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Chemistry as a technoscience?

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It is a common complaint that the philosophy of chemistry has been neglected in mainstream twentieth-century philosophy of science and that philosophers' views have been distorted by an undue attention to theoretical physics.
For instance Joachim Schummer used today criteria for the evaluation of scientific activity to point out a paradox : Chemistry is by far the largest scientific discipline in terms of the number of publications indexed by the major journals of abstracts. Nevertheless there are few philosophical studies of chemistry compared to other scientific disciplines. Thus, twentieth-century philosophy of science virtually ignored the major part of scientific activity. "Had those philosophers without prejudice gone into the laboratories, Schummer noticed, then they would have stumbled on chemistry almost everywhere".[i]
This reasoning was meant to emphasize the prejudices which oriented the philosophers' attention towards theoretical issues and the subsequent increasing gap between philosophical reflection and science in action.

It is for similar purposes that the Belgian philosopher Gilbert Hottois coined the term 'technoscience' in the late 1970s. He sought to alert philosophers that by confining themselves to the analysis of language and logic they were blind to the dramatic changes going on in the world around them.[ii] The term technoscience was meant to emphasize not only that technological applications were a prime mover of scientific research but also that a lot of technology is embedded in science.[iii]

The similarities between the two polemical charges against "the linguistic turn" in twentieth-century philosophy of science invites to look further at the rapprochement between chemistry and technoscience. *To what extent the identity of chemistry could be reconfigured as a technoscience?*

Obviously the answer to this question requires a precise definition of the rather loose concept of technoscience. However there is nothing like a standard and consensual definition of this term, which could be referred to and be confronted to a standard definition of chemistry. I will consequently refer to different definitions of technoscience – from the weaker to stronger notions. Finally I will argue that the problem has to be turned inside-out and is better addressed as: *To what extent the emergence and fashionable uses of the notion of technoscience over the past three decades did change the identity and the status of chemistry*. In other terms, the concept of technoscience will help me to emphasize the changes occurred both in the philosophical perspectives on chemistry, and in the practices of chemistry.

This attempt relies on a presupposition that should be clarified from the outset : that there is no fixed, transhistoric identity of chemistry. The view of chemistry as a historical construction, continuously reconfigured by the contexts of its practices, is one major result of the *History of Chemistry* that I co-authored with Isabelle Stengers.

1) Technoscience as interaction of science and technology/

In 2005 two issues of the journal *Perspectives on Science* applied the concept of technoscience to chemistry in a discussion of the "technoscientific productivity" of experimental sciences. For instance Ursula Klein argued that 17th and 18th century chemical research was technoscientific *avant la lettre*.[iv] And Hans-Jörg Rheinberger claimed that the notion of "phénomenotechnique" that Gaston Bachelard forged to characterize 20th century physics and chemistry was a precursor of technoscience.[v] The inclusion of chemistry in the extension of the concept of technoscience was based on the following definition of technoscience as "firstly, the alliance of modern science, technology and industry; and, secondly, the technical shaping and production of scientific objects within the experimental sciences ».[vi] In this view chemistry is a technoscience for two major reasons: because of its dual face as science and technology and because there is a lot of techniques embedded in experimental practices.

Among other advantages this perspective is interesting because it broadens the scope of the the history and the philosophy of chemistry.

1) Historical studies: In the early twentieth century historians of chemistry evaluated the advances in chemistry from the standpoint of the standards and values of physics.
- standard view : The emergence of modern chemistry was described as the result of the adoption by chemists of atomic and mechanical theories. Hélène Metzger for instance argued that alchemy was defeated by Cartesian corpuscularism.[vii] Most historians of chemistry considered alternative theories based on qualitative principles and elements as « errors » that had to be overcome.
- Revisions of the standard view: In paying attention to laboratory procedures Lawrence Principe, William Newmann gave an alternative account of the transition between alchemy and modern chemistry: not only many principles and practices characteristic of modern chemistry were already familiar to alchemists but also "chymists" had a way of their own to get out of the scholastic paradigm and embrace experimental philosophy.[viii]

- The historiography of the chemical revolution centred on Lavoisier's theoretical achievements by Henry Guerlac and his followers was divorced from the study of the chemical revolution that occurred in technological modes of production as described by Clow and Clow.[ix] So different were the stories told by historians of science and historians of technology that one could believe that there were two radically different cultures of chemistry in the eighteenth-century.
This view has been radically changed by historians of chemistry such as Larry Holmes who reacted against the privilege of matter theories and emphasized the role of the laboratory practices.[x] Taking seriously the painstaking laboratory work which conditions the production of chemical knowledge, Holmes developed new perspectives on eighteenth-century chemistry.[xi] No longer was it centred on phlogiston theory – its triumph and defeat by Lavoisier. It was a flourishing experimental science with a collective investigative pathway and a conceptual framework of its own.
- More recent historical studies on the pedagogical practices of chemistry in the eighteenth-century confirm the intricacy of academic culture and craftsmen practices.

2) Philosophical studies: Historians of chemistry are venturing new philosophical perspectives: For instance Ursula Klein and Wolfgang Lefevre *Materials in Eighteenth-Century Science: A Historical Ontology,* bridges the gulf between the history of chemical science and the history of chemical technology by focusing on materials rather than on heroic figures.[xii] Materials are rightly defined as 'boundary objects' connecting academic science and craftsmen cultures. The authors remind us that laboratory science produces artefacts. They remarkably emphasize that 18th century chemistry belonged to "experimental history", and developed techniques for identifying and tracing material individuals, or "pure substances", out of necessity for daily practices.

2) The shift from the linguistic turn to the practical turn has hardly begun in the philosophy of chemistry. Only recently philosophers did timidly broaden the scope of the philosophy of chemistry beyond the traditional issues of the theoretical foundations of chemistry in quantum theory and reductionism. In the collective volume published in 2006 by Davis Baird, Eric Scerri and Lee McIntyre only one third of the volume deals with the traditional issues.[xiii] The attention has shifted to actual practices displayed by chemists: such as computer-aided process design, molecular imaging and electron microscopes.
The appropriation of physical instruments by 20th century chemists and promotion of their own instrumental culture sheds a light on the chemical ways of measuring and theorizing.[xiv]
It is important in my view to further broaden the scope of the philosophical studies of chemistry and to expand it to industrial or agricultural practices of chemistry.

So chemistry can be approached as a technoscience if the internalization of technology in its investigative practices and its dual face as pure and applied science are fully taken into account.

2 Technoscience as impure science: a polemical notion

2.1: Nevertheless technoscience is not just a mixture in various proportions of two ingredients, science and technology. Just as a mixt is something different from the sum of its components, technoscience is something different from both science and technology.
"Technoscience" is an alternative to "science and technology" with its assumption of two distinct but interacting spheres. 'Technoscience' is a not a neutral descriptive term. It is not a disciplinary label that would refer to a subset of the sciences.
Bruno Latour used the term in *Science in action* as shorthand for a fusion of "science-and-technology," that is, as a hybrid where the two cannot be separated out from one another in terms of basic and applied research (Latour, 1987). For Latour and in a rather different way for Dona Harraway, the concept of technoscience points to the **true face of science** once the complex alliances between human and non-human actors, nature and society are acknowledged. The notion applies to the construction of scientific objects as well as technological objects by a multitude of heterogeneous actors "no matter how dirty, unexpected or foreign they seem".[xv] This concept is meant to deconstruct the purified image of science, as a purely cognitive, autonomous, disinterested, enterprise.
2.2: Chemistry the impure science
- The polemical charge of technoscience provides a useful tool to describe chemistry as an "impure science". In the volume that I co-authored with Jonathan Simon *Chemistry the impure science* we made a strong argument for the philosophical interest of chemistry based precisely on the fact that it is an 'impure science'. It is impure not just because it pollutes air, contaminates soils and poison rivers. It is impure because it challenges the purified image of

science. Its epistemological specificity and its ontology are closely associated to its "impurety".

a) The epistemology of chemistry can be adequately defined by the phrase "knowing through making". Laboratory chemical practices are not just aimed at testing preconceptions or theoretical hypotheses. Chemists do not use the mediation of instruments to understand natural phenomena, like experimental physicists do.

The laboratory determines the object of chemical investigation. Chemists have always use the detour of the laboratory to access nature. Only man-made, artificial products provide information about natural substances. As the etymology of the term (coined by chemists) reminds us, the laboratory is a place of labour, of manual work rather than of inductive or deductive reasoning. The knowledge of nature can be obtained only at the cost of painstaking experiments[xvi]. Whatever the importance of chemical theory, chemistry is first and foremost concerned with making.

b) Theories are narratives of experiments Making is the chemists' major activity, the major part of the work found in academic publications.[xvii]. And it is both a material practice and an intellectual practice. Roald Hoffmann wrote that chemists are "making up stories" about what they are doing with their hands and flasks. Chemical theories, unlike theories in physics, are not really aimed at explaining phenomena. Chemists are not primarily interested in clarity and distinctness, and do not hold consistency to be a very high value. Just as early-modern hooked and spiny atoms were a "Cartesian novel", modern electronic orbitals could be regarded as a "**quantum novel**".. Rather than being ideal accurate representations of nature, theoretical narratives display meanings, with atoms and molecules best described as **actors** in a story. Even when these invisible entities are visualized using imaging techniques, they do not mirror the ultimate reality underlying phenomenological appearances, although they do *mean* something for the chemists. In certain cases they may mean that there is a possibility of breaking a bond, or of substituting a functional group or of encapsulating certain atoms within a cage molecule, etc. In addition stories require a temporal structure: temporality plays a prominent role in chemical narratives as the kinetics determines whether the reaction will be a success story or not.

c) operational realism The ontology of chemistry should be re-examined accordingly. The traditional realism/positivism debate is not adequate to chemistry. Rather than framing the debate in terms of the question 'what can one know?' it might be better to pose the question 'what can one do?' and then examine the ontological consequences. I suggest the term "operational realism" to emphasize that chemists do not claim to represent the real structure of material substances. They rather aim at identifying specific dispositions for operations. They are interested in capacities and believe in the reality of their agencies. Operational realism is akin to Hacking's "entity realism" but should be extended to abstract concepts such as elements as well as concrete entities.

So chemistry can be redefined as a technoscience in the Latourian sense of the term as a science which is indifferent to the ideal of purification that defines "science" in the singular.

3**. Technoscience as an ideal type**

3.1. Value-laden : It is not sufficient however to present chemistry as an alternative to the ideal type of science. Technoscience is not just a polemical notion used by social scientists to deconstruct the mythical image of science, it has become an ideal-type in itself.

The historian of science Paul Forman defines technoscience as a reversal of the values attached to science (Forman, 2007). Whereas modernity was characterized by the high cultural rank of science and scientists – " the primacy of science to and for technology" –, post-modernity is characterized by the primacy of technology over science..

Without endorsing Forman's view of an epoch-making inversion or transmutation of values this perspective is interesting because it suggests that the definition of technoscience includes not only the actual hybridization of science, technology, commercial and industrial interests but also a new ideal of scientific practice where epistemic values (such as truth, simplicity, etc) are **explicitly** challenged by non-epistemic values such as social robustness, social & economic relevance and sensibility to environment.

As approximations of this new ideal-type of value-laden sciences, one can think of Materials Science and Engineering, of genomics or nanotechnology. They are all hybrid of science and technology, they are presented as potential solutions to all kinds of societal, environmental and economic problems. Far from being neutral they are presented as serving certain values such as durability, human enhancement or solidarity…

In addition they result from the convergence of various disciplines: physics, chemistry, biology, informatics, and others. Today chemists are working in multidisciplinary research groups and they play a crucial role in materials and nanotechnology research. But such collaborations may seriously impact on the disciplinary identity of chemistry and consequently undermine the project of a philosophy of chemistry as a discipline.

3.2 Changing practices

Through their collaborations with other specialists in multidisciplinary projects chemists have significantly change their practices. In particular their *linguistic practices*. The term "material" is more and more fashionable and has displaced the traditional term "substance". The phrase « molecular machine » which has been popularized by the pioneers of nanotechnology is now appropriated by chemists who had designed exotic "molecular architectures", for instance catenanes and rotaxanes.

Such vocabulary changes may be symptoms of more radical philosophical changes. In adopting an engineering view of nature, chemists less and less consider the periodic table as a foundational system and tend to look at it as a practical tool-box, a kind of department store where to find materials and devices. In Rom Harré's terminology one could say that the periodic system charts 'affordances' rather than simple 'dispositions'.

3.3 the chemistrisation' of biology

But concepts and models do not travel one-way. In the convergence of disciplines chemistry may be seen as a model science for renewing biology. Synthetic biology, an emerging discipline aimed at engineering living organisms can be seen as a modern replica of nineteenth-century synthetic chemistry. Molecular biology and genome sequencing would thus be considered as a kind of analytical biology which paved the way for the emergence of synthetic biology.[xviii] In their attempt to move beyond the limits of descriptive biological science, synthetic biologists have adopted the epistemological style of chemists: they express their credo in knowing through making through repeated quotations of Richard Feynman's alleged words "What I cannot create I do not understand". .

3.4: Resilience of disciplinary identity

Although disciplinary identities are changing in current transdisciplinary research programs, so far the disciplinary identity of the chemical community proves extremely resilient. Chemists engaged in Materials Science or nanotechnology clearly express a feeling of belonging to the chemical tribe. One of them once nicely expressed his belonging with the help of a chemical metaphor: "Weak van der Waals bonds attach him to MSE while he is linked to chemistry by strong covalent bonds"

Most unexpectedly MSE biotechnology and nanotechnology seem to revive great ambitions for chemistry. Leading figures of chemistry such George Whitesides and Jean-Marie Lehn deliberately drop the positivistic attitude of prudence that characterized nineteenth-century chemistry and are addressing big metaphysical questions. Far from confining their work to the production of useful materials, they want to expand their area of competence to questions such as the origin of life and even the origin of consciousness.[xix]

Conclusion

The philosophy of chemistry can no longer ignore that chemistry is a technoscience at least if this concept is taken in two different meanings.

Those who stick to the weak meaning of technoscience as the close interaction of science and technology will describe chemistry as an exemplar "phenomenotechnique" and as a model utilitarian science.

Those who are more inclined to adopt the Latourian demystifying meaning of technoscience, will describe chemistry as an impure science, challenging the canons and moral economy of the ideal of pure science, which has attracted the attention of philosophers for too long. Describing chemistry as an impure science is in fact denouncing the irrelevance of mainstream philosophy of science since WWII. They will call for a profound re-thinking of the curriculum of philosophy of science courses around the world.

Finally those who tend to consider technoscience as an alternative ideal promoting value-laden, targeted, and transdisciplinary research will come to conclusions with an additional problem to address. Yes chemistry will help reform the entire field of the philosophy of science because it is closer to the new ideal-type of knowledge society than many other disciplines. Most of its characteristic features such as "knowing through making", the emphasis on "operations", and the "ontological indifference[xx]" seem to permeate through a variety of research fields. The relevance of a disciplinary approach of the philosophy of science should no longer be taken for granted : it becomes an issue in itself. How are we to understand the chemists' claim for a strong disciplinary identity for their strong attachment to their ideal of disciplinary identity ?

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[i] Schummer, 2006, "The philosophy of chemistry. From infancy toward maturity, in Davis Baird, Eric Scerri and Lee McIntyre eds , *Philosophy of Chemistry, Synthesis of a New Discipline,* Springer Verlag, pp. 19-39, on p. 21.

[ii] Hottois Gilbert, « La technoscience de l'origine du mot à son usage actuel » in J.Y. Goffi éd. *Regards sur les technosciences*, Vrin, Paris, 2006, pp. 21-38.

[iii] Gilbert HOTTOIS, *Le signe et la technique. La philosophie à l'épreuve de la technique*, Aubier, Paris, 1984. p. 60-61.

[iv] Klein, U. (2005): "Technoscience *avant la lettre*" *Perspectives on Science,* 13, Summer 2005, 226-266.

[v] Rheinberger H.-J. Gaston Bachelard and the Notion of 'Phenomenotechnique', *Perspectives on Science*, 13, 3, Fall 2005, 313-328.

[vi] Klein Ursula, « Introduction : Technoscientific Productivity » *Perspectives on Science,* 13, Summer 2005, 139-141, on p. 139.

[vii] See for instance D.L.S. Cardwell ed., *John Dalton and the Progress of Science*, Manchester, Manchester University Press, 1968. Siegfried, Robert, *From Elements to Atoms, A History of Chemical Composition*, Philadelphia, American Chemical Philosophy, 2002.

[viii] William Newmann Lawrence Principe, *Alchemy tried in the Fire, Starkey, Boyle and the Fate of Helmontian Chymistry*, Chicago, The University of Chicago Press, 2002.

[ix] Guerlac, H. (1961) Lavoisier- The crucial Year: The Background and origin of his First experiments on Combustion, in 1772 , Ithaca, New York, Cornell University Press. Clow, A.&.N. (1952)The chemical revolution: A contribution to social technology , London.

[x]Holmes,F.L. "La chimica nell'eta dei Lumi" in *Storia delle scienze Natura e Vita*, vol. 3, *Dall'Antichita all'illuminismo*, Torino, Giulio Einaudi, 1993, p. 478-525. "The problems and objects of study of chemistry have been provided by and limited by the operations that could be performed on materials in a chemical laboratory […]. As theoretical structures changed and new objectives

supplemented or displaced older ones, the stable setting of the chemical laboratory both identified chemists and distinguished them from other natural philosophers who dealt with some of the same phenomena that concerned them." Cit. P. 478.

[xi] Holmes, *Eighteenth-Century Chemistry as an Investigative Enterprise*. Berkeley: Office for the History of Science and Technology, University of California,1989.

[xii] Ursula Klein and Wolfgang Lefevre*, Materials in Eighteenth-Century Science: A Historical Ontology,* MIT Press, Cambridge, Mass, 2007.

[xiii] Davis Baird, Eric Scerri and Lee McIntyre eds , *Philosophy of Chemistry, Synthesis of a New Discipline,* Springer Verlag, 2006

[xiv] Reinhardt, Carsten (2006) Shifting and Reappraising. Physical methods and the Transformation of Modern Chemistry, Dagamore Beach, Science History Publications.

[xv] Latour, Science in Action, 1987, p. 174.

[xvi] Van Helmont, J.B. De febribus, Opuscula chap. 15, N°26, p. 58 quoted in Newman & Principe, 200, p. 180.

[xvii] Joachim Schummer's survey of 300 papers on synthesis from 1980 to 1995 concluded that most of them were aimed more at syntheses rather than at classification or theoretical reflection (Schummer, 1997).

[xviii] See Yeh Brian J., Lim Wendell A. (2007) "Synthetic Biology: Lessons from the history of synthetic organic chemistry", *Nature Chemical Biology*, 3:521-525. B. Bensaude-Vincent, "Synthetic biology as a replica of synthetic chemistry? Uses and misuses of history », *Biological Theory* 4(4) 2009, 1–5.

[xix] Philip Ball, 'What chemists want to know' *Nature*, **442/3**, August 2006: 500–502, on p. 501.

[xx] This phrase is used by Peter Galison to characterize technoscience. Ref???