the order of learning, from the known to the unknown, and the order of things, from the simple to the complex, were one and the same. However the alleged coincidence did not really help the authors of elementary textbooks required for the new educational system set up by the French Revolution. Hence the variety of classifications adopted in the early decades of the nineteenth century. The issue of classification resurfaced in the 1830s

[4] Recent literature in the history of science has emphasised the extent to which science teaching influenced the construction of a discipline and the pace of its changes. For physics, see, for instance, Rudolf Stichweh, *Zur Entstehung des Modernen Systems Wissenschaftlicher Disziplinen: Physik in Deutschland, 1740-1890* (Frankfurt am Main: Suhrkamp, 1984); K. M. Olesko, *Physics as a Calling: Discipline and Practice in the Königsberg Seminar for Physics* (Ithaca, N.Y.: Cornell University Press, 1991); D. I. Kaiser, *Making Theory: Producing Physics and Physicists in Postwar America* (Ph.D. diss., Harvard University, 2000). Special attention has been paid to textbooks: W. Clark, "German Textbooks in the Goethezeit," parts 1 and 2, *History of Science* 35 (1997): 219-239 and 295-363; Lundgren and Bensaude-Vincent, eds., *Communicating Chemistry*. For a broader discussion of French textbooks, see A. Choppin, *Les Manuels Scolaires: Histoire et Actualité* (Paris: Hachette, 1992); Jonathan R. Topham, "Scientific Publishing and the Reading of Science in Nineteenth-Century Britain: A Historiographical Survey and Guide to Sources," *Historical Studies in the Philosophy of Science* 31 (2000): 559-612.

vhen a number of textbook writers, following André Marie Ampère, imported nto chemistry the notions of "natural classification" and "artificial classifica-ion" used in natural history. This debate, described below, involved many ıctors, but it did not result in a divide of the chemical community like most scientific controversies. Rather it ended up with the adoption of a hybrid classification, combining features of both natural and artificial classifica-ions.

Of Ambiguous Simplicity

From the simple to the complex, this order was the basic principle underlying he new system of chemical nomenclature designed by four French chemists in 1787. Lavoisier who was one of the reformers, provided a philosophical egitimation for the simple-to-complex order already formulated and used by eighteenth century authors. Referring to Etienne Bonnot de Condillac's 'metaphysics of language," he assumed that words, facts, and ideas were, so to speak, three faces of one single reality. A language proceeding from the simple o the complex was the expression of the "natural logic" in two different ways. First, it was the mirror image of all chemical compounds; whatever their nineral, vegetable or animal origin, they were supposedly formed by two simple substances or two radicals acting as elements. Second, ideas in human nind were also formed according to the same analytical logic: the association of simple sense data generated primary ideas that gradually led by association o more complex and more abstract notions. Therefore Lavoisier claimed that he new language would bring about a "revolution in chemistry teaching" and wo years later he presented his *Elements of Chemistry* as the natural outcome of he reform of language. In the preliminary discourse, Lavoisier explicitly compared the genesis of ideas in children's mind with the learning of chemistry and decided to proceed from the known to the unknown. He claimed that the strict application of this rule would make his textbook different from any previous one, that his would be the first really elementary extbook intended for beginners.[5]

Many historians, taking Lavoisier's claim for granted, have assumed that his *Elements of Chemistry* was the first modern textbook because it reorganised chemistry according to the simple-to-complex order. In fact, this logic was hardly revolutionary. Antoine Baumé, for instance, had already adopted what he called the "synthetic order," that is, "from simple to compound and from compound to more compound."[6] This order, whether it be called analytical or synthetic, had prevailed in the exposition of chemistry for a few decades along with the redefinition of the notion of element as a simple substance. Far from

[5] Guyton de Morveau, A.-L. Lavoisier, C.-L. Berthollet, and A.-F. Fourcroy, *Méthode de Nomenclature* (1787; Paris: Seuil, 1994), 63-74; A.-L. Lavoisier, *Traité Élémentaire de Chimie ...* (Paris: Cuchet, 1789), vol. 1, x-xi. See also B. Bensaude-Vincent, "A Language to Order the Chaos," *Bulletin for the History of Chemistry* 23 (1999): 1-10.

[6] Antoine Baumé, *Chymie Expérimentale et Raisonnée, par ...* (Paris, P. F. Didot le jeune, 1773), vol.

subverting the traditional organization of chemistry textbooks according to the three realms of nature, it rather legitimised the progression from mineral to vegetable and animal chemistry. Moreover, Lavoisier's assumption that there was no distinction between the two principles — from the simple-to-the-complex and from the known-to-the-unknown — was already manifest by the mid-eighteenth century. Textbooks entitled *Elements of chemistry* played on the ambiguity of the term "element" and tacitly assumed that what is elementary in the order of substances was also elementary in the order of knowledge. Pierre-Joseph Macquer, for instance, presented his *Elements of Theoretical Chemistry* in these terms:

> Assuming that my reader knows no chemistry, I plan to lead him from the simplest of truths, which requires the least knowledge, to compound truths which require more. This order obliges me to start by treating the simplest substances that we know and that we look upon as the elements of which the others are composed, because knowledge of the properties of these elementary parts leads naturally to the discovery of those of their different combinations. And contrariwise, knowledge of the properties of compound bodies requires that we be already familiar with that of their principles. The same reasoning obliges me when dealing with the properties of a given substance, not to speak of those of any other substance of which I have not spoken."[7]

Lavoisier was thus following a common, established, view when he assumed that the simple in nature was also simple for human understanding. He simply provided the philosophical legitimation for a shared belief. The reference to empiricist philosophy nevertheless helped change the meaning of the term "element." Lavoisier's famous definition of elements as provisionally-in-decomposable substances was certainly not new, but it deprived the elements of their function as universal constituents of the material world. Insofar as they were simple residues of experimental attempts at decomposition — and we know that such was not the case for the first category of five elements, including light and caloric — the elements listed in Lavoisier's "table of simple substances" were empirical substances with no ontological status. The ambiguity involved in the notion of element no longer referred to the parallel between nature and the human mind. The coincidence of the *ratio cognoscendi* with the *ratio essendi* became a coincidence with the *ratio operandi*, i.e. the

[7] Pierre-Joseph Macquer, *Élémens de Chymie Théorique ...* (Paris: J. T. Hérissant, 1753), xvi-xvii: "Le plan que je me suis principalement proposé de suivre, est de ne supposer aucune connaissance chymique dans mon Lecteur; de le conduire des vérités les plus simples, et qui supposent le moins de connaissances, aux vérités les composées qui en demandent davantage. Cet ordre que je me suis prescrit, m'a imposé la loi de traiter d'abord des substances les plus simples que nous connaissions, & que nous regardons comme les éléments dont les autres sont composées, parce que la connaissance des propriétés de ces parties élémentaires conduit naturellement à découvrir celles de leurs différentes combinaisons; & qu'au contraire la connaissance des propriétés des corps composés, demande qu'on soit déjà instruit de celles de leurs principes. La même raison m'engage lorsque je traité des propriétés d'une substance, à ne parler d'aucune de celles qui sont [illegible] dont je n'ai point parlé."

laboratory practices of analysis which gave access to the simple substances and elementary notions. The prevalence of the operational criterion of simplicity, along with the decomposition of a number of substances that Macquer and Baumé had considered as elements, inspired Antoine de Fourcroy's claim in 1800 that chemistry was conquering its autonomy. Thanks to a classification of its own based on the nature and proportion of the constituent principles, chemical science would soon be emancipated from natural history and its reference to the realm of nature.[8]

The criterion of composition underlying the reform of the language of chemistry at the end of the eighteenth century thus favoured the claims that chemistry had become an autonomous and teachable science. However the chemists' optimism rested on the ambiguity of such terms as "simple" and "elementary," referring both to the composition of material substances and to human understanding.

Alternative Classifications

Despite Lavoisier's and Fourcroy's optimism, the adoption of the order of increasing complexity neither opened the access of chemistry to beginners nor guaranteed the autonomy of chemistry. Certainly chemists, Fourcroy in particular, played a key rôle in the decision of the first republican government to introduce chemistry teaching at the secondary level (in the *écoles centrales)* as well as in the schools of pharmacy. However the new language of chemistry that they had created did not miraculously bring a revolution in chemistry teaching, at least in the organization of courses and textbooks contents.

Although most chemistry teachers adopted the new language together with its logic of composition, they had to face many difficulties in their didactic practices. In order to respect the rule of proceeding from the known to the unknown they had to start with familiar substances, such as water or air. But water and air being compound bodies, could only be introduced after dealing with simple substances such as oxygen, hydrogen, nitrogen and caloric. In short, the coincidence between the order of things and the order of learning proved more rhetorical than effective. In his *Elements of Chemistry,* Chaptal clearly pointed to the dilemma that presumably caused headaches to several generations of textbook writers:

> One can proceed in one of two ways on the examination of chemical bodies: either by going from simple to compound or by descending from compound to simple. Both methods have their disadvantages, but undoubtedly the biggest inconvenience in following the former is that in starting from simple bodies, one presents bodies that nature does not but rarely offer in this state of simplicity and bareness, and one is forced to hide all the operations that were employed to denude these bodies of their relationships and bring them to this elementary state. On the other hand, if one presents the bodies as they are, it is difficult to get to know them because their reciprocal action and in general most of their phenomena cannot be known without previous and exact knowledge of their constituent principles since it is on them that they depend.[9]

[8] Antoine-François Fourcroy, *Système des Connaissances Chimiques et de Leurs Applications aux*

Since the two principles were not easily compatible, each individual author had to make a choice. Even among the pioneer elementary textbooks published by Fourcroy, Lavoisier and Chaptal, in the 1790s, there was no consensus on a standard organisation.[10] Later on, most authors invented a compromise of their own, according to the targeted audience. For instance, Jean-Louis Lassaigne, who wrote a textbook for veterinary and medical students, chose to begin with two chapters on "water and air, whose properties and composition should be known for the explanation of a host of ordinary phenomena that could not be understood without a clear knowledge of the true nature of these substances."[11]

Moreover, the simple-to-complex principle provided a general framework, but no clues for the exposition of chemical compounds . As Berzelius noticed in the preface of his successful *Lärbok i kemien,* translated into many languages, there were again two alternatives :

> Sometimes one seeks, so far as it does not cause inconvenience, to put together a collection of monographs on simple substances, and as for the combinations into which each of these substances is capable of entering, they are arranged in some sort of order, but an order that has been fixed in advance so that one will not be obliged to describe a compound twice, or even more times. In my opinion, it is in this form that science is reduced to its most simple expression, and is most easily inculcated in the memory ... Sometimes one deals first of all with the simple substances, and then examines, in a given order, the combinations of all substances with all the others, and then one looks at the combinations of these various combinations with each other, in such a way as to proceed from the simple to the complex. At first glance this

[9] Jean A. Chaptal, *Élémens de Chimie* (Montpellier: 1790); citation in third edition (Paris: an V [1796-7]), vol. 1, 51: "On peut ... procéder de deux manières dans l'examen chymique des corps, ou bien aller du simple au composé, ou descendre du composé au simple: ces deux méthodes ont des inconvéniens, mais le plus grand sans doute qu'on éprouve en suivant la première, c'est qu'en commençant par les corps simples on présente des corps que la nature ne nous offre que rarement dans cet état de simplicité et de nudité, et l'on est forcé de cacher la suite d'opérations qui a été employée pour dépouiller ces mêmes corps de leurs liens et les ramener à cet état élémentaire. D'un autre côté, si on présente les corps tels qu'il sont, il est difficile de parvenir à les bien connaitre, parce que leur action réciproque, et en général la plupart de leurs phénomènes, ne peuvent être saisis que d'après la connaissance exacte de leurs principes constituans, puisque c'est d'eux seuls qu'ils dépendent."

[10] B. Bensaude-Vincent, "A View of the Chemical Revolution through Contemporary Textbooks: Lavoisier, Fourcroy and Chaptal," *British Journal for the History of Science* 23 (1990): 435-460.

[11] Jean Louis Lassaigne, *Abrégé élémentaire de Chimie Considérée comme Science Accessoire à l'Étude de*

> method seems to be one that best fulfils the requirements of a book written for beginners.[12]

Berzelius renounced all systematic order and sacrificed the sequence from simple to complex at his own convenience. True, several choices were available to textbook writers. And the exploding population of elements discovered in the early decades of the nineteenth century increased the flexibility. The criteria had to be carefully chosen since the sequence of the much more numerous chemical compounds largely depended on the arrangement of elements.

How then was one to organise the presentation of an ever expanding list of elements? Using chemical analogies to make groups of elements was the most obvious solution envisaged by chemistry teachers in order to save time and avoid fastidious repetitions. Therefore Louis-Jacques Thenard explicitly mentioned three guiding principles in his *Traité de chimie* first published in 1814:

> The method that I have always followed consists in proceeding from the simple to the compound, from the known to the unknown, grouping together all analogous bodies and studying them first generally way and then specifically.[13]

In fact, analogies — the third organizing principle — were already operational in the late eighteenth century. Analogical reasoning was deeply rooted in the chemical tradition and the use of analogies for ordering the multiplicity of chemical substances was by no means an innovation. Although Lavoisier gave priority to the simple-to-complex logic, he made use of analogies since the system of nomenclature could not dispense with a classification of substances based on analogies.[14] So chemists still had to face the well-known problem raised by the use of analogical reasoning: they had to discriminate between superficial and significant resemblances to select the relevant analogies.[15] Fourcroy began with the first group and then distinguished between two categories of simple substances: combustible and non-

[12] Jöns Jakob Berzelius, *Lärbok i Kemien* (Stockholm: H. A. Nordström, 1817); since this work was never translated into English, the quote is translated from the French edition, *Traité de chimie ...* (Paris: Firmin-Didot, 1829-33), vol. 1, 2: "La méthode que j'ai constamment suivie consiste à procéder du simple au composé, du connu à l'inconnu, à réunir dans un même groupe tous les corps analogues, et à les étudier d'abord d'une manière générale et ensuite d'une manière particulière."

[13] L.-J. Thenard, *Traité de Chimie Élémentaire, Théorique et Pratique* (Paris: Crochart, 1813-16), vol. 1, i-ii. There were six editions: 2d ed., 4 vols., 1817-18; 3d ed., 4 vols., 1821; 4th ed., 5 vols., 1824; 5th ed., 4 vols., 1827; 6th ed., 5 vols., 1834-36.

[14] For instance, Lavoisier distinguished four groups of simple substances: simple substances belonging to the three realms of nature that can be regarded as elements of bodies (including light, caloric, oxygen, hydrogen, nitrogen); non-metallic simple substances generating oxides and acids; metallic substances generating oxides and acids; earthy simple substances generating salts.

[15] On the importance of analogies in chemistry, see Gaston Bachelard, *Le Pluralisme Cohérent de la Chimie Moderne* (1930; Paris: Vrin, 1973), 29-30; Thenard, *Traité de Chimie*, 30.

combustible. Most textbooks in the early nineteenth century maintained imponderable substances in the first chapters and then proceeded to the classification of ponderable simple substances. For the latter, Berzelius adopted the general distinction between metals and "metalloids" in his treatise although he later favoured an arrangement based on the electric charge of the elements. In keeping with Lavoisier's oxygen theory, Thenard selected the affinity for oxygen among many potential candidates as the leading organizing principle.[16] He ordered non-metallic elements by using this criterion.[17] He established a classification of metals in six sections, which was based on their reactions with water and oxygen at different temperatures (see Table 1).[18]

Table 1: Thenard's classification of metals[19]

Sections	Metals
1	Mg, Be, Y, Al, Th, Zr, Si
2	Ca, Sr, Ba, Li, Na, K
3	Mn, Zn, Fe, Sn, Cd
4	(a) As, Mo, Cr, W, Columbium
	(b) Sb, U, Ce, Co, Ti, Bi, Cu, Te, Ni, Pb
5	Hg, Os
6	Ag, Pd, Rh, Pt, Au, Ir.

Thenard also employed oxygen in his classifications of plant and animal immediate principles. He distinguished three main groups according to the proportion of oxygen and hydrogen in their composition. In 1810, Gay-Lussac and Thenard had suggested that this ratio was related with the acid-alkali properties of immediate principles.[20] In organic as well as in inorganic chemistry, Thenard tacitly assumed a straightforward relationship between elemental composition and chemical properties. He considered that the phenomenological behaviour of chemical substances was determined by the nature and proportion of their constituents. This assumption, albeit implicit,

[16] Ibid., 2d ed., vol. 1, vii, and 3d ed., vol. 1, vii: "L'oxigène étant le corps simple le plus généralement répandu et le seul qui ait une grande influence sur presque tous les résultats chimiques, j'ai continué de le considérer à part, et d'appeler *corps combustibles* chacun des élémens avec lesquels il est susceptible de s'unir. Ce nom est donc le même que celui de *corps oxidable* ou *oxigénable*."

[17] Ibid., 2d ed., vol. 1, 145.

[18] Ibid., 1st ed., vol. 1, 208-210. These criteria were maintained in subsequent editions: 2d ed., vol. 1, 240-1; 3d ed., vol. 1, 256-7; 5th ed., vol. 1, 320-322.

[19] Taken from ibid., 4th ed., vol. 1, 288-9.

[20] J.-L. Gay-Lussac and L.-J. Thenard, "Extrait d'une Mémoire sur l'Analyse Végétale et Animale par MM. ... Lu à la Séance de la Première Classe de l'Institut, le 15 Janvier 1810," *Annales de Chimie* 74 (1819): 47-64. See R. Löw, *Pflanzenchemie zwischen Lavoisier und Liebig* (Straubing/Munich: Donau, 1977): 268-9, and F. L. Holmes, "Elementary Analysis and the Origins of Physiological Chemistry," *Isis* 54 (1963): 50-81, on 58.

made possible the coexistence of the simple-to-complex order with the respect of chemical analogies.

However, the selection of one single criterion among the various networks of analogies was criticised by Marie André Ampère. In 1816, he published a memoir in the *Annales de chimie* criticizing the overestimation of oxygen in chemical classifications. Instead he suggested that chemists following the example of naturalists should design a "natural classification," i.e. a classification based on all the characters of the substances to be classified as opposed to the "artificial classifications" based on one single character. A natural classification in chemistry would take into account the most numerous and most essential analogies.[21] Convinced that the "natural order" would be unveiled by the "natural method," Ampère reacted strongly to the tendency to retain only the affinity for oxygen and mentioned Gay-Lussac as the one exception to this general trend.[22] Ampère made the first attempt at a natural classification of chemical elements. After testing various arrangements, Ampère first tried a circular arrangement of chemical elements in which properties changed gradually from one group to another. Ampère emphasised the continuity by stressing the similarities between bodies placed at the edge of chain. He then renounced the chain model and distinguished three major families of elements "gazolytes," "leucolytes" and "chroïcolytes" whose names derived from the kinds of compounds they formed. The three groups were further subdivided into fifteen genres and the genres themselves further subdivided into species (see Table 2).[23]

Ampère presented his *Essai* as a first step toward a bigger project of classification of all chemical substances that never came into being. His first essay certainly did not go unnoticed, but it had no immediate influence on the French chemical community. In the early decades of the nineteenth century, Thenard's classification enjoyed a wider circulation for two reasons. Firstly, Thenard's treatise had been officially presented as a model for all teachers by the Ministry of Public Instruction. Given Thenard's prestige and authority, his textbook became a reference in the French system. Thus, most textbooks

[21] A. M. Ampère, "Essai d'une Classification Naturelle pour les Corps Simples," *Annales de Chimie* (1816): 295-308, 373-394, 1-32, 105-125, quote on 296. On former drafts of his classification, see Dowland-Pillingier, "A Chemist Full of Bold and Ingenious Ideas': The Chemical Philosophy of A. M. Ampère (1775-1836)"(Ph.D. diss., Cambridge University, 1988); D. M. Knight, *The Transcendental Part of Chemistry* (Folkestone: Dawson, 1978), 251-253.

[22] Ampère, "Essai d'une Classification," 296: "M. Gay-Lussac, dans le cours de chimie qu'il fait à l'École royale Polytechnique, a établi entre les corps simples un ordre dont les détails me sont inconnus, mais dont l'ensemble se rapproche beaucoup de l'ordre que je donne dans ce mémoire, et qu'il m'a semblé le plus naturel. Sa principale division, qui a l'avantage de ne rompre aucune analogie essentielle, consiste à ranger dans une classe tous les corps qui peuvent former des acides en se combinant avec un autre corps de la même classe, et dans une autre, tous ceux dont aucune combinaison ne présente les propriétés des acides."

[23] Ibid., 120-5. The term "gazolytes" meant that these elements combined with other elements belonging to the same class would form permanent gases that would not decompose when mixed with atmospheric air; the term "leucolytes" meant that these substances would form white or colorless salts; the term "chroïcolytes" ...

Table 2: Ampère's classification of chemical elements[24]

Gazolytes:	Leucocytes	Chroïcolytes:
Anthracides: C, H	Argyrides: Ag, Bi, Hg, Pb	Titanides: Ti, Os
Borides: B, Si	Calcides: Ca, Sr, Ba, Mg	Cérides: Ce, Mn
Chlorides: Cl, F,I	Cassitérides: Sn, Sb, Zn	Chrysides: Au, Pt, Pd, Rh, Ir
Thionides: S,N,O	Téphralides: Na, K	Chromides: Cr, W, Columbium, Mo.
Arsénides: As, Te, P	Zirconoïdes: Zr, Al, Be, Y	Sirérides: Fe, Cu, Ni, Co,V

adopted Thenard's classification whether they be intended for medical students, military schools or secondary schools.

Secondly, even though several new groups of substances jeopardised Thenard's classification, Thenard actively revised his *Traité* in order to adapt his general scheme to new discoveries. For instance, after Humphry Davy had ruined Lavoisier's theory of acidity, Thenard conceded in the second edition that "certain acids were hydracids" and did not contain oxygen. Symmetrically, ammonia or volatile alkali that had been traditionally grouped with soda and potash (fixed alkalis) were admittedly composed of hydrogen and nitrogen. However, when Davy suggested that fixed alkalis were metallic oxides of two new elements (sodium and potassium) the remarkable similarities between the three alkalis were at odds with such different elementary composition. Several authors tried to solve this problem. After studying an amalgam of ammonia and mercury, Davy suggested that ammonia could be an oxide of an unknown metal that he called "ammonium."[25] Many chemists such as Berzelius supported the latter hypothesis.[26] Thenard by contrast was sceptical and in his second edition, he acknowledged that ammonia could be an exception to his classification as well as hydracids.[27] Although a growing number of exceptions threatened the consistency of Thenard's classification, a number of French chemists were confident that such exceptions would gradually disappear with further investigations. Thenard's classification of metals, in particular, was so convenient that a few inconsistencies could be tolerated.

To sum up, a classification based on the affinity of elements for oxygen

[24] Taken from ibid.

[25] See H. Davy, "On the Production of an Amalgam from Ammonia, and on Its Nature and Properties," in *The Collected Works of Sir Humphry Davy* ..., ed. John Davy (London: Smith, Elder, 1840), vol. 5, 122-130; D. Knight, *Humphry Davy: Science and Power* (Oxford: Blackwell, 1992), 69.

[26] J. Berzelius, "Suite des Expériences sur les Proportions Déterminées, d'après lesquelles les Élémens de la Nature Inorganique s'Unissent, *Annales de Chimie* 79 (1811): 233-264; E. M. Melhado, *Jacob Berzelius: The Emergence of His Chemical System* (Stockholm: Almqvist & Wiksell, 1981), 203-209; E. M. Melhado and T. Frängsmyr, eds., *Enlightenment Science in the Romantic Era: The Chemistry of Berzelius and Its Cultural Setting* (Cambridge: Cambridge University Press, 1992), 153-

ame the standard system for chemistry textbooks in France in the 1820s. › different aspects prompted the triumph of this system: the overarching uence of one chemist, Thenard on the French academic and educational ieus and the shared belief that the nature and proportion of constituent nents determined the chemical properties of the compounds.

Natural versus Artificial Classifications

. all textbook writers, however, blindly followed Thenard's model. sidence came first from the margins of chemical science. To many irmacists and mineralogists, Ampère's classification appeared as an rnative model to Thenard, although most of its supporters criticised the del and introduced minor or major changes in it.

For instance, in 1822, the pharmacist Nicolas Jean-Baptiste-Gaston ıbourt (1790-1867) published a memoir with an attempt at a natural ısification. Guibourt followed Ampère in rejecting the metal versus nontal dichotomy and adopting his groups and families. However he had to ·grate three new elements recently isolated: lithium, cadmium and ·nium. Whereas the first two elements were easily integrated in Ampère's ups, selenium posed tricky problems due to its analogies with sulfur and urium, two elements that Ampère had placed in separate groups. Guibourt ked sulfur out from the oxygen-nitrogen group and tellurium from the up of arsenic-phosphorus and he joined them with selenium. He also ıed to this group the Ampère "chlorides," that is, fluorine, chlorine and ine. In doing so, Guibourt argued that he grouped all elements which were e to "acidify hydrogen."[28] He also erased the group of "titanides," which luded titanium and osmium, placing the first element in the "chromides" up and the second one in an appendix that he called "*incertae sedis.*" other pharmacist, lecturer at the preparatory school of medicine in Amiens, arles Louis Constant Pauquy (1800-1854) published a new natural ısification.[29] But those pharmacists did not really disturb the chemists.

A controversy was sparked by François-Sulpice Beudant (1787-1850), a ıeralogist, who adopted Ampère's classification with its three groups – olytes, leucolytes and chroïcolythes – in his *Traité élémentaire de minéralogie,* ıed in 1824. This publication prompted a sharp criticism from Berzelius, o tended to act as a universal judge of chemistry:

> M. Ampère's classification is very interesting in that it presents a parallel of simple bodies conceived of in a certain perspective. But it is not independent enough of all speciality in ways of seeing for it to be adopted as a basis for the scientific ordering of bodies. Besides, it is not

[28] N. Guibourt, "Sur la Classification et la Nomenclature Chimiques" (extrait d'un mémoire lu Société de Pharmacie, séances des 15 juin et 15 juillet 1822), *Journal de Pharmacie* 10 (1824): -333, on 320-1.

[29] C. Pauquy, *Nouvelle Méthode Naturelle Chimique, ou Disposition des Corps Simples et Composés Propre 'endre l'Étude de Cette Science Plus Facile et Plus Courte* (Amiens: Caron-Duquenne/Allo-Poiré, 8).

> necessary to have great knowledge of their characters to find that the junction of the extremities is completely artificial seeing that three completely different bodies — oxygen, nitrogen and hydrogen — are placed next to each other only because they are gazeous. The proof that the system is artificial is that one can make any number of interesting ones of this kind by similarities between bodies, but where they will be differently arranged.[30]

According to Berzelius, Ampère's classification rested on partial views. By selecting the criterion of gazeous state to form the gazolytes group, Ampère did not respect chemical analogies.[31] The so-called natural classifications were more artificial and conventional than his own electrochemical arrangement of elements. Thus the main argument against natural classifications in chemistry was that they occulted a number of natural analogies and were consequently disguised artificial classifications.

Antoine Bussy (1794-1882), a chemistry lecturer at the Paris School of Pharmacy, defended a Ph.D. dissertation on chemical classification in 1833. Bussy picked up the same example of oxygen, nitrogen and hydrogen against Ampère and condemned all attempts at a natural classification. Instead he suggested a classification based on a mixture of Berzelius's and Thenard's criteria, that is, electrochemical properties and affinity for oxygen.[32]

The first important attempt to introduce natural classifications in chemistry textbooks was made by César Mathurin Despretz (1791-1863), a former assistant of Gay-Lussac and a teacher at the Collège Henri IV.[33] He organised his *Traité de chimie* intended for secondary school, according to a "completely new" classification inspired by botanical and natural history

[30] J. Berzelius, "Des changemens dans le système de minéralogie chimique..." *Annales de Chimie et de Physique* 31 (1826): 5-37, on 35-6: "Des changements dans le système de minéralogie chimique, qui doivent nécessairement résulter de la propriété que possédent les corps isomorphes, de se remplacer mutuellement en proportions indefinites."

[31] This objection had been anticipated by Ampère. In his 1816 memoir, he noted that the gazolytes were grouped together not only because they yielded permanent gaseous substances, but due to their chemical similarities. According to Ampère, natural classifications were open-ended and could be changed when new chemical knowledge of substances was obtained. The critical point was not to single out a conventional characteristic, as in artificial classifications, but to gather all accurate information about chemical properties and analogies, which could be used to create natural groups. Ampère, "Essai d'une Classification," 431.

[32] A. Bussy, "Comparaison des Bases de la Classification des Corps Organisés et Inorganiques" (thèse, Faculté de Médecine de Paris) (Paris: Imprimerie de P. Dupont et Laguionie, 1833), 31.

[33] According to his eulogist Antoine-César Becquerel, Gay-Lussac became a "powerful patron of Despretz during all the phases of his academic life." *Discours de M. Becquerel Prononcé aux Funérailles de M. Despretz ... le Mardi 17 Mars 1863* (Paris: Impr. de F. Didot frères [n.d.]). Despretz worked on subjects related to atomic theory and thermodynamic properties of gases, and he even gained a payment from the Academy of Science in 1822, thanks to his research on animal heat. According to Ampère, "Essai d'une Classification," 296, and Ferdinand Hoefer, *Éléments de Chimie Minérale* (Paris: Dezobry et E. Magdeleine, 1841), 45, Gay-Lussac already used a natural classification in his lectures at the École Polytechnique, but since he never authored a textbook, there is only indirect evidence of that issue. Stenographic notes of Gay-Lussac's lectures taken by students were published in 1828, but Gay-Lussac energetically criticised them because they covered only a small part of a course of lectures delivered with Thenard. See Maurice Crosland, *Gay-Lussac, Scientist and Bourgeois* (Cambridge: Cambridge University Press, 1978).

classifications and taking into account all analogies. He disagreed with Ampère and his criteria of classification. He based his system on "more chemical" criteria. In the case of non-metals, he joined elements whose oxygenated or hydrogenated compounds shared similar acidic or alkaline characteristics. In some cases, he considered whether they could combine directly with oxygen or not. He stressed that the resulting natural families included elements sharing strong analogies from the point of view of the combining volumes as, for instance, in the case of hydracid acids of "chloroïdes" and "azotoïdes."[35] Despretz introduced an intermediate group including chrome, tungsten, molybdenum and cobalt, between metals and non-metals[36] and he distinguished nine families of metals ranging from "stannoïdes" to "potassoïdes." In this case, Despretz paid attention to their chemical behaviour with oxygen and water at different temperatures, their resistance against acid dissolution, the stability of their salts and their "precipitation" with hydrosulfuric acid or zinc.[37] Oxygen and hydrogen were described at the beginning of his textbook, but they were not included in a natural family. The result was the classification shown in Table 3.

Table 3: Despretz's natural classification[38]

1e famille	Chloroïdes	Cl, Br, F, I
2e famille	Sulfuroïdes	S, Se, Te
3e famille	Carbonoïdes	C, B, Si
4e famille	Azotoïdes	N, P, As
5e famille	Chromoïdes	Cr, W, Mo, Columbium; + Ti
6e famille	Stannoïdes	Sn, Sb, Os
7e famille	Auroïdes	Au, Ir
8e famille	Platinoïdes	Pt, Rh
9e famille	Argyroïdes	Ag, Hg, Pd
10e famille	Cuproïdes	Cu, Pb, Cd, Bi
11e famille	[no name]	Fe, Co, Ni, Zn + Mn, U, Ce
12e famille	Aluminoïdes	Al, Be, Y, Zr
13e famille	Baroïdes	Mg, Ca, Sr, Ba
14e famille	Potassoïdes	Li, Na, K

So important became the trend in favour of natural classifications in the 1830s, that Thenard felt he had to justify his choice of an artificial classification. In the last edition of his *Traité* published in 1834-1836, he

[34] C. Despretz, *Élémens de Chimie Théorique et Pratique avec l'Indication des Principales Applications aux Sciences et Aux Arts, Ouvrage dans lequel les Corps Son Classés par Familles Naturelles* (Paris: Méquignon-Marvis, 1829-30), 2 vols.
[35] Ibid., vol. 1, 59, 184.
[36] Ibid., 261-2.
[37] Ibid., 512-3. For instance, Despretz distinguished between "cuproïds" and "ferroïds" due to their different behaviour with zinc. In some cases, he distinguished two genres among the elements of one family.
[38] Taken from ibid.

commented on Ampère's approach ... first defined classes (gazolytes and metals) then families and ended up with genres. Rather, Thenard preferred an inductive approach, a "synthetic method" in contrast to Ampère's "analytic method."[39]

Meanwhile, the supporters of natural classifications were trying hard to improve Ampère's essay and to introduce natural classifications in their classrooms. In a remarkable brochure on nomenclature and classification published in 1845, Ferdinand Hoefer, a chemist and historian of chemistry, gave a survey of the controversy.[40] He identified eight different systems of classifications, including his own one published in his textbook in 1841.[41] Hoefer's system mainly based on isomorphism distinguished eleven families of elements (including radicals such as ammonium and cyanogen because they functioned as simple bodies" (see Table 4):

Table 4: Hoefer's natural classification of chemical elements[42]

Nom de famille	Corps
Oxacés (oxacea)	O, S, Se, Te
Chloracés	Cl, Br, I, F, cyanogène
Carbacés	C, B, Si, Ti, Ta, N, H
Phosphacés	P, As, Sb
Kaliacés	K, Na, Li, ammonium
Baryacés	Ba, Sr, Ca, Mg, Pb
Aluminiacés	Al, Be, Th, Zr, Ce, La
Ferracés	Fe, Mn, Cr, Co, Ni, Zn, Cd, Cu
Hydrargyracés	Hg, Bi
Stannacés	Sn, Mo, W, U, V
Auracés	Au, Ag, Pt, Pd, Rh, Ir, Os

Hoefer's natural classification offered a sound basis for potential reconciliation of the two camps because it included families that were accepted by almost all authors. His groups of metals were very similar to Thenard's. More controversial aspects such as the grouping of titanium, tantalum, nitrogen and hydrogen with carbon, boron and silicon in the group of "carbacés" could have been negotiated since Hoefer acknowledged the imperfections of his classification. He confessed the limitations of his emphasis on isomorphism while on the opposite side, Thenard wrote in his "Essai de philosophie chimique" that isomorphism would certainly become the most reliable criterion in the near future.[43] In our view, Hoefer's classification was very

[39] Thenard, *Traité de Chimie*, 6th ed., vol. 5, 512-514.
[40] Ferdinand Hoefer, *Nomenclature et Classifications Chimiques* (Paris: J. B. Baillière, 1845).
[41] Hoefer, *Éléments de Chimie Minérale*, 48.
[42] Taken from ibid., 47.
[43] Thenard, "Essai de Philosophie Chimique," in *Traité de Chimie*, 6th ed., vol. 5, 409-519.

similar to Thenard's revised classification. It was as artificial as Thenard's classification since it singled out one criterion: isomorphism. But Hoefer was a staunch supporter of natural classifications and a polemicist. He raked the fire with his criticisms of Thenard's "exaggeration of the rôle of oxygen" and bluntly declared that Thenard's classification was "rejected by almost all chemists." Hoefer pointed out four major advantages of natural classifications:

(a) They facilitate the learning of chemistry because the properties of a group of substances could be studied through the characteristics of the substance regarded as "type of a family." For instance, the description of the properties of sulfur were sufficient to convey the properties of selenium and tellurium.
(b) If an element has been discovered in a region, other elements of the same family could be expected to be found in the same area. "Where you found chlorides you will easily find iodides and bromides." Because "isomorphism played an immense rôle in nature," bodies that could replace each other without changes in their crystal structure could be located together.
(c) In medical and technological applications, natural classifications were also very useful, since a parent element could be used as a substitute for a substance belonging to the same family.
(d) Finally, natural classifications indicated not only "what has been done" in chemistry, but also "what still remains to be done and discovered."

In short, for Hoefer, natural classifications were both heuristic and didactic tools. With a few minor improvements they would provide the ideal solution satisfying the research imperative and the didactic imperative.

The Issues at Stake

In fact, there was a consensus on both sides on the superiority of natural classifications. Even Thenard confessed that artificial classifications could be misleading because they favoured an "incomplete and sometimes false view of [chemical] facts."[44] He did not condemn the search for natural classifications. Ampère's essay was simply premature and natural classifications were the ultimate goal of chemistry. Artificial classifications were only transitional and provisional steps that would lead one day to the construction of a natural classification when chemistry is more complete. Similarly Victor Regnault, a professor and author of extremely successful textbooks, praised the natural classifications while advocating an artificial one. He summarised the debate in these terms :

> For the former [the advocates of artificial systems], bodies are arranged according to one single property, one single character; the classification can then be nothing but artificial; nonetheless it can be very useful if the chosen characteristic is one of the most important. By contrast, the other way of classification takes account of, and embraces, all the general properties of bodies ; it places them one next to the other depending upon the number of similar characteristics and the most important characteristics.[45]

The champions of artificial classifications defended their systems exclusively on the basis of pragmatic considerations and for want of anything better. Ironically they held natural classifications in higher esteem than their partisans since they considered the natural classifications as an ideal out of reach given the current state of chemistry.

In fact, on both sides, the pedagogical concern was a prime concern and became a key argument in the controversy. For instance, Despretz claimed that his natural classification was extremely advantageous for didactic purposes because it conveyed "general ideas" and "general relationships that were not showed by artificial classifications." It was especially suitable for elementary teaching because teachers had no time to describe all the characteristics of all substances and should only outline general features. Despretz did not doubt that the increasing number of chemical elements would lead to the replacement of artificial classifications by natural classifications.[46] On the other side, Thenard argued that students more easily learnt and memorised artificial classifications because they relied on one single character while natural classifications being based on several characters were much more difficult to grasp.[47] The critical point at stake was this: which of the two systems is best suited for chemistry teaching? If the pedagogical concern could balance the traditional ideal of classifications mirroring the order of things, would it be possible to admit two coexisting classifications: one for the purpose of investigation and one for the purpose of teaching?

Alexandre Baudrimont (1806-1880), a chemist and disciple of Ampère who made repeated attempts at a natural classification, was not far from reaching such a conclusion. As a lecturer at the *École spéciale de chimie*, a private institution that he established in Paris in 1835, he had considerable experience in teaching which convinced him that "the teaching of chemistry should aim at providing an understanding of the ensemble rather than at developing all its parts." Baudrimont was also an active researcher who ventured bold hypotheses on the arrangement of atoms within the molecules and tried to

[44] Ibid., 511.

[45] H. V. Regnault, "Recherches Relatives à l'Action de la Vapeur d'Eau à une Haute Température sur les Métaux et sur les Sulfures Métalliques. Essai d'une Nouvelle Classification des Métaux d'après Leur Degré d'Oxidabilité," *Annales de Chimie* 62 (1836): 337-388, on 337: "Suivant les uns, les corps ne sont rangés que d'après une seule de leurs propriétés, un seul de leurs caractères; la classification ne peut être évidemment alors qu'une classification artificielle, mais elle peut être cependant très utile, si le caractère que l'on a choisi est un des plus importants. L'autre mode de classification, au contraire, considère toutes les propriétés générales des corps, il en embrasse tout l'ensemble; il place les uns à côté des autres, les corps qui se rapprochent par le plus grand nombre de leurs caractères et par les caractères les plus importants."

[46] Despretz, *Élémens de Chimie*, vol. 1, i-ii.

[47] Thenard, *Traité de Chimie*, 6th ed., vol. 1, 511.

reshape the foundations of chemistry accordingly.[48] In his *Traité de chimie* published in 1844, he confessed that for many years he had tried to design a classification embracing all the properties of inorganic bodies whatever their origin. For this purpose he had assembled a lot of materials and had exposed the general principles of a natural system in his doctoral thesis defended at the Faculty of Medicine in 1839. He also remarked that Jean-Baptiste Dumas who was a member of the thesis committee had developed his principles. Nevertheless their attempts only demonstrated the huge amount of difficulties raised by a natural classification.[49] Baudrimont concluded that science teaching might well require an arrangement of the contents quite different from the one obtained by the "philosophical method":

> Philosophical methods are excellent to show the analogies of bodies by bringing them together in the most appropriate way in order to generalise and to get to know certain laws; but they are not always the best for teaching purposes. I have recognised for a long time that in order to be easily understood by complete laypersons it is best to start with things that are most familiar to them and in a short time give them a general idea of the whole of the science that they are studying. They are able to string the ideas which they acquire with they already have however popular they might be ; they thus understand the aim of the science; their imagination is satisfied because they follow the development of the new knowledge that they acquire.[50]

To be sure Baudrimont's classification was not particularly convincing. It was a complex, non-linear system, with fourteen series, that included some radicals like Hoefer's system and some elements occurring in several series. Baudrimont's system was based on his notion of "isodynamic bodies," meaning bodies that presented the same potential (*puissance*) for combination.[51] It should be noted that both Hoefer and Baudrimont were inspired by atomistic convictions. In reality, many attempts at natural classifications rested on the conviction that the nature and proportion of the elements no longer sufficed to determine the chemical behaviour and properties of the compounds. The

[48] On Baudrimont, see L. Mice, "Discours d'Ouverture ... (Éloge de Baudrimont)," *Actes de l'Académie de Bordeaux*, 3d. ser., 42 (1880): 729-766, and 44 (1882): 557-624; Myriam Scheidecker, "Baudrimont (1806-1880): Les Liens entre Sa Chimie et Sa Philosophie," *Archives Internationales d'Histoire des Sciences* 47 (1997): 26-56.

[49] Alexandre-Edouard Baudrimont, *Traité de Chimie Générale et Expérimentale avec les Applications aux Arts, à la Médecine et à la Pharmacie* (Paris: J. B. Baillière, 1844-46), vol. 1, 301.

[50] Ibid., 303-4: "Les méthodes philosophiques sont excellentes pour démontrer les analogies des corps en les réunissant de la manière la plus convenable, pour permettre de généraliser et même pour arriver à la connaissance de certaines lois; mais elles ne sont pas toujours les meilleures pour l'enseignement. J'ai reconnu depuis longtemps que, pour être facilement compris d'auditeurs complètement étrangers à une science, il était convenable de prendre un point de départ dans les choses qui leur sont les plus familières, et de leur donner, en très peu de temps, une idée générale de l'ensemble de la science qu'ils étudient. Ils rattachent facilement les notions qu'on leur donne à celles qu'ils ont déjà, si vulgaires qu'elles soient; ils comprennent le but de la science; leur imagination est satisfaite parce qu'ils suivent le développement des connaissances nouvelles qu'ils acquièrent."

distinction between atoms and molecules – whatever the names given to the two entities – and the arrangement of atoms in the molecules were to play a significant rôle.

The controversy raised by textbook writers thus seems to resonate with another controversy – more familiar to historians of chemistry – that divided the French chemical community between atomists and equivalentists.[52] Without pretending that the destiny of natural classifications was a consequence of the great retreat from atomism to equivalentism in the 1840s, it seems that the two issues overlapped.

Jean-Baptiste Dumas instantiates this link. In 1826, Dumas published a memoir "Sur quelques points de la théorie atomistique," where he developed a method to obtain accurate data on vapour densities that allowed him to determine the atomic weights of a number of elements. In this memoir, Dumas clearly stated that his goal was not only to ground the atomic hypothesis (meaning Avogadro's hypothesis) on positive data, but also to build up a "natural classification of simple bodies."

> By natural classification I mean a disposition of bodies in group founded on characteristics important enough for us to consider them as being capable of determining all the secondary properties. These characteristics are the various modes of combination of the body, its capacity for heat and the volume of its atom in the solid state.[53]

Dumas assumed that the "atomic volume" – defined as the ratio between atomic weight and density – together with the heat capacity and the "modes of combination," would provide the clues for a natural classification in which substances whose "molecules had similar properties" were grouped together. He thought that such a classification would make easier the study of chemistry and, at the same time, it would offer "fair analogies" leading to "the discovery of new compounds"

Two years later Dumas adhered to this program when he published the first volume of his *Traité de chimie appliqué aux arts*. He emphasised that, in some cases, groups of metals with similar chemical properties had almost the same atomic volume. However he soon noticed some exceptions and the hypothetical character of some of his conclusions. He consequently decided to follow

[52] Alan J. Rocke, *Chemical Atomism in the Nineteenth Century: From Dalton to Cannizzaro* (Columbus: Ohio State University Press, 1984); *The Quiet Revolution: Hermann Kolbe and the Science of Organic Chemistry* (Berkeley: University of California Press, 1993); *Nationalizing Science: Adolphe Wurtz and the Battle for French Chemistry* (Cambridge, Mass.: MIT Press, 2001.

[53] J. B. Dumas, "Mémoire sur Quelques Points de la Théorie Atomistique," *Annales de Chimie et de Physique* 33 (1826): 337-391, on 340: "J'entends par classification naturelle, une disposition des corps en groupes fondés sur des caractères assez importants pour qu'on puisse les regarder comme capables de déterminer toutes les propriétés secondaires. Ces caractères sont les divers modes de combinaison du corps, sa capacité pour la chaleur et le volume de son atome pris à l'état solide." See T. M. Cole, "Early Atomic Speculations of Marc Antonie Gaudin: Avogradro's Hypothesis and the Periodic System," *Isis* 66 (1975): 334-360, on 335-6. For Dumas's later attempts at chemical classifications, see van Spronsen, *The Periodic System*, 74-75, 85-87.

another path in order to establish natural families.[54] Dumas arranged non-metals according with the number of their atoms combined with hydrogen. He pointed out that substances grouped together in the former table shared "remarkable analogies": they formed compounds with similar properties when they combined with oxygen or hydrogen and some of these compounds were isomorphic.[55] Due to their conspicuous specific properties, Dumas placed carbon, nitrogen and oxygen as appendices to the genres of elements to which they bore more resemblance. The resulting classification is shown in Table 5.

Table 5: Dumas's classification of non metals[56]

1° Genre	Hydrogène
2°Genre	F, Cl, Br, I
3° Genre	Se, S, Appendice: O
4° Genre	P, As, Appendice: N
5° Genre	B, Si, Appendice: C

When he turned his attention to metals, in the second volume, Dumas insisted that their classification was even more important given their number and their practical applications. He considered various perspectives: one could classifiy metals according to their usefulness; or distinguish the yellow metals from the white metals, or fixed metals from volatile metals. From a chemical point of view; Dumas concluded, it is inacceptable to consider only one character. Without explicitly naming Thenard, Dumas rejected the principle of his artificial classification:

> Let us for instance classify metals according to their various relations with oxygen. This classification will be good for reactions where oxygen intervenes, but it will not be good in all the cases where oxygen is not part of the reaction.[57]

In Dumas's view, a natural classification of metals required an accurate study of their reactions with a large number of substances, so that metals sharing the "greatest number of common characters" could be placed in the same group. Even though Dumas acknowledged that such research had not yet been accomplished, he confidently stated that metals could be grouped "assez approximativement" with the scanty data already available. He thus presented a rough draft of a natural classification of metals in his second volume that consisted of a "first family" with "two sections": 1. potassium, sodium, lithium;

[54] J. B. Dumas, *Traité de Chimie Appliqué aux Arts* (Paris: Béchet jeune, 1828-45), 8 vols, vol. 1, xlv-xlviii.
[55] Ibid.
[56] From ibid., lxxvii.
[57] Ibid., vol. 2, 39.

and 2. barium, strontium and calcium. Dumas announced that this classification would be fully developed in his third volume. However nothing came after this optimistic first attempt. Quite surprisingly, when the third volume came out, in 1831, Dumas followed Thenard's model. He arranged metals according to their affinities for oxygen.

Here is a paradoxical situation: Dumas who was a staunch supporter of natural classifications finally made use of an artificial classification of metals in his textbook. Symmetrically, Thenard who was a staunch advocate of artificial classifications adopted Dumas's classification of non-metals in the last edition of his *Traité*.[58] Although he stated that "nature did not want to separate metals from non-metals," Thenard acknowledged the great difficulty to extend Dumas's approach to all the elements. His method suitable to classify sixteen non-metallic elements was not applicable to elements that did not combine with hydrogen. However Thenard believed that the time was not ripe to build up a natural classification of metals.

Thenard and Dumas, who initially advocated two alternative classifications ended up in agreement. They agreed that no sharp boundary could be established between metals and non-metals. Nevertheless in their textbooks they adopted two different systems of classification for these two categories of elements. They both recognised the superiority of natural classifications and their relationship with the atomic theory. Natural classifications were undoubtedly the future of chemistry as a science whereas artificial classifications came to be seen as provisional and imperfect tools. The leaders of the French chemical community thus developed the image of chemistry as an imperfect science far behind the ideal of a rational science deducible from one general law or principle. By contrast a number of more obscure writers of textbooks for secondary schools, medical students or industrialists stubbornly pursued the quest for a natural classification. Far from being the ideal of pure academic chemists, as opposed to teachers or applied chemists, the natural classification became the territory of many teachers and textbooks writers who did not easily renounced the ambitions of mirroring the order of things. Thus in this respect, elementary education textbooks strictly constrained by pedagogical rules appeared as more creative, more original and bolder than the higher education textbooks authored by the leading figures of French chemistry.

The Triumph of a Hybrid System

Victor Henri Regnault, who made original research on both physical and chemical topics, was also author of a number of very successful textbooks. In

[58] Thenard, *Traité de Chimie*, 6th ed., vol. 5, 516-518. Thenard discussed Dumas's criteria at length. He pondered the respective roles of atomic weight and electric conductivity. He noticed that the affinity for hydrogen decreased when atomic weight increased and concluded that in a natural classification there should be no borderline between metals and non-metals since there is a gradual and insensible transition between metallic and non-metallic properties. Following up on Dumas's program, Thenard suggested that more attention should be paid to metallic chlorides, considering them as analogous to hydrogenated compounds of non-metals.

:36, in the midst of the controversy between natural and artificial ıssifications, he published an article in the *Annales de chimie*.[59] At the outset, ·gnault appeared as a supporter of natural classifications. Not only did he ıphasise their superiority "from a philosophical perspective," but he strongly ›approved of the separation between metals and non-metals. He also dressed detailed criticisms at Thenard's classification, pointing out numerıs "anomalies." After such an hors d'oeuvre, one would expect an attempt at natural classification as the main dish. But Regnault set out to improve ıenard's classification. Like most of his colleagues he argued that it was emature to introduce natural classifications in chemistry and that artificial ıssifications could be useful provided the correct criterion were identified. ·gnault assumed that most anomalies of Thenard's classification should be duced and he launched a campaign of experiments to compare the ıctions of various metals on water vapour. He consequently introduced a ımber of important modifications in Thenard's system : arsenic and lurium were no longer included among the metals. This change ensured the mpatibility of his classification with Dumas's natural classification of non:tals, which included arsenic and tellurium in the phosphorus and sulfur oups respectively.

In fact Regnault's initial declarations in favour of natural classifications ·re mainly rhetorical since he never questioned the validity of Thenard's terion of the affinities for oxygen; he simply wanted to be more precise. In ; view, artificial classifications were not intrinsically imperfect because they ıgled out one criterion among the variety of parameters that determine the emical behaviour of individual substances. Indeed, his use of the term ıomaly" suggests that he assumed that a general law governed the intricate ıgle of chemical analogies. But the underlying order of things would not be veiled in an attempt to embrace all the chemical analogies at once. Rather : order would be gradually revealed through local experimental researches :used on one single property. In other words, his attitude suggests a choice tween two investigative strategies: either the quest of a general law of nature, e Newton's law, at the cost of local discrepancies with experimental data, this :learly the pathway that led Mendeleev to the periodic law in 1869; or more ›dest attempts at eliminating local anomalies in order to weave a robust twork of analogies and this is clearly Regnault's inclination.

Regnault's improved artificial classification coupled with Thenard's and ımas's institutional influence on the French system encouraged the :eptance of a compromise between natural and artificial systems. Such a mpromise is exemplified in Adolphe Dupasquier's textbook. A chemistry ıcher at the *Ecole de la Martinière* in Lyon, Dupasquier (1793-1848), declared ıt a natural classification was "the most logical." Yet it was impracticable not ly because of lack of data on a number of substances, but also because there s "an almost insensible passage from the properties of one body to

another."[60] All bodies being related by "a general liaison" it was impossible to distinguish groups of related elements.[61] Natural classifications were bound to fail, and Dupasquier claimed that the time had come for a compromise, a combination of natural and artificial classifications:

> All attempts to establish a good natural method having failed, and the adoption of a purely artificial method being little adapted to the classification of simple chemical bodies, we do not see any need to change the generally adopted division of these bodies into *metalloids* and *metals*, and the latter into classes and sections. Only we shall also create sections among the metalloids by combining the natural and artificial methods. We shall not present these divisions as essentially good, but only as very convenient to facilitate the study of these bodies.[62]

Dupasquier consequently adopted a natural classification for non-metals distributed in four groups: organogens (O, N, H, C), sulforoïds (S, Se, P), chloroïds. (F, Cl, Br, I) and boroïds (B, Si) while he planned to adopt Thenard's artificial classification of metals in the second volume that was never published.[63]

Most French chemistry textbooks published in the 1840s adopted such hybrid solutions. The compromise was indeed totally inconsistent since textbook writers formally criticised the separation between metals and nonmetals. But the hybrid solution was so to speak frozen in the official syllabus laid down in 1852 by Hippolyte Fortoul, the Minister for Public Instruction, who was responsible for the reform of the *baccalauréat*. The new syllabus was established by a committee set up on June 17 1852, chaired by Thenard and which included Dumas and Adolphe Brongniart among its members. The syllabus inspired by Dumas simply juxtaposed the natural classification of nonmetals and the artificial classification of metals.[64] The numerous chemistry textbooks published in the 1850s and 1860s were organised according to these official guidelines. There was no place for a discussion about natural or artificial classification. The question of the best arrangement to be used in textbooks was no longer debated in the forewords who simply referred the

60 Alphonse Dupasquier, *Traité Élémentaire de Chimie Industrielle* (Lyon: C. Savy jeune, 1844). The second volume was not published due to Dupasquier's premature death in 1848. See Amédée Bonet, *Éloge d'Alphonse Dupasquier* ... (Lyon: Imprimerie de Léon Boitel, 1849): 29-30.

61 Dupasquier, *Traité Élémentaire*, 60.

62 Ibid., 65-66: "Toutes les tentatives pour établir une bonne méthode naturelle ayant échoué, et l'adoption d'une méthode purement artificielle étant peu convenable pour la classification des corps simples chimiques, nous ne voyons pas qu'il y ait nécessité de changer la division généralement adoptée de ces corps en *métalloïdes* et *métaux*, et celle de ces derniers en classes ou sections. Seulement nous établirons aussi des sections parmi les métalloïdes en combinant la méthode naturelle et la méthode artificielle. Nous ne donnerons pas ces divisions comme essentiellement bonnes, mais seulement comme très-convenables pour faciliter l'étude de ces corps."

63 Dupasquier, *Traité Élémentaire*, 107.

64 [illegible] Belhoste, *Les Sciences dans l'enseignement Secondaire en France: Tome 1, 1789-1914* (Paris:

reader to the official syllabus. The modified syllabus promulgated in 1865 maintained the dual system with a chapter on "classification of metalloids in natural families" followed by a chapter "Metals in general. Their properties and their classification."[65] As some textbooks went through more than twenty editions, the generation educated in the decades of the mid-nineteenth century had no reason to be aware of the existence of a controversy about classifications. The hybrid solution became conventional to the extent that it now seemed "natural." It undoubtedly nurtured the public view of chemistry as an imperfect science, a poor relative of physics, far behind in the hierarchy of rational sciences. The quest for a natural classification was so far beyond recall that even when Mendeleev's periodic system was introduced in chemistry teaching by a minority of French professors it did not overthrow the hybrid solution. In Edouard Grimaux's lectures for instance, the periodic system was not perceived as "the" answer to the longstanding quest for a classification of elements. Rather it was presented as a confirmation of the atomic theory and used as a weapon against the equivalentist school.[66]

Should we conclude that textbook writing is not a creative activity? This case study leads to surprising conclusions. Undoubtedly, the increasing number of textbooks published in the nineteenth century brought the issue of a system of chemical elements to the forefront as they required an order convenient for didactic purposes and at the same time which mirrored chemical analogies. As long as textbooks were the expression of the individual experience of a teacher-writer rather than the end product of an official syllabus, the classification of chemical elements remained an open problem whose solution would require the mobilization of all possible resources of chemistry. In this respect, the most creative books were not necessarily the great treatises written by creative academic chemists. Obscure chemistry teachers, who were not necessarily active in scientific research, attempted innovative and ambitious systems of elements in order to satisfy both didactic and scientific constraints. Textbook writing remained a creative activity, if by creativity we do not necessarily imply innovation, or great discovery. They were creative in a more modest way as they expressed original and ambitious interpretations of the foundations of chemistry.

[65] Ibid., 391-407.
[66] F. Grimaux, *Introduction à l'Étude de la Chimie* [illegible]

AMBIX, Vol. 49, Part 3, November 2002

REVIEWS

The Structure of Knowledge: Classifications of Science and Learning Since the Renaissance. Five lectures deliv-ered at the International Summer School in History of Science, Uppsala, 1998. Edited by TORE FRÄNGSMYR. Pp. i + 158, illus., index. Office for History of Science and Technology, University of California: Berkeley. 2001. $25.00. ISBN: 0-9672617-1-6.

It is almost impossible to say in few words something useful about an intelligent and instructive collection of papers. So mere hints as to the contents of the papers must suffice. The first one of these, "Building the house of knowledge: The structures of thought in late Renaissance Europe" by Paula Findlen, is the heavy-weight among the papers, both in length (48 pages) and in scope. It is a brilliant tour de force in which the author shows the intricate relationship between the intellectual contents of the new or restructured sciences and their representation in theatres, gardens, models, collections, and commonplace books. Building the house of knowledge was not at all a naive endeavour meant only to support the quest of knowledge in nature, it was itself a quest and an effort to rebuild the world in the world. Paradoxically, building the house of knowledge as an effort to acquire and to transfer knowledge by widening its realm, helped to destroy the very building it tried to erect. There is so much more to say about the paper, for instance, about the relation of the ancient idea of the encyclopaedia and the Renaissance attempts to structure all knowledge, about the relationship between the real and the imagined in the world picture of the Renaissance (I would have liked to learn a little more about it), and about the different styles of ordering the world: in astronomy, in medicine etc. It must be enough though to recommend the paper to all historians of Renaissance science.

A new and very interesting point of view is presented in Robert Darnton's paper on "Epistomological *Angst*: From encyclopedism to advertising". Darnton not only shows how Diderot's great project of the *Encyclopédie* by "rearranging categories and realigning borders" (p. 64) for instance in respect to the place of religion in the canon of knowledge served as a propaganda tool for the *philosophes*, he also makes clear how the pressure of publishing and republishing became instrumental in rearranging the order of the *Encyclopédie*, distorting Diderot's original intentions.

The paper on Linnaeus by Tore Frängsmyr, who edited the volume and added a useful introduction, presents the great and almost compulsive classifier, who "showed how logic could bring order to empirical findings" (p. 88) as a creator of a scientific tradition in Sweden that reached through the generations to the leading Swedish scientists of the twentieth century.

The paper by Nicolaas Rupke on "Humboldtian distribution maps. The spatial ordering of scientific knowledge" also has something new to offer. Rupke's notion that in the wake of Humboldt's travel accounts the preoccupation with "the spatial distribution of natural phenomena" (p. 93) characterised the 19th century, is well documented. Equally well documented, if not very surprising, is his observation that geography usually had its starting place and its basis of interpretation in the home countries of the respective geographers. But the strange notion of Guyot — which was new to me — that [illegible] of Europe in proportion to its size proves the