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CHEMISTRY, SOCIETY AND UNCERTAINTY

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Abstract. Over the last years, besides the increased interest in philosophy of chemistry, we have also witnessed a "material turn" in philosophy and the history of sciences with an interest in putting instruments, objects, materials and practices at the core of historical reports. Since its alchemic past, chemistry has always worked with and on materials, so that its history is a "material history" as well. Thus, in the wake of this "material turn", it is up to philosophy and the history of chemistry to perceive the chemical substances, the chemists that create them and the industries that produce them as part of the culture, of society and of politics. This overlap between chemical reasoning and materiality as well as the artificial character of its products makes chemistry an eminently technoscientific science. In this context, we will analyze, firstly, the most general aspect that led us to identify it as "technoscientific", the hybrid that exists between chemistry and society. With that, we intend to argue in favor of considering the modern societal necessities (material, environmental, and human) *with* chemistry, in an effort to build a more harmonious relationship, being that it will be long and, maybe, indissoluble. Following that, our aim is to develop a concept that can not be separated from the capillarity of chemistry in societies and in the environment, the imprevisibility and essential uncertainty of the behavior of chemical entities in multiple contexts. Finally, we will highlight some reflections concerning chemical ethics associated with the production and creation of new substances that may become a part of the lifeworld.

Keywords: chemistry • society • values • technoscience

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1. Introduction

Over the last years, besides the increased interest in philosophy of chemistry, we have also witnessed a "material turn" in philosophy and history of sciences with an interest in putting instruments, objects, materials and practices at the core of historical reports. Since its alchemic past, chemistry has always worked *with* and *on* materials, so that its history is a "material history" as well. Thus, in the wake of this "material turn", it is up to philosophy and the history of chemistry to perceive the chemical substances, the chemists that create them and the industries that produce them as part of the culture, of society and of politics. Materials have shaped chemists and their science by stimulating the foundation or the reorganization of disciplinary fields, epistemic communities, sets of tools and instruments, cognitive representations and experimental practices. As a result, there is a co-construction of the chemical subject and the object of chemistry. Besides, new materials and their chemical compounds help give rise to new behaviors in society, such as the reconfiguration of consumption habits concerning the ever-growing number of synthetic materials used in commercial products. Over the last two centuries, chemists and the chemical industry have begun performing, to a certain extent, the role of architects, both in terms of matter and in terms of society (Teissier *et al*. 2017; Werrett 2019). Therefore, the material entities that the chemists have produced and produce are participators both of human history and of our planet's history. Consequently, we can consider that new materials and social configurations guide chemists in their effort to move forward with some matters of investigation while neglecting others. In such a way that the products of chemistry integrate, besides cognitive values that are pertinent to the field, economic interests, and demands of a social, medical, military or environmental nature (Lacey 2008, 2 v).

Does this overlap between chemical reasoning and materiality as well as the *artificial* character of its products make chemistry an eminently technoscientific science? The chemical knowledge certainly has a distinctive particularity, because its *locus* lies between science and technology, theory and practice, abstract and concrete. It does not find its provenance only in the conceptual framework, on the contrary, it has its roots in the baconian Maker's Knowledge Tradition, of artisans and craftsmen. However, if we consider chemistry to be technoscientific, we must establish that it is not only about identifying the existence of a predominance of technology over pure science and the orientation of scientific research in favor of specific social sectors. It is a question of a more precise sense, that chemistry has always been a hybrid between science and technology, without making the former a subordinate of the latter. Contemporary chemistry certainly contributes to technoscientific investigations that are out of context, in the sense that it produces instruments, new objects and structures with the goal of achieving practical, industrial, medical or military innovation. Thus, in their most general aspects, the science of chemistry and its industry are, without a doubt, intimately associated with the ideals of scientific and technological progress, which submits them inexorably to the interests of the capital and the market.

Yet chemistry is a scientific activity that, historically, has never separated what Bruno Latour defines as the "inside" (the laboratories) and the "outside", which covers everything from the process of recruiting new professionals to the promotion of specific research or yet, the social assimilation of its products (Latour 2003, cap.4).

Thus, we will consider chemistry as a technoscience only with the purpose of highlighting its hybrid characteristics. It deals with knowledge concerning the material world, which emerges from complex interactions between science and technology, laboratories and the industry, nature and society. Chemistry, then, represents an emblematic case of the manner in which Hugh Lacey sees the term "technoscience", meaning it creates the objects themselves that it investigates, at times for technological innovation (medical, agricultural. . .), though there is no concrete separation between science and technology but a dynamic interaction between them (Lacey 2012).

More precisely, when attributing a technoscientific character to the construction of the chemical science and its industry, we seek to highlight, above all, its transgressive nature. We can identify this transgression phenomenon according to three perspectives. From an anthropological point of view, chemistry defies the great divisions of our culture, such as the ones between natural and artificial, nature and culture, the inert and the living, the pure and the impure. From an epistemological point of view, chemistry equally defies the division established between science and technique, between making and knowing, between representing and intervening. Finally, from an ontological point of view, besides manipulating material entities that are already known, chemists create new ones, defying the division between realism and positivism as well (Bensaude-Vincent 2005, p.255s). The ontology of these material objects is made explicit from things chemists consider to *exist* and that allow them to *act*, which also demands identification and classification. In this outlook, the work *about* and *with* material entities bring chemists closer to what Ian Hacking classifies as "entity realism", while pushing them farther away from a "theory realism" as well as "metaphysical realisms" (Hacking 1997). These transgressions reinforce, thus, why it is pertinent to view chemical knowledge as technoscientific. Besides, analyses of the implications of this "techno chemistry" are fundamental not only within the boundaries of philosophy and history of chemistry, but also for a substantial improvement in pedagogical models applied in teaching both subjects (Chamizo 2013).

By associating the chemical science to technoscience and to the study of certain kinds of material entities (elements, ions, molecules) we also avoid proposing a general definition of "what chemistry is". After all, the definitions of chemistry vary in space and time, in such a way that there is no definition of chemistry that is capable of embracing the research made by chemists (and alchemists) throughout history. Nevertheless, we would like to point out that we postulate here a general thesis about the cognitive identity of chemistry. It is a case of admitting that the relations of chemical entities and their properties are the result of a material *emergence*. Here, we keep in mind only that in the emergentist perspective the properties of a specific level of materiality, though derived from an inferior level, are exclusive to this level. Even if chemical properties emerged from a more basic physical universe (subatomic), this did not imply that they were reducible to the properties of these physical entities, much less to the even more basic propositions such as the ones from Mathematics. Finally, we consider that this perspective allows for a solid justification that chemistry is an autonomous science both in epistemological and ontological terms, being that emergentism admits an ontological and epistemological pluralism. Therefore, chemical entities, chemical bonds or molecular orbitals exist within an ontological and epistemological scope pertaining to chemistry (Labarca & Lombardi 2010; Llored 2013; Lewowicz & Lombardi 2013).

In this article, we intend to analyze three aspects of this technoscientific science and some of its products. Firstly, our objective is to treat the more general aspect that led us to identify it as technoscientific, the hybrid that exists between chemistry and society. With that, we intend to argue in favor of considering the modern societal necessities (material, environmental, and human) *with* chemistry, in an effort to build a more harmonious relationship, being that it will be long and, maybe, indissoluble. Following that, we develop a concept that is inseparable from the capillarity of chemistry in societies and in the environment, the imprevisibility and essential uncertainty of the behavior of chemical entities in multiple contexts. Finally, we will highlight some reflections concerning chemical ethics associated with the production and creation of new substances that may become a part of the lifeworld.

2. Chemistry and Society

Chemistry and its products capillarize permanently in contemporary societies and in natural environments. The occupation of the world by products from the chemical industry reached new heights during the 20th century, with ever-growing demand, both from society in general and the military apparatus. If coal, wood, cast iron and steel continued to be the most used materials in the civil society, new materials came onto the scene, like aluminum and other light metals, rubber (natural and synthetic), synthetic polymers (such as plastics and elastomers), ceramics, silicon or even composites and hybrid materials. The synthetic polymers derived from oil, for instance, are certainly some of the materials that contribute the most for the human “presence” in our biosphere. Created in the laboratories of chemists and produced by the chemical industry, they are present in the vast majority of objects we use in our daily lives. Light, cheap and resistant, these synthetic materials have progressively substituted traditional materials and have become the symbol of modernity over the last few decades. They are essential to the contemporary way of life, an important creation of chemists, a proof of the ingenuity of engineers, industrial designers, metallurgists, architects, and at the same time, a real threat to the natural environment, maybe without precedent. Chemical substances must be considered, then, as hybrid bodies between nature and society.

This capillarization, which intends to represent social progress generates, thus, uneasiness and serious preoccupations as well. Part of the social wariness with regard to chemistry and its industry comes from its association to pollution. It was in Great Britain that pollution was consolidated as a side effect of the Industrial Revolution and the urbanization of cities, becoming an object of scientific research. That is how the effect of pollution in the atmosphere caused by burning coal was determined, and a conclusion was reached that the gases being released were the cause of a new "natural" phenomenon, called "acid rain", in addition to being the cause of respiratory ailments. Some laws were enacted, such as the one that limited, for example, the burning of coal in an urban setting and the one that regulated the production of alkaline and acid substances, whose manufactures was considered by neighboring populations as the cause of destruction of environments such as rivers and forests, which were until then seen as collective goods (Thorsheim 2017).

But this weariness has certainly been justified also by the countless accidents caused by chemical products. In fact, chemistry and danger are inextricably linked. The social demands for the establishment of protocol regulation aiming to protect workers in chemical industries, its environmental and human surroundings, as well as the consumers, are beneficial. But it is necessary to leave aside the illusion that all risks are controlled. That is because accidents are ordinary in chemistry, incorporated in the substances we manipulate and which resist complete domestication. Throughout the 20th century, over 30,000 accidents or incidents were documented all around the world (Bensaude-Vincent 2020, p.294). The last one to date (2020) devastated the port and part of the city of Beirut, Lebanon, having been provoked by ammonium nitrate, fundamental for the manufacture of fertilizers, but with known explosive properties. Therefore, better than fantasizing with zero-risk, it is necessary, besides maximum prevention, to promote research that can anticipate the reparation of the consequences of accidents, which can occur at all times.

The conventional response to the apprehension and the negative image of chemistry in the public eye, seen by the field professionals as distorted, has been to point out its benefits and the need for teaching the discipline, coupled with the promotion of its feats and achievements. This approach for promoting the science of chemistry generally sees the public as students waiting to be taught about what is best for them, without bearing in mind the real concerns and wariness of said public. As an example, we can think of the objectives set by UNESCO on occasion of promoting the International Year of chemistry, in 2011: increase the public appreciation and understanding of chemistry in meeting world needs; encourage the interest of young people in chemistry; generate enthusiasm for the creative future of chemistry; celebrate the role of women in chemistry or major historical events in chemistry, including the centenaries of Marie Curie's Nobel Prize and the founding of the International Association of Chemical Societies (Unesco 2011). However, commending its utilitarian aspects, fundamental for the contemporary way of life, and its importance for the scientific progress man has reached, though necessary, does not seem to reduce public distrust, much less to promote the cognitive and social values incorporated in chemical knowledge (Schummer; Bensaude-Vincent & Tiggelen 2007).

Certainly, lack of knowledge of chemistry and the philosophical reflections concerning this science have been a larger obstacle to advance the public debate about its products. We are not as rude with chemistry when tasting ice cream, chocolate or other delicacies from a bakery. For instance, we rarely realize that the desserts which we describe in generic terms as "ice cream" have a history, for consumption of ice cream was popularized from chemical substances which started to be incorporated to this food for preservation purposes, which marks the beginning of its industrialization, during the second half of the 19th century. In addition to new manufacturing techniques and the use of refrigerators starting at the beginning of the 20th century, preservation and the flavor of ice cream are very difficult to be kept for a long time without the help of antioxidants and artificial flavoring (Clarke 2004). Another emblematic case of the use of chemistry in the food industry is the famous meat extract (*extractum carnis*) invented in 1847 by German chemist Justus von Liebig (1803-1873). Meat now had another formulation apart from *in natura*, it was becoming industrialized, and that made possible the transportation of animal protein from the South American continent to Europe, which at the time was suffering with the malnourishment of its population. Besides, this process of chemical conservation of meat was also an example of the close relation of chemists with the industry and society starting from the 19th century, seeing that Liebig was among the creators of the first transnational food industry (Lewowicz 2016).

But let us take a simpler case that is of great importance currently, in which chemistry is no less fundamental and that also shows how purity is a technical construct. It is the case of oxygen production for hospital use. Demand has increased exponentially in 2020 and 2021 because of the high numbers of patients with low levels of oxygen saturation due to infections of COVID-19. Well, only through a rigorous physical-chemical process can we extract oxygen for hospital use, which must have a level of purity above 99.5%. Usually extracted from the oxygen present in air, which besides oxygen, is composed of nitrogen, argon, among other gases, through fractional distillation, initially, it is necessary to transfer air to a gaseous state. After that, this liquid will be slowly heated, for nitrogen, oxygen and argon have different boiling points. Nitrogen will boil at −196 degrees Celsius, after that, argon at −186 degrees Celsius and finally oxygen at −183 degrees Celsius. However, after this phase it is still necessary to reach an extremely high level of purity, which means it goes through a filtering process to remove all dust and particles in general that are present in it, besides the water present in the air. The chemist is the person who, in the final stage, attests to the purity of this oxygen produced and stored in green cylinders, to finally reach hospitals with the expected quality of purity. This case also makes it explicit that we only realize how important chemistry is in our lives when we require from it the molecules and products we need urgently, either already known or still to be synthesized.

Finally, as a technoscience, chemistry is impure and the construction of its conceptual and experimental framework always happens in a hybrid manner. Its theories are imbricated with its practices, its artifacts capillarize in the human and environmental world, its benefits are inseparable from its damages and our material needs are derived from the work of chemists. The relationship between chemistry and society is always dynamic and its public image may vary according to the real social demands or the ones created by industries to sell new materials. This knowledge becomes scientific as chemists structure it according to the cognitive values admitted by their disciplinary community. In this sense, it seems that in the construction of its science, chemists do not fail to obey cognitive and methodological values that are common to other scientific fields. For instance, acting as researchers, chemists considered following what Lacey calls the "impartiality ideal", which requires that social and ethical values, as well as their applicability do not perform a cognitive role in the acceptance of their theories (Lacey 2011). Nonetheless, chemical entities are technoscientific objects and their cognitive evaluation is still insufficient for its production on a large scale and consequently, its social use. Maybe a more objective manner would be to think of a society *with* chemistry, understanding all its products as *pharmaka* (s. *pharmakon*), to employ an expression used by Jacques Derrida in his *Plato's Pharmacy* (Derrida 1968). Chemistry can be both *medicine* and *poison*, such that the better the dialogue between chemists, industries and societies, the smaller the harmful effects provoked by it will be.

For this purpose, deepening the reflections and clarifications with regard to the philosophical, epistemological, methodological and evaluative issues that are pertinent to the activities of chemists and their relations with other fields of science and society seems important for us. Bringing chemistry closer to the public debate does not merely consist of doing publicity, but actually in promoting clarifications having to do with the implications of productive and societal choices when assimilating products from its industry, many times driven merely by economic interests. Research in philosophy and history of chemistry can offer narratives that help this clarification process on the subject of nature and the characteristics of chemical knowledge. These narratives will be useful in the several stages of teaching chemistry, particularly in the one that will graduate future chemists, but also to the public in general and the people who are institutionally responsible, for they can contribute in clarifying the economical, social and environmental context in which chemistry and its industry are present.

3. Chemistry and Uncertainty

Chemistry has as one of its main goals, besides studying and mapping out the properties of known chemical substances, creating new material entities. The science of the concrete deals with substances that are around us all of the time, present in food, beverages, synthetic materials, fertilizers, drugs and pharmaceuticals, as well as in conventional, biological and nuclear weapons. In fact, our everyday life is full of chemical substances: alcohol, acetone, table salt, caustic soda, paper, plastics, ink, pesticides, cotton, water, formaldehyde, oil. However, by working with real bodies, chemistry has to face two fundamental problems, capillarity and the ways of existence of these substances, manufactured and made available for all kinds of applications. The complexity of these problems lies in the fact that chemical substances do not interact only among themselves but also with the natural environment and with the living systems in general, and this happens in temporalities that vary from a few seconds to thousands of years.

This means philosophers of chemistry have to put aside methodologies and objectives of classical physics and chemistry that addressed preferably the discovery of universal and necessary laws of nature in a causal, deterministic and thus reductionist perspective. This perspective is in fact called by some contemporary thinkers such as Hugh Lacey and Pablo Mariconda as the decontextualized methodological approach (Lacey & Mariconda 2014). This view, originated in modernity, follows, *grosso modo*, the Cartesian Worldview which stated it was possible to study and comprehend a specific phenomenon of nature by decomposing it into simpler elements. Through the use of geometry, with its figures, shapes and movements, a — mechanistic — comprehension was born, declaring that all natural phenomena could be explained simply through efficient causality. In this sense, it was believed that knowledge could be achieved through reduction of a specific system to its simple and elementary properties. We know that the model used was the clockwork universe, which had separable parts, therefore susceptible to being portrayed objectively.

Well, concerning modern dualism and its belief in nature as something that can be reduced to the mechanical and material spectrum, we see one of the assumptions of modernity, that is, the dissociation between facts and values. From there comes the belief in the myth of scientific neutrality or, in more precise terms, an axiological neutrality provided to objects of nature. As a direct consequence of this epistemological position, we see a conception of science in which nature and the objects are liable to being controlled and dominated, erasing any purpose in the realm of nature. If nature possesses no purpose, if there is a clear distinction between facts and values, the subject is then free to execute its goals and purposes, controlling, manipulating and dominating nature as one sees fit. The value of control is installed in science (Mariconda 2006; Lacey 2008, v.1, cap.5).

Nevertheless contemporary chemistry moves away from this reductionist perspective because it operates within a scope of 'complexity' and therefore, moves away from determinism. Complexity can be understood here when, in a specific system, properties that are not expected when its parts, or elements, are isolated, appear. The whole, in physical or biological terms, is not the result of the mere sum of its parts. In other words, knowledge of parts of a specific system is not enough. And this complexity forces us to reflect about a non-causal epistemology in which new elements, such as uncertainty, contingency, imprevisibility, risk, disorder and destruction can be present. Thus, we should move closer to an epistemological model such as the one of functional biology, more than evolutionary biology, because in the latter, the particularities of specific organisms appear within the scope of totality and cannot be reduced only to elementary level.[1] The emergence of new relations with other substances, with the environment, with human life, for instance, becomes essential. In this sense, research in biology and chemistry cannot be restricted to the laboratory anymore, they must take into consideration the "lifeworld", meaning, the elements of the living world.

Important aspects of this epistemological perspective can be elucidated through the philosophy proposed by Hans Jonas. The author, known by his already classic book *The Imperative of Responsibility* (1979), proposes a very distinct ethics compared to the classics. By breaking with ethical anthropocentrism he believes in the urgent need to think of an ethics that takes into consideration not only the human scope but the entire biosphere of the planet. From there comes his important concept of ethics of responsibility, towards future generations, that cannot be held responsible by our past and current mistakes. To understand the reason behind this innovative proposal of the German thinker, it is interesting to analyze his considerations regarding the new biological technique that, as we shall see, introduces elements that are unique with reference to the mechanical technique.

In his work *On Technology, Medicine and Ethics*, published in 1985, Jonas, by having as his main concern problematizing exactly the challenges and threats introduced by the new biologic technique as opposed to the technique of mechanical engineering, brings us important instruments to rethink the chemistry of the 20th and 21st centuries. In the case of mechanical technique there has always been a clear definition between the active subject and the passive nature, the latter being an object of technical domain. What happens, asks Jonas, with the advent of new biology?

> The advent of biological technology which extends to the living species (...) means a radical distancing of this clear separation, even a detachment of potential metaphysical importance: man can be a direct objective of his own architecture, and this happens in his inherited physical constitution (Jonas 1985, p.110).

Next, the philosopher maps out eight aspects that can differentiate both techniques. With regard to the dimension of *manufacturing*, he argues that the scope of Mechanics, by operating with an amorphous and dead matter, can produce its works in a planned and complete way, differing from the biological scope, which mobilizes agents that possess autonomous realities, the organisms, which makes it impossible for conditions to be delineated completely. With regard to *doing*, there is also a fundamental distinction, while in mechanical construction the manufacturer is the only one that acts on the inert matter, in biological techniques, the material is active and therefore can participate in its formulation as well. The question of predictability is nuclear, as we shall see, because in mechanical construction the unknown factors are minimal, after all they come from relatively stable and homogeneous materials, being then able to operate with predictability. However, in the biological and chemical scope, many of the decisions are not so precise, for there is a complexity of factors involved, system autonomy, relationship with the environment, etc., which therefore possess their own dynamics. With regard to the difference between a mere experiment and a *real action*, Jonas points out that in Mechanics, the experiments can be undone, redone and corrected, that is, reversibility is possible, but not in biology, after all it operates in "the real life of individuals and maybe entire populations" (Jonas 1985, p.12). Real action takes us to the fifth aspect mentioned by the philosopher, the theme of *reversibility*. In the mechanical dimension, stages are reversible, in the biological one "when the results become visible it is already too late for any correction" (Jonas 1985, p.112). With regard to genetic *planning*, we observe that in the biological technique the way to reach goals is indirect, through the insertion of a new causal factor in the inherited series. With that, the effects will only be observed through successive generations. With regard to *power*, Jonas has stated that if Bacon believed in the indissociable relationship between science and power in the realm of nature, now with the birth of the biological technique something unexpected happens, power increases in a gigantic manner, not only over nature, but over man himself, "the power of man over man and the inevitable subjugation of some to the power of others, not to mention the common subjugation to needs and dependence created by technique itself" (Jonas 1985, p.112). Finally, with regard to objectives, in Mechanics the purpose is defined using the criterion of utility, meaning a benefit for mankind, while in biological technique it seems that the purpose is not to create, after all, man exists already, but to improve man. And here, Jonas reaches the central point of his complex discussion: improve man following which criteria? He warns us:

> this would be a metaphysical rupture with the normative essence of the human being and, at the same time, because of the unpredictability of consequences, the most frivolous of all games of chance, a blind and arrogant demiurge playing with the most sensitive heart of Creation (Jonas 1985, p.131).

Thus, an ethical philosophy that not only points to the subject who fears for himself, but who fears for the fates of others as well is presented. In this sense, both the future generations and the environment can no longer be ignored.

This ethical background is fundamental to get us closer to our discussion involving chemical substances, after all, even though we can start from the assumption that the synthesis of a specific substance must, above all, aim at a beneficial potential for society, we know that this is not always the case. From a general standpoint, this beneficial potential is not always reached because, at the limit, each new molecule can carry potential threats that we still ignore. A fitting case is the example of chlorofluorocarbons (CFCs), artificial compounds that possess carbon, fluorine, and chlorine in their structure. As these are gaseous compounds, they were used since the 1930s in technologies of refrigeration and aerosol due to their relative stability and safety. At the time of its introduction, in fact, CFC was considered extremely important, because it replaced highly flammable and toxic substances, such as chloromethane and sulfur dioxide, besides liquid ammonia, known as first generation refrigerants. However, a few years later, it was discovered that these substances had harmful effects for the environment, especially when released into the atmosphere, causing the destruction of the ozone layer in the stratosphere. Therefore, what was originally considered a great advantage of CFCs, its stability, became a significant environmental problem (Kovac 2015, p 9).

A very interesting case regarding the possible uncertainties of new chemical products inserted in the social context concerns the discovery of bleaching agents, made by Claude Louis Berthollet (1748-1822) in 1785 (Berthollet 1790). At that time, the French chemist produced, in his laboratory, one of the first bleaching solutions (which has as its main component an aqueous solution of sodium hypochlorite NaOCl). For that, he passed chlorine gas through a solution of sodium carbonate (Na_2CO_3). The resulting solution became known as *Eau de Javel*, since his laboratory was located in 'the Javel neighborhood'; in Brazil the liquid is called Sanitary Water. By demonstrating that chlorine bleaches fabrics, Berthollet changed the lives of millions of people who, until then, drenched their fabrics in stale urine, sour buttermilk, or sulfuric acid for an effective bleaching. The time spent was unthinkable: three months to bleach cotton and six to bleach linen, by leaving the fabrics laid stretched over the fields. "A humane and scrupulously honest man, Berthollet refused to patent his process; he knew it would release thousands of acres of farmland for food crops and speed up textile manufacturing 1000 times over" (Mc Grayne 2001, p.IX). However, later, in 1789, Scottish chemist Charles Tennant (1768-1838) patented bleaching powder, which, though highly irritating, was nevertheless much safer to transport and easier to use. The solution has a high bleaching and disinfectant power and is used for clothes and surfaces, removing stains, purifying water suppliers and pools. For that reason, it has become a widely used product in complex chemical industries such as painting, glass, paper, pharmaceutical and the food industry. Sodium hypochlorite is highly reactive and stable. In an aqueous solution, hypochlorous acid (HOCI) is formed, which is a very strong oxidizing agent and can react in the destruction of several types of molecules, such as dyes. HOCI can also 'attack' the chemical bonds in a dyed component, able to destroy the chromophore completely, the part of a molecule responsible for its color, or still by converting the chromophore's double bonds into single bonds, preventing the absorption of visible light by the molecule[2]. When it reacts to microorganisms, sodium hypochlorite attacks proteins in the cell causing their aggregation and can lead to death. It can also lead to the destruction of cell membranes that suffer ruptures. This wide attack makes bleaching effective against countless types of bacteria (May 2011).

However, once again, what seemed like a definitive solution did not come without damages:

> Berthollet's chlorine bleach helped dress the world in sparkling white. Later it purified drinking water, saving lives around the world. His process solved two important problems, but it unwittingly created an unexpected one that came to light almost two centuries later. Only after modern chemists learned how to analyze and identify minute traces of chemicals could they discover that chlorine bleach produces tiny amounts of chloro-form and dioxin. Today, many paper-bleaching mills and European water systems are replacing Berthollet's chlorine bleach with other chemicals (Mc Grayne 2001, p.X).

Dioxin is a group of organochlorine compounds that are highly bioaccumulative and toxic. Its class is composed of around 75 substances, constituted by tricyclic aromatic groups with ether function. It is found in the impurities of herbicides and pesticides, in the manufacturing of plastics, such as PVC and in the production of the paper industry which uses chlorine as a bleaching agent. Because of the potential human and ecological toxicological risks of these compounds and because of its insufficient biological degradability, environmental protection organizations have been pushing for minimal liberation of this substance in the environment. Their demands have brought about important consequences to the cellulose industry, especially since the mid-eighties. Polychlorinated dibenzodioxins and dibenzofurans with a high toxicological potential were found in residues and affluents of cellulose factories and in the paper produced by them (Bajpai 2014, p.279). As a result of extensive research made over the last decades, the spectrum of consequences to health issues caused by dioxins has grown considerably. Among them are included cancers, effects causing reproduction and development issues, immunological deficiency, endocrine disruptions including diabetes, alterations in levels of testosterone and thyroid hormone, neurological damages including cognitive and behavioral alterations in newborns from mothers exposed to dioxin, liver damage, high level of lipids in blood, which accounts to a risk factor for cardiovascular disease and skin damage (Assunção & Pesquero 1999).

Another important example comes from the tradition of chemical substances used in agriculture, fertilizers and pesticides. The use of arsenic-based pesticides, such as the famous Paris green [$Cu(C_2H_3O2)_{23}Cu(AsO_2)_2$], began with the arrival of large insect pests to the potato crops in the United States of America, but it also started to be used to combat rodents. Lead arsenate [$Pb_3(AsO_4)_2$] was the most widely used pesticide, together with calcium arsenate [$Ca_3(AsO_4)_2$], until, in 1948, the arrival of a product which seemed to be the solution to replace these arsenic salts, highly toxic to mammals.

This was DDT (dichlorodiphenyltrichloroethane), which had been synthesized in 1874 by Othmar Zeidler (1850-1911), but whose action in controlling typhus in malaria was determined by Swiss chemist Paul Hermann Müller (1899-1965) in 1939, which resulted in him being awarded the Nobel Prize in Physiology or Medicine in 1948. DDT started to be used all over the world, causing a dramatic fall in cases of malaria, and was deemed a ‘divine substance’ by the Nobel Foundation. At the time, while Müller was researching about what would be the ideal in pesticide, he described the following characteristics: it should be toxic for insects, but harmless to mammals, fish and plant; it should act quickly; its odor should not be irritating; its cost should be low; it should affect as many kinds of insects as possible and finally, it should be chemically stable for a long time. For such, he used his own research as a starting point, which indicated that substances with the CH_2Cl group showed considerable insecticidal effects; studies made by pharmaceutical chemist Henry Martin about chlorinated hydrocarbon that worked as a poison to destruct bookworms and an article published in 1934 by the *Journal of the Chemical Society* which described the preparation of diphenyltrichloroethane, which Müller found to be poisonous for flies. From these studies he reached the conclusion that he should use chlorine as the basis for his insecticide. After testing over 300 compounds, he combined the soporific chloral, chlorobenzene and a catalyst, sulfuric acid, thus reaching the formula for DDT. In fact, this new substance proved incredibly effective: it worked to combat lice infestations, typhus and malaria and saved, therefore, millions of people during the War, 5 million people alone in the fight against malaria during the 1950s.

> DDT was wildly popular with the buying public. Norwegian dairy farmers sprayed it on stable walls and, for the first time, had fly-free milk. Housewives used it on fabrics, furs, and babies’ rooms—with toddlers present—to kill lice, fleas, bedbugs, cockroaches, crickets, silverfish, and houseflies. Farmers sprayed everything from farm animals, pets, and stables to orchards, fields, and timberlands. In the United States, Western apple growers switched from poisonous lead arsenate to more benign DDT, and Kansas cattle herds gained 2000 pounds for every pound of the fly-killing compound used (Mc Grayne 2001, p.159).

But what seemed to be a miracle obtained through chemical war against pests soon became a serious environmental problem (Riegert 1980; Wurster 2015). In the early 1960s, studies began to point out the prejudicial ecological effects of using these pesticides. In the case of DDT, the environmental alarm was rung by Rachel Carson in 1962, with her important book *Silent Spring*. Carson's criticism culminated in the abolition of DDT use, first in the USA, then in Europe, and later and partially, in tropical countries. In Brazil its use for agricultural purposes was forbidden in 1985, and in the control of the malaria mosquito in 1998; however complete prohibition and importation was only made official by law (law n°11936) in 2009. If the replacement of arsenic salts by DDT had as its main argument its (supposed) low toxicity, the same happened when replacing this organochloride with a new family of organophosphorus compounds, glyphosates (*N*-(phosphonomethyl)glycine), starting from the 1970s. Used as a herbicide, its main manufacturers (Monsanto and Syngenta) claim low toxicity for this product, however researchers have pointed out important evidence with regard to the impact on the environment as well as on human and animal health. It seems history now repeats itself, but in a different way, after all, differently from DDT in its origins, genetically modified organisms (GMOs) are used even with knowledge from the scientists with regard to their potential risks for human, animal and vegetable life. The choice is, therefore, deliberate and its reasons clearly economical (Lacey 2010, v.2, cap.10).

The issue is that even when best intentions are involved in a specific synthesis, or even, a genuine belief that these substances will be more effective and specially more beneficial than others used up to that point, when it comes to chemical synthesis, as we saw in the aforementioned examples, there is the need for a reflection that encompasses a larger and more comprehensive temporality, to perhaps minimize possible risks, uncertainties and the results of its effects for the environment and for human beings and animals. Unpredictability is, therefore, indissociable, in many senses, of chemical processes.

This unpredictability can also be elucidated by another very specific point of view in chemical activity. Unexpected biological effects can occur, for example, because of chirality, the geometric property attributed to molecules which prevents them from being superimposed to their image, for they possess one or more atoms, normally carbons, which have their tridimensional orientation very well-defined. A study that clearly shows that two compounds, identical in all their aspects, except for the fact they are stereoisomers, can cause substantial differences in a given organism is the extremely sad case of the history of thalidomide ($C_{13}H_{10}N_2O_4$) use, a compound which exists in the form of an equivalent mix of R/S isomers. The substance, or better yet, this mix of enantiomers (whose cost of separation, as well as lack of knowledge of effects made it easier for it to be commercialized as such) was prescribed to help pregnant women between the years of 1957 and 1962 to minimize their sickness. After it was discovered it has a teratogenic character, that is, it can cause a series of birth defects — lack of hearing, ocular alterations, deafness, facial paralysis; malformations in the larynx, trachea, lungs and heart, and mental retardation in 6.6% of affected individuals — it was removed, partially, from the market.[3] Well, research made after this episode suggests that one of the enantiomers, (S), is related to the effects of thalidomide, while (R) is responsible for its sedative and anti-inflammatory properties (Hoffmann 2000, p.171s; Kovac 2018, p. 50s). The tragedy of thalidomide forced a new regulation with respect to medication and clearly points to the insufficiency of the epistemological scope in dealing with these complex matters of organic chemistry, after all, not taking into consideration risk and precaution analyses is, above all, an ethical issue.

Other important examples, maybe less known, of enantiomers of molecules that present differences in their pharmacological, pharmacokinetic or toxic properties are: in barbiturates, enantiomers (+) have a sedative effect, while enantiomers (—) stimulate the central nervous system provoking excitement; in the drug ethambutol the enantiomer (S,S) inhibits the growth of the tuberculosis bacterium (*Mycobacterium tuberculosis*), however, its enantiomer (R,R) causes blindness; penicillamine in its S form possesses activity, while the R form has a neurotoxic effect. Indeed, there is always the need for more effective legislation that worries about the ever-growing commercialization of drugs in their optically pure forms, that is, without the mixture with its enantiomer. When this does not occur, one must be sure that the stereoisomer is completely inactive, presenting no biological activity at all. When we buy a substance in the form of a mixture, we must be aware that we are ingesting a larger dose than if the substance were pure and therefore, at each ingestion we absorb 50% of an unnecessary chemical substance. The non separability of enantiomers is still fairly common, for the asymmetric synthesis is too costly. Through these examples, we would like to emphasize that epistemic uncertainty is intrinsic to the chemical way of existence. And that this initial unpredictability may cause even worse tragedies if ethical values are not incorporated, in fact, in the respective reflections about uncertainty and risk, overall, in public control by way of a rigid legislation which holds accountable the decision-makers who are aware of the uses of substances that will be harmful to society and the environment.

Finally, we could not abstain from discussing the matter of temporality of chemical substances and their relation to unpredictability. An exemplary case is plastics, a real threat to the natural environment. A simple package produced with plastic material constitutes, in reality, various temporalities, condensed. Going from its nearly instantaneous production to the long geological, biological, and historical periods that are connected to its main raw material, oil, and the long period of its existence.

It is impossible to think about our daily life without their presence. Since 1950 the production of plastics has surpassed 9 billion tons! With that, we are forced to question ourselves about its temporality, one of the biggest issues, without a doubt, faced by contemporary society. If a banana peel takes 3 to 4 weeks to decompose, an orange peel takes 6 months, paper and newspaper from 3 to 6 months, vegetables from 3 months to 2 years, a simple disposable plastic coffee cup takes 400 years to decompose! A fishing line? 600 years. Plastic bottles and disposable diapers? 400 to 500 years. Plastic decomposition operates in a different temporality, much superior to paper, wood (6 months on average), cigarettes (5 years), leather shoes (30 years) and cotton fabric (15 years) for example. We are describing materials that take about four centuries to reach their final decomposition stage, which means, as we know, they are accumulating in the environment. What is interesting is that, due to its structural stability, which gives it versatility, resistance, impermeability, low weight, low cost, durability and which makes it so present and useful in our society, outweighing the difficulty in handling, cost, and weight of older materials, the issue brought forth is exactly that by having these chemical properties it has become resistant to different types of degradation such as photodegradation or chemical degradation and, with that, it is currently the second most disposed of material in the world, behind only paper. The reflection about temporal unpredictability of certain synthesized chemical substances can no longer be absent from a science that regards itself as minimally responsible.

The examples above express some catastrophes and risks of accidents when the uncertainties intrinsic to the knowledge of the chemical substances in different contexts are associated solely for the purposes of technological advances driven by the market and the capital. Thus, it is necessary to integrate the uncertainties of chemistry in the institutional and ethical evaluations of its producers and its products, because in its aspect concerning exclusively the market, precaution with regard to the future is considerably limited.

4. Elements for an Ethical Chemistry

Currently, with the omnipresence of chemistry and the ascension of molecular biology, there is a generalized tendency to suspect that, in fact, in one way or another, these domains are related to ethics. For example, if we take one of the domains of ethics, deontology, which addresses correct action and the nature of duty, and we apply that to scientific investigation, we are led to admit that, in principle, any scientific experience involves a measure of risk and, therefore, responsibility. That is because any action, which interferes in the spontaneous evolution of nature or in the ordinary mechanisms of changes in human society, can cause some undesirable effect. But, once making science is something good, as it increases our knowledge, why is it that experiments for strictly scientific purposes must be cause for an ethical concern? In what sense and to which measure must a scientist try to establish if the decision of making a specific experiment or a group of experiments is right or wrong? These issues make sense because any interference with a pre-established balance is ethically relevant. Thus, in scientific investigation, the researchers are faced with choices that, though on different levels, are not indifferent from an ethical standpoint (Del Re 2001).

The choices made in the domain of organic synthesis chemistry can serve as an example. Contrary to other fields of science, the scientific products of synthetic chemistry are not only ideas, but also new substances that change our material world, and are beneficial or prejudicial to the beings that inhabit it. However, once the synthesis alters the material world, the knowledge gained must be compared to the increase of non-knowledge or lack of knowledge, determined by the number of its properties that remain unknown. With each production of a new substance, the scope of the not known increases by the number of undefined properties of the new substance, as well as all the chemical reactivity of the already existing substances with the new one. Consequently, in general, the synthesis of new substances produces much more non-knowledge than knowledge, though this can differ in specific cases in which synthesis is performed to enhance or qualify more general knowledge. Not only is it difficult to balance that with the traditional points of view of science as an activity that produces knowledge, but also one can inquire if synthetic chemists should hold any responsibility for general chemical knowledge about the material world, considered a public good. Besides academic interest, the production of non-knowledge by synthesizing new substances is of general interest, for if the new substances leave the laboratories and become part of our material environment, this will necessarily increase its chemical complexity.

For Joachim Schummer it is exactly this complexity that makes synthetic chemistry, among all other fields of natural sciences, the most peculiar when we consider chemistry from an ethical principle standpoint. Hence, the ethical question pertinent to what synthetic chemists do is if they, both as individuals and as a research community, should be held accountable by any environmental damage caused by their new substance. Even if synthetic chemists themselves do not introduce their new substances in the environment, nor promote them for commercial use, the first synthesis of a substance is the crucial causal step for its existence and the possible damage caused by it. Therefore, in principle, synthetic chemists, as free creators of new substances, could be considered responsible for all the possible damages caused by their creations (Schummer 2001). In fact, because chemistry is necessarily imbricated with political, social and economical values that are dominant in the capitalist system, chemists must necessarily also be held accountable for their actions. Because, as Marcuse reminds us, when a discovery is publicized, it necessarily becomes merchandise, that is, of public domain (Marcuse 2009). Well, from then on it can come into being, it can become something with the most different purposes, a placebo, a drug, a bomb. This means the products of chemistry that will be capillarized by society will be directly influenced by interests of a public or even private nature.

The same phenomenon can be observed in the production of nanostructures, be it by the reduction of pre-existing dimensions, or by the formation of new molecular arrangements, with the end goal of creating chemical, biological, and physical effects which are applicable in a wide range of industrial and technological activities. In this last case we have the emergence of a new domain of chemical investigation, nanochemistry. The synthesis of nanostructures and nanomaterials through the use of supramolecular and biomimetic materials which make bottom-up nanostructured materials emerge constitute the pillars of nanochemistry. Nanochemistry has two important aspects. One of them is associated with obtaining knowledge about particularities of the chemical properties and reactivity of the nanostructured particles, which feeds the research in this domain of chemistry. Another aspect, related to nanotechnology, consists in the application of nanochemistry to synthesizing, modifying and stabilizing individual nanoparticles and in their directed self-assembly, to result in more complex nanostructures (Steed, Turner & Wallace 2007; Sergeev & Klabunde 2013).

Demand for good use of chemical knowledge and for attentiveness with regard to the effects of its products is part of the principles of professional conduct established by the national entities that represent chemists. For example, in the code of conduct of the *American Chemical Society* (ACS) it is expected that its members contribute to ”the improvement of the qualifications and usefulness of chemists through high standards of professional ethics, education and attainments (...)” Thus, “the chemical professional endeavors to advance the broader chemistry enterprise and its practitioners for the benefit of Earth and its people, and has obligations to the public, to colleagues, and to science (The Chemical Professional’s Code of Conduct, 2021). In Brazil, the requirement of a professional ethic to chemists is regulated by an ordinary resolution (927/70) from the *Conselho Federal de Química* (Federal chemistry Council) which establishes what the chemist must and must not do (Code of Ethics, 1970). However, in both cases, general and corporate principles are viewed as enough, shared by all other professions with punctual added elements, besides taking the public as a simple receiver/consumer of chemical products. Nevertheless, to advance the debate about what the best professional procedure of the chemist should be, Kovac points out that more than moral maxims are necessary, for without adequate comprehension of the historical process of the self-definition of chemistry as a profession (its internal working codes), the intrinsic relationship between ethics and epistemology itself becomes opaque, as well as the complex relations between these professionals and society (Kovac 2006).

Finally, an example of a concrete result of this increase in social demand for a larger ethical and social control of products of chemistry was the enactment of the

REACH (Registration, Evaluation and Autorisation of Chemicals) regulation in the European Union, which came into force in June 2007. This regulation stipulates, in an innovative manner, the conditions for registration, evaluation and authorization of chemical substances. REACH aims for better knowledge about potential impacts of substances on both human health and the environment, through more effective management of the risks linked to the use of these products. The regulation provides a series of arrangements, as well as obligations that are expected of the producers and importers of chemical substances, with the effect of reverting the role of proving the toxicity of a product, moving it from public health authorities to industries. From then, it would be up to the industry to demonstrate that its product follows regulation, and not to public authorities to prove that it does not. The analysis of the dossier of each substance and the inspection with regard to the compliance to regulation standards are made by the European Chemicals Agency (ECHA). For its supporters, REACH represents a paradigm shift, for it provokes deep change in the procedure to authorize the commercialization of a chemical product. Besides increasing current and future precaution with regard to humans and the environment when it comes to the action of these products, the regulation would also favor scientific research and competition within European chemical industries, as well as provide a market barrier to manufacturers that did not comply with it (Sillion 2020, p.313).

However, these safety protocols remain limited and circumscribed to certain geographical regions. In fact, many of the potential dangers caused by chemical products are distributed in an uneven manner, besides the well-known transference of contaminated materials from industrialized countries to poor countries in Latin America, Africa and Asia. The products of chemistry have been present in the great catastrophes of the 20th century (Auschwitz, Nagasaki, Bhopal, Chernobyl), analyzed by sociologist Ulrich Beck in his now classic Risk Society (Beck 1992). Therefore, if national States and globalized chemical industries do not come up with international ethical protocols, short-term changes become of little believability in the escalation of pollution and new potential tragedies provoked by the products of chemistry and its industry.

5. Final considerations

Technoscience, as we know, is a polysemic term. We agree with Lacey regarding the emergence of technoscience in the contemporary lifeworld. It regards a commercially oriented technoscience, resulting from certain convergences between science and technology with the end goal of producing material objects that will mainly serve an economical and market logic.

> For me, “technoscience” is a broadly descriptive term, not a deep theoretical term or even a very precise one. Nevertheless, it is worth using be-

> cause nowadays powerful social/economic/political forces emphasize the value of technoscience, largely to the exclusion of other forms of science. (...) Typically, of course, corporate (or military) funders of research want to implement innovative possibilities with little delay, and take for granted that this is legitimate. Generally questions about how innovations might be used to address issues of importance to poor people follow only later; and then usually ignoring that technoscientific objects are not only physical/chemical/biological objects, but also socioeconomic objects whose uses are constrained by regimes of intellectual property rights, which often entail that they can play little or no role of significance in practices that serve the interests of the poor. (Lacey 2012, p.105)

Consequently, technoscience, search as it is developed today, is distinguished less by the inversion of priorities between science and technique and more because of political and market values becoming entrenched in the world of scientific and technological research. As Bensaude-Vincent points out, it is "necessary to stop invoking terms such as 'revolution' or 'new paradigm' to impose a direction to history. Technoscience is less a historical moment and more a process which connects several histories. That is why we can find traces of it in a distant past — well before the rise of the term" (Bensaude-Vincent 2009, p.195). The history of chemistry and its industry offers, precisely, elements for us to understand technoscientific practices that constitute chemical science. As a consequence, we understand that chemistry has an epistemic identity which makes it technoscientific, without confusing the participation of this science in technoscientific programs that are commercially oriented. For this reason, we attempted to highlight some hybrid and transgressive characteristics that identify chemistry as a technoscience. More precisely, it seems to us that chemistry and its industry have historically developed according to one of the fundamental aspects of technoscience, such as described by historian of sciences John Pickstone:

> Technoscience is a way of knowing and a way of making. [...]. Synthetic technoscience is when academics and industrialists work on model systems that are philosophically and commercially interesting, and when synthetic experiments/inventions are developed in networks of universities, research institutions and industrial research laboratories (Pickstone 2000, p.163-164).

With regard to materials one can ask oneself about their mechanical, thermodynamic, electromagnetic, biological, and ecological properties, but among all, there is one property in particular, the one that refers to chemical reactions. The chemical properties of the matter can be characterized in three axes which have constituted, throughout time, what chemists do: the method (analysis/synthesis), the measure (amount of material — currently the mole) and the language (which indicates composition and structure). Analysis has always been one of the main objectives of chemists, which led to the development of separation and purification techniques.

Synthesis consists in the production of new substances, a method that produced some hundred substances in the 19th century, but that currently produces millions of news substances.

These numbers certainly represent an increase of chemical knowledge about matter, but also point to a substantial growth in the lack of knowledge we have about material entities that can be part of human societies and natural environments. How can one know, manage and legislate over this immense amount of chemical substances? Certainly it is up to the chemists to construct the knowledge about the entities they produce. However, the change in context in which these entities will be present after they leave the laboratories and the chemical industries calls for the convergence of other sciences, such as biological and human, but also the sciences concerning non-cognitive values, such as social and ethical. Thus, if we believe the products of chemistry should be considered as *pharmaka* it is because the relationship between chemistry and society is essentially ambivalent. That is, if a chemical substance can represent the solution to certain problems, there is no guarantee that it cannot become the cause of new difficulties and complications. Therefore, besides the compliance of chemistry professionals to cognitive values associated with the research, the legislation established by the public power to regulate the production and commercialization of chemical products must be strict. Otherwise, a ”medication” produced by chemical science can become a dangerous ”poison”.

By problematizing, as we saw, aspects of modern technique of a biological nature in contrast with the technique of classical engineering, Jonas sheds light on central aspects of an ethical theory for our time. He proposes a theory which, by breaking with ethical anthropocentrism, puts future generations and the environment at the center of the debate as well. And here responsibility, besides traditional classical elements such as virtue, honesty, and charity, emerges as a fundamental condition, after all it is through responsibility that we may be able to “maintain authentic human life on Earth” (Jonas 2011, p.47). Well, the question that arises is how, in Jonas's perspective, we would be able to put this new ethics into practice. More than that. If the central point is rampant technoscientific progress, how would it be possible to separate the value of control from current science? And here Lacey's proposal which, as we know, operates within the effective interaction between science and values, can maybe elucidate a few points that were not conceptualized and discussed by Jonas.

From Lacey's perspective, big laboratories and the different scientific institutions work with the idea that science should generate technoscientific innovation aimed at economic growth. Thus, the adoption of materialistic strategies decontextualized from research, which emphasizes the relationship between science and the values of technological progress, capital and the market, prevails. The choice of a research strategy depends, therefore, on the types of phenomena which occur within a particular domain of interest and constitutes one of the stages in conducting scientific activities. Until recently, it was considered that this choice arose strictly from the cognitive evaluation of theories and hypotheses used to explain the empirical evidence of the phenomena in question, and that this strategy was free from other types of values (personal, social, ethical, religious). Research conducted in this manner is thought to be decontextualized. Nevertheless, it is shown that it is possible to preserve some guiding ideals of scientific activity, such as impartiality and cognitive neutrality in the evaluation of theories and hypotheses, anchored in cognitive values, and even so, to assimilate other values in the choice of research strategies. Lacey then, will propose an epistemic and ethical perspective, which while not putting cognitive values — empirical adequacy, explanatory power, predictability — aside, is able to minimize the value of control, prioritizing values such as sustainability, equality and democracy. The basis of this ethics should be the one that favors human flourishing, that takes into consideration the modern humanist ideal of a science concerned with the well-being of the majority. That is why the Australian thinker talks about methodological pluralism, which would break with the modern decontextualized approach, by incorporating diverse perspectives such as the ones of feminism, marginalized groups and alternative practices.

Adopting social and ethical values has proved to be fundamental to the development of research that incorporates, for example, traditional knowledge and agro-ecological practices so that, in fact, society disposes of information that allows it to make democratic choices and not be submitted solely to the interests of the capital and the market. It is important to observe that the interaction between non-cognitive values and scientific activity can occur in the choice of strategies, in the way research is conducted, in the disclosure of the results or the application of scientific knowledge, but these values should not interfere in the cognitive evaluation of theories and hypotheses employed by the chosen strategy. In this case, only cognitive values, such as empirical adequacy, theoretical consistency, explanatory power, simplicity, fruitfulness and certainty must be admitted and accepted, preserving thus the ideals of impartiality in the acceptance of theories and hypotheses and of cognitive objectivity (Lacey 2008, v. 1, p.84, footnote 3).

But can this perspective explain the uncertainty that constitutes the epistemic identity of chemistry? Uncertainties that cannot, of course, legitimize and justify the irresponsible practice of chemical institutions but that, on the contrary, discusses and problematizes how complex, dangerous and many times fatal the applicability of chemical knowledge is. The criminal case of Thalidomide is one among thousands of examples. It is about more complex uncertainties than the failure to comply with cognitive values or individual ethical deviations, for, besides the unpredictability that is intrinsic to chemical substances, ethical values should be at the center of the debate. Finally, we believe that misconduct should be punished and the industries responsible for accidents and pollution should be compelled to compensate both society and the natural environment. We also believe that risk analyses as well as precaution must serve as guiding principles in many instances of chemical research. However, it is important to make clear that there is no such thing as an absolute determinism which allows us to predict all behaviors a chemical substance might present, so that its uncertainty must always be taken into consideration. And that makes the issue of interaction between science and its values even more complex.

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Notes

[1] According to Nei Freitas Nunes-Neto and Charbel Ninõ El-Hani: "Functional biology deals with the proximal causes of biological phenomena. Proximal causes are the determinants of biological events which have a place within ontogeny, in the lifespan (or somatic time) of individual organisms and are generally associated to physiology. The reference to proximal causes answers questions such as, for example, the following: how does the circulatory system of a mammal work? In turn, investigations in evolutionary biology resort to remote causes of biological phenomena. *In this field of biology, the organism is always seen from a point of view focused on its integration in more inclusive organization systems, such as lineage and populations.* Therefore, the causes to which evolutionary biology resorts to explain current events concern events that took place in the evolutionary history of the lineage to which an organism pertains, in its phylogeny (Nunes-Neto & El-Hani 2009, p.358, emphasis by us).

[2] Berthollet explained the bleaching process in a completely distinct manner than in contemporary chemistry. By distancing himself from the phlogiston theory, popular at the time, he reinterpreted the gains and losses of phlogiston (and color) in the bleaching using chlorine as gains and losses of oxygen. For an analysis within the chemical point of view at the time, Keyser, 2006.

[3] According to a 1973 article in *Veja* magazine titled "Still, thalidomide", we read: "it was, without a doubt, a tragedy made of incomprehension. And, above all, of absurd negligence. Since 1957 the directors of Grünenthal ... knew that its product ... could have negative side effects for the nervous system. In spite of that, they continued to manufacture, promote, and sell it for over four years. In 1961 . . . thalidomide, up to that point sold in 51 countries around the world, was pulled from the market . . . In Brazil, victims . . . now made up an unknown legion . . . the first cases are being notified." (Moro & Invernizzi 2017). Well, after the first cases of malformation in children were diagnosed, the drug should have been immediately suspended, which did not happen for clear matters of intervention regarding economical and market values. A tragedy that begins within the epistemic scope of the unknown and ended with an ethical criminal case. About the history of thalidomide in Brazil and its regulation, Oliveira *et al*. 1999.