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# Is technology (still) applied science?☆

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ABSTRACT

The thesis that technology is applied science is called by Niiniluoto (1997) *the standard view*. That is surprising because the identification between technology and applied science has been widely rejected by both historians and philosophers of technology, including Rapp (1974), Bugliarello and Doner (1976), Derry and Williams (1977), Feibleman (1983), Skolimowski (1966), Vermaas et al., (2011), Don Idhe (2013). The reasons of such rejection mainly stem from the fact that technology has historically progressed without the benefit of science, i.e., it has been possible to design technological devices without the explicit and systematic development of the scientific theories and laws that would explain their functioning. Polish philosopher Henryk Skolimowski has attacked this identification based on historical evidence. He argues that in the development of technology, there are many cases wherein technological designs have supported pure scientific research, rather than the other way round if technology were applied science. According to Skolimowski, some cases that dispute the identification of technology as applied science are the design of the transistor, supersonic aircraft, and the Manhattan Project. However, this historical evidence should not persuade us for two reasons: 1) Rejecting the previous scientific research that served as the basis for the said technological designs commits Skolimowski to anachronism. 2) From a realistic perspective of science, technological devices are not only subject to the principles and laws of science, regardless of the extent of our knowledge of them, but incorporate insights on more articulated explanations that while not available at the time of designing, do inspire our practical and theoretical efforts and guide further work. In this paper, we posit that the cases offered by Skolimowski to motivate his rejection of the standard view are far from being conclusive. To this end, we not only critically assess each case but also identify other historical examples that might be even more promising to support Skolimowski's thesis. Finally, we critically deal with those more promising cases and argue for a deflationary interpretation of *the standard view*.

## 1. Introduction

Defenders of *the standard view* on the relationship between technology and science hold that technology *is* applied science [1]. But many scholars (e.g. Jarvie; Rapp [2]; Bugliarello and Doner [3]; Derry and Williams [4]; Feibleman [5]; Skolimowski [6,7]; Don Idhe [8]; among others), based on historical case studies, have argued against this thesis. Since these arguments amount to the contention that progress in the design of technological devices does not necessitate a parallel and corresponding progress in the scientific theories which could support or explain those technological achievements, all the reasons offered by these scholars are liable to the same criticism: they ignore the role of previous and contextual research and they neglect the role of specific technological achievements to launch practical and theoretical investigations that lead us to disclose the scientific laws, principles and reasons behind them. Taking into account that Skolimowski's arguments are, by far, the best examples of this family of criticisms against the view of technology as applied science, we will concentrate exclusively on his historical case studies to offer a general rebuttal of his standpoint.[1]

This family of arguments against the standard view depends on the ontological priority of the design process of technological devices which seems to prove a corresponding epistemic priority of the technological

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[1] In addition, these scholars not only share the same general argument but appeal to similar examples [7] discusses the design of the transistor [4]; analyze the steam engine and so does [5]. This provides a good justification to deal only with Skolimowski's case studies.

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achievements over the discovery and formulation of the scientific laws, principles and explanations of their functioning. On this account, it would be a relatively easy task to demonstrate not only such contention but also to conclude that technological progress could be completely independent of scientific progress and, at the end of the day, that science and technology are totally different in nature and that technology cannot be applied science. But, as we will show below, the argument of ontological priority disregards previous scientific work, which is essential to the practical designs used to support the rejection of the standard view. And the idea of epistemic priority neglects the role of practical advances as the inspiring force to engage in both technological and theoretical work which, concatenated with a realist interpretation of scientific realizations, reveals the genuine nature of the relationship between technology and science.

While there is not a sharp criterion capable of dividing science from technology, we believe that turning to the recent label "technoscience" as "the new standard view" (like current work in STS seems to suggest) fails to solve the difficulty. As we all know, the limits between science and technology are hazy and, sometimes, totally absent. If we take the theorizing activity as the distinctive mark of science and contrast it with the designing vocation of technology we soon find that, nowadays, a criterion like this would be inappropriate. There are full grown theories in technology –the engineer's beam-theory (Euler-Bernoulli), the classical theory of plates and metal sheets (Kirchhoff)– while we can design experiments in science, what could confirm Niiniluoto's reading [1] of the recent label "technoscience" as a move to fade away the traditional interpretation of the relationship between science and technology. However, we might still find a *prima facie* distinctive criterion between science and technology: while most of the problems dealt with by basic science are not practical ones (i.e. their solution does not aim at satisfying a human need which goes further than the desire for knowledge) the problems that technology addresses are fundamentally of a practical nature (even in the domains of research in engineering).

To make our point clear, by means of critical analysis, we will show that the aforementioned family of arguments against the standard view is inconclusive. Using a realist perspective of science and an argument by analogy we will show that the ontological precedence of technological designs fails to prove the epistemic priority of technology over science not only due to the fact that technological realizations are clever applications of the laws and principles of science (whether or not their full-fledged formulation is available) but because, in the same way a rational agent might be a good arguer even if he lacks a systematic and full knowledge of the formal principles of reasoning, a good designer can produce functional technological devices using his intuitive understanding of the laws and principles of science. This argument, which concatenates realism with analogy supports a deflationary interpretation of the standard view: technology is applied science, even in those cases in which we lack a complete and satisfactory formulation of the laws and principles required to explain a device's functioning since those shortcomings can be met by an intuitive comprehension of the scientific principles and laws at work.

## 2. Critical analysis of Skolimowski's historical arguments

In his seminal essay, *The Structure of Thinking in Technology,* Skolimowski maintains, among other things, that it is inappropriate to identify technology with applied science [6]. His argument is based on three historical cases. According to the first case, Skolimowski holds that the development of computers resulted from the replacement of vacuum tubes with transistors. Therefore, it was the transistor's design what made it possible to investigate many of the properties and laws that guide semiconductor behavior.[2] In the Polish philosopher's opinion, the second historical case—the construction of supersonic aircraft and rockets—supported the study of metal fatigue and several other phenomena concerning the behavior of solids in space. As per the third case, the Manhattan Project made it possible to discover plutonium. The alleged argumentative strength of these three cases is that they show that, historically, there exists an ontological priority in design, and it is the device itself what supports the discovery of certain phenomena that are later researched by scientists under the domain of basic science. According to the aforementioned historical evidence, we can reconstruct Skolimowski's argument in a more schematic way as follows:

(P1) If it is possible to design devices and tools that historically precede the development of scientific laws explaining their functioning, then it is incorrect to identify technology with applied science.

(P2) Historically, devices and tools preceding the development of scientific laws that would explain their functioning have been designed. Therefore, it is incorrect to identify technology with applied science.

Although the evidence offered by Skolimowski might seem conclusive, a more careful analysis of the historical arguments shows that, in these cases, Skolimowski is anachronistic. Despite conceding that the invention of the transistor by American physicists John Bardeen, Walter Houser Brattain, and William Shockley between 1947 and 1948 inspired important research in pure science,[3] we cannot neglect (as the history of technology shows) that the study of semiconductors dates back to the 18th century.

The author of a rather informative study on the "early history" of semiconductors, Georg Busch [9]; stresses that the first scientist to use the word "semiconductors" was Alessandro Volta (1745–1827), who included it in his report submitted to the London Royal Society in 1782. By touching a charged electrometer with different materials, he discovered that contact with metals caused the immediate discharge of the electrometer. By contrast, contact with dielectrics caused no discharge at all. However, some materials (semiconductors) caused discharge within a short but non-zero time. Later, in 1800, Volta constructed the first electric battery, which opened up a new field: the experimental study of electrical properties of different materials [10].

In subsequent years, physicists analyzed various properties of semiconductors and made important contributions to the understanding of their behavior. For instance, in 1914, Johan Koenigsberger divided solid-state materials into three groups with regard to their conductivity: metals, insulators, and variable conductors [11].

The recent history of physics reveals that "the development of solid-state physics was needed, mainly from 'band theory'[4] to invent electronic devices based on crystals" (Filardo Bassalo, [23]: 14). The band theory of semiconductors was developed by Alan Wilson (1906–1995) in 1931, soon after the basis of quantum mechanics was established. In two of his articles, he drew a picture of energy bands and energy gaps in between. […] Although the basic features of the semiconductor theory were developed in the 1930s, semiconductors remained "unpopular" until the mid-1940s for lack of suitable technologies [10].

Because the theory of semiconductor bands is based on quantum mechanics, particularly on the theory of molecular orbits, we can conclude that, at the end of the 40s, there was already a study that was systematic enough to inspire technological applications, such as

[2] Interestingly, for [22], the transistor's design serves to support the thesis that technology is applied science.

[3] In fact, one of its inventors, John Bardeen, received his second Nobel Prize for his theory of superconductivity in 1972.

[4] According to this theory, a material's structure can be understood as a structure of energy bands. The theory stems from the orbital model of atoms and suggests, among other things, that for a material to be a good conductor of electric current, there must be little or no separation between the energy bands which can even overlap. The greater the separation between bands, the lower its conductivity. Sometimes, the separation between bands allows them to jump between only some electrons. In those cases, the material behaves like a semiconductor.

designing the transistor, in the same decade.[5] In fact, a quantitative description of charge transport in semiconductors was possible after quantum mechanics was available and applied to solids. From historical records, we can conclude that the argument posed by Skolimowski is not conclusive, given that the history of the physics of semiconductors shows that physicists already knew about several properties of solids, long before the invention of the transistor. In fact, in 1926, Bloch suggested a theorem of quantum mechanics, called Bloch's theorem, which describes the wave function of electrons by taking into account the crystalline structure of solids. In addition, experiments with semiconductors, primarily with silicon and germanium, have been recorded at least since1930.[6]

Based on previous historical records, it is incorrect to claim that it was the transistor's design what served as an organized development of the semiconductor theory in solid-state physics, as the history of solid-state physics shows that physicists studied semiconductors long before the transistor was designed in Bell laboratories.[7]

The second historical case offered by Skolimowski is as debatable as the first one because the phenomenon of “fatigue” had already been identified by physicists and engineers since at least 1800. Fatigue was initially recognized in the early 1800s in Europe from the observed fact that bridge and railroad components, subjected to repeated loading, were cracking. Three basic factors to cause fatigue are (1) a sufficiently high tensile stress, (2) a large variation in the applied stress, and (3) a sufficiently large number of repetitions in loading and un-loading [12].

In the same article, Singal et al. [12] offer an exhaustive list of the most significant theoretical contributions to understanding mechanical fatigue, which were carried out by engineers from all over the world, from 1837 to 1968. It is noteworthy that Wilhelm Albert published, in 1837, the first article among the studies about fatigue on conveyor chains used in Clausthal mines. In 1839, Jean Victor Poncelet described fatigue as exhaustion in metals and in 1842, William John Macquorn Rankine recognized the importance of concentrations of stress in the faults of railroad axles. In the same year, a railroad accident occurred in Meudon, France, when a train locomotive covering the Versailles–Paris route derailed owing to the breakage of one of its axles. Hence, Rankine studied, in particular, the effect of stress concentration on the growth of cracks in railroad axles.

In 1849, Eaton Hodgkinson was granted a small sum of money to inform the United Kingdom's Parliament about the results of his experiments to determine the impact of the continuous load changes on iron structures and to what extent they could be charged without endangering safety. Later, in 1860, Sir William Fairbairn and August Wöhler conducted systematic tests on fatigue, which, in 1870, made it possible for Wöhler to identify that the range of cyclic tension is more important than the peak of effort in railroad axis faults. Another theoretical contribution of Wöhler's was coining the phrase “endurance limit.” [12].

In 1903, Sir James Alfred Ewing demonstrated that the cause of fatigue was the microscopic cracks, and, in 1910, O.H. Basquin proposed a record relationship for S-N curves (or S-N Diagrams), using Wöhler's experimental data [12]. In fact, calculating resistance to fatigue from the state of stress is considered the most classic and basic method of studying fatigue; this consists of calculating the span life of a piece by comparing the nominal value of the stress intensity factor (S) to the number of cycles of use (N).

Furthermore, the de Havilland Comet aircraft accidents that occurred in the 1950s (among the most famous in aeronautics), also contributed to the theoretical analysis of metal fatigue. These British models were the first jet aircrafts designed for civilian use. The accidents took place during flight, with disastrous consequences. An investigation of the causes determined that during flight, cracks appeared because of fatigue of the fuselage. The tensions in that area were studied with regard to the design and were found below the standard elastic limit; however, material fatigue was not taken into account.

According to this historical record, we can conclude that, at least since 1860, engineers had already been constructing theories to explain what caused the axles of train wheels to break. It is noteworthy that it was not until 1947 that a plane was first able to exceed the speed of sound. Therefore, taking into account this historical information, it does not seem necessary to hold that it was the supersonic aircraft design what supported studying material fatigue.

It would be possible to respond to the previous objection, by reframing Skolimowski's historical case in such a way that it would be immune to the criticism of anachronism. This could be done by arguing that it was the invention of the railroad what led to studying mechanical fatigue instead of supersonic aircraft or rocket designs. However, we can still argue against this version of the argument, as we maintain—from a realistic perspective on scientific laws—that devices and their design process not only suppose the principles and laws of science (even though we had not discovered them) but imply an intuitive comprehension of such theoretical tools; we will develop this argument more thoroughly in the final part of the paper. Next, we consider Skolimowski's last historical case.

The third historical case is based on military engineering. According to Skolimowski, the implementation of the Manhattan Project made the discovery of plutonium possible: “It was in the Manhattan Project that plutonium, an element not found in nature, was developed in the process of producing the atomic bomb” [6]; p. 374).

This is the only historical case wherein Skolimowski does not seem to incur in anachronism, as, in fact, the first phases of the Manhattan Project date back to 1939. Plutonium was discovered in 1940 by Glenn Seaborg, J.W. Kennedy, E. McMillan, and A.C. Wahl, who obtained it by bombarding uranium with deuterons in the Berkeley cyclotron; it was included in the periodic table in 1941 after the project was launched. Nevertheless, the claim that the Manhattan Project facilitated the discovery of plutonium is false, given that the very idea of the Manhattan Project took birth owing to the surprising development of nuclear physics and chemistry at the beginning of the last century. In particular, historical records show that the project came to light only after the discovery of nuclear fission by Lise Meitner and Otto Hahn [13]. Fission, as a nuclear reaction, occurs when a neutron is fired at the nucleus of the atom of a radioactive element and causes division of the nucleus. In turn, this division releases more neutrons that impact other nuclei, so, if the chain continues, it produces an immense amount of energy in a relatively small space. That the discovery of the phenomenon of fission is what undoubtedly inspired the Manhattan Project, can be better appreciated if we take into account that on August 2, 1939, Leo Szilard, Edward Teller, and Eugene Wigner dissuaded Albert Einstein from warning President Roosevelt of the potential dangers of nuclear fission.

Another debatable historical aspect of Skolimowski's argument is that the discovery of plutonium was not originally related to the Manhattan Project but was the result of a theoretical search for transuranic elements. In fact, the Manhattan Project was intended solely for uranium research; plutonium was actually obtained at the University of Berkeley in 1941, without any apparent relation to the project. It is true

[5] For a more detailed analysis, see G. Busch.

[6] Among them, the experiments conducted by Wilson, Peierls, and Schottky. In addition, the “doping” technique (dissolving traces of impurities in the crystal) was developed to turn semiconductors into conductors. See [23], 15.

[7] A reviewer claims that for this argument to work, either we should know exactly the laws and properties governing the behavior of semiconductors that Skolimowski had in mind when he made his case and show that they were known prior to the arrival of the computer or prove that all of them were known previously. We reformulated our argument in such a way that in the amended version both requirements are too demanding and neither is necessary for our purpose. What we intend to prove is that a careful consideration of the previous knowledge might reveal trends of research and an intuitive comprehension of the laws and principles at work, not matter if we lack a suitable formulation of them. Our point also illustrates the give and take productive and beneficial relationship between technology and science.

that plutonium was incorporated into the project, and this was done for two fundamental reasons. On the one hand, uranium only has the radioactive potential necessary to develop an atomic bomb in two of its isotopes: uranium-235 and uranium-238; uranium-238 occurs naturally, but due to this same characteristic feature, its energy potential is poor. On the other hand, uranium-235 has greater radioactive potential; however, it is rare—so rare that project scientists had to "distill" it from its cousin uranium-238. Plutonium, on the contrary, has characteristic features similar to uranium-235, and it is easier to obtain [14]. In fact, the atomic bomb that was dropped on Hiroshima—nicknamed *Little boy*—had a nucleus of uranium-235 and not plutonium [14]. Second, plutonium was included in the atomic bomb research project because of the ease with which it could be obtained compared to uranium-235, which allowed the mass production of nuclear warheads (that would later be used for military purposes) as well as to produce electrical energy from nuclear fusion.

Thus, we can conclude that it is false that the Manhattan Project made the discovery of plutonium possible (because its discovery was made possible by the search for transuranium elements in basic science); but also (*pace* Skolimowski) that the atomic bomb's design serves as evidence supporting the identification of technology with applied science, since, as Niiniluoto [1] points out, nuclear bombs and reactors were constructed by using information provided by physical theories about atoms and radioactivity.

However, let us suppose, for the sake of the argument, that the history of technology provides evidence against identifying technology with science. To defend this view, we could even resort to other historical cases that, unlike those used by Skolimowski to support his views, are not controversial. If historically, technique is much older than science (hominids designed and used instruments and devices since at least 3 million years ago; science has only existed for 2.500 years) it is not surprising that in the historical development of technology, one can find substantial evidence supporting the thesis that technical knowledge precedes, by centuries, the theories and scientific laws that would explain the design or operation of a device or would establish the causes of the success of a technique. For instance, Feibleman [5] argues[8] that in medical practice the healing properties of ephedrine[9], cocaine, and quinine[10] were known long before biochemistry was developed as a consolidated scientific discipline. A historical argument like this shows that empirical medicine, for example, is a step ahead of science.

In the same vein, we must remember that societies that discovered the use of the wheel did not know anything about friction forces, just as many farmers knew the convenience of fertilizing their fields; though they had no clue why it was beneficial to do so. If these historical cases do not make the point, consider these three additional cases:

The steam engine: Poet and philosopher Feibleman reminds us that the steam engine design preceded the theory explaining its operation by more than half a century. According to Feibleman "Carnot discovered the pure science of thermodynamics as a result of his efforts to improve the efficiency of steam." (1983: 39). The steam engine was patented by James Watt in 1769; and Thermodynamics was formulated by Sadi Carnot in 1824, when he published his *Reflections on the Motive Power of Fire*. The first and second laws of thermodynamics were formulated in 1850 by Clausius and Lord Kelvin. Therefore, it is common to find the claim in philosophical literature that "science owes more to the steam engine than technology owes to science" (Don [8]: 54) or in the words of Derry and Williams,

> "… the steam engine turns thermal energy into mechanical energy, and its performance is governed by the laws of thermodynamics. These laws, however, were not established until the mid-nineteenth century, and therefore, until then, the nature of heat had never been understood: this situation reminds us once again that technology is not, in any way, synonymous with applied science" [4]: 494–495).

In light of a historical perspective, the invention of the steam engine resulted from a whole process of experimentation and improvement of the prototypes that preceded it—atmospheric machines—so that the device was the result of the search for efficiency. While the notion of *thermodynamic efficiency* was not explicitly available to the inventors, it was implicitly decisive for the machine's continuous improvement. Thermodynamically, *efficiency* is defined as the coefficient obtained from the quotient of the net output work and the net heat supplied [15]. This shows the maximum thermodynamic efficiency a machine produces. Therefore, although the fundamental laws of thermodynamics had not been explicitly developed when the steam engine was invented, we can say, without fear of being mistaken, that the machines respected these laws because, regardless of whether they were explicitly stated, the steam engine transforms water's thermal energy into mechanical energy, thereby following the natural law of energy conservation.

Consider the following historical case, which as evidence is even more impressive than the previous one, given that the device precedes scientific laws that would explain its operation by centuries.

Windmills: As a source of mechanical energy, windmills seem to have originated in Persia in the 7th century BC. […] they were firmly established in the Persian province of Seistan in the 10th century and were used for irrigation [4].

Windmills spread through Arab countries and proceeded to Europe around the 12th century, probably brought by the Crusaders. It is believed that it was the Templar Knights, returning from the Holy Land, who popularized these mechanical machines [16]. However, some of the scientific principles that explain their operation, including fluid dynamics, were not expressed until the 18th century, specifically in 1738, when Daniel Bernoulli published his studies on hydrodynamics. For Bernoulli, the energy of a fluid at any time consists of three components: *kinetic energy*, which is the energy from the speed that the fluid possesses; *potential energy* or gravitational energy, which is the energy provided by a fluid's altitude; and *pressure energy*, which is the energy that a fluid has because of its pressure. Bernoulli expresses one of the fundamental principles of fluid dynamics, experimentally verifying that the internal pressure of a fluid decreases to the extent that the fluid's velocity increases. In other words, for a fluid in motion, the sum of the pressure and velocity at any point remains constant.[11]

So, how are studies on fluid dynamics related to windmills? Wind, as we all know, is nothing but air in motion. All bodies or masses in motion have energy, called *kinetic energy,* and therefore are able to complete a task. This shows why scientific principles proposed on fluid dynamics would explain how mills operate, although it is not the only principle that would explain their operation. According to Valera [16]; the principle of conservation of linear momentum—a result of the

[8] For a critical analysis of this argument and others see: The nature of technology and its links to science: a realistic and analogical perspective. Discusiones Filosóficas Jan.-Jun. 2017. 63–78. https://doi.org/10.17151/di l.2017.18.30.4.

[9] What was known in the Far East as *Ma huang*, and was widely used in traditional Chinese medicine.

[10] Quinine was known for its healing properties by Native Americans, but it was not incorporated into European cultural heritage until its anti-malarial properties were discovered. When the Europeans carried malaria to America, the natives realized that one of their traditional medicines, cinchona bark or cinchona, offered relief from the disease's symptoms. The Incas knew the medicinal properties of the plants that grew in the Andes and in the Amazon jungle, including a tree that produced the bitter bark that could cure many ailments, cramps, colds, and arrhythmias. The Quechua word "quina" means *bark*, but this bark with extraordinary properties was known as quina-quina, "cortex bark" thus giving rise to the name "quinine". (See Wikipedia).

[11] Bernoulli's theorem is formally expressed as follows: $p + 1/2\ dv^2 = k$; $1/2\ dv^2 = pd$. **p** = pressure at a given point **d** = fluid density **v** = velocity at that point **pd** = dynamic pressure.

action–reaction principle or Newton's third law—explains the blades' operation, given that “the force resulting from the composition of basic forces that act on the body, generated by the fluid's turning point on its impact with the object, has two components: the strength of resistance and lift force” [16].

It is noteworthy that in this historical case, a mechanical machine's design, such as that of windmills, preceded the explicit development of scientific principles that would explain its operation by centuries; among them is the *principle of fluid dynamics*.

The pigment production technique: The pigment or dye production technique has been used since prehistoric times with artistic and decorative interests. Archaeologists have found evidence of the mastery of this technique in the Paleolithic and Neolithic cave paintings, particularly from iron oxide.

The first pigments were primarily of natural origin (terrestrial, mineral, and even biological pigments, some of which were difficult to obtain, e.g., the purple of Tiro). One of the oldest pigments—Egyptian blue—dates approximately from 3100 B.C. Other pigments such as alizarin, hematite (red ocher or ($Fe_2O_3$)), goetite (yellow ocher or ($Fe_2O_3 \cdot H_2O$)) were used in India, Persia, and Egypt. Charcoal has also been used as a pigment since prehistory.

One of the fascinating historical records related to this technique is the serendipitous discovery of Prussian blue (an iron and cyanide coordination compound) at the beginning of the 18th century. Painter Heinrich Diesbach obtained this intense blue pigment by heating soda and animal waste, in a failed attempt to produce a red dye, in collaboration with alchemist Johann Conrad Dippel.

The example of the pigment technique is historically and philosophically interesting for the purposes we have outlined in this article because the production of pigments and dyes have contributed to the birth of one of the most important branches of modern chemistry: *the chemistry of coordination compounds* that describes the nature, geometry, and properties of coordination compounds.[12] It is a historical fact that, while the pigment technique is millennial, the scientific theory that explains the chemical structure of some pigments (as not all are coordination compounds), is rather recent: *the chemical theory of coordination compounds* was developed in 1893 by Alfred Werner. Thanks to Werner's theoretical contributions, inorganic chemistry stipulated from then onwards, a systematic nomenclature of coordination compounds, including the pigments synthesized in the 18th century.

Before the lavish development of chemistry as a mature science during the 18th century, the first coordination compounds were differentiated by artists and alchemists according to their qualities, primarily including color (e.g., hexaamminecobalt (III) chloride—known as *luteo*—a term originating from the Latin word *luteus* that means yellow) or even its place of origin (e.g., natural or roasted Sienna, which came from this Italian city).

By contrast, Werner's theory manages to explain, among other things, the structure of coordination compounds and how these compounds are formed. In his opinion, they are formed by fulfilling the principle of primary and secondary valences of the central atom: a metallic ion possesses not only a characteristic charge (or principal valence) but also a coordination index that expresses the number of ligands (secondary valence).[13]

However, these are not the only scientific principles that alchemists and artists did not know, despite applying the pigment technique with a brilliant skill. Another scientific principle that we could mention is the *law of conservation of matter*, which is a principle that operates in all chemical processes, and which, as is well known, marked the beginning of the scientific revolution in 18th-century chemistry. This law, developed by Mikhail Lomonosov and Antoine Lavoisier, stipulates that in any chemical reaction, the mass remains constant. Likewise, the *law of definite proportions*, developed by Joseph-Louis Proust in 1795, states that when two or more elements are combined in a compound, the elements are always combined in the same weight percentage. If these principles govern all chemical reactions, we can affirm, without fear of being mistaken, that the preparation of pigments and dyes followed the natural restrictions imposed by these principles, although they had not been explicitly developed.

Are we committed, by the available historical evidence, to the view that it is wrong to identify technology with applied science? The answer is not straightforward. We can admit that to design a technological device (e.g., the steam engine) or to successfully apply a technique (e.g., the pigment technique), it is not necessary to have explicitly and/or systematically developed scientific principles or an operational technological device or successful technique that would explain them. For many practical purposes, when engineers invent something, they do not have to know all the causal relationships implied by their designs and devices. In fact, we can make use of laws and scientific principles that we do not know or have not satisfactorily formulated for various practical purposes, as it is appropriately illustrated by traditional non-scientific medicine in addition to the mastery of artists and alchemists of the pigment technique [17]. In addition, a purported ignorance of those laws and principles does not rule out completely an intuitive knowledge or understanding which enable us to use them in the appropriate ways to produce functional devices. As it is well known, there are also many cases in which the design of devices is the result of the correct application of background scientific knowledge. And it is for this reason that Niiniluoto [1] holds that the standard view of the relationship between science and technology (i.e. that technology is applied science) has a restrictive validity. Such thesis can be confirmed by the fact that some artifacts (among which we should count nuclear bombs and nuclear reactors) were designed thanks to the development of the scientific theory that explains their functioning, and once we achieved a full understanding of what physics has to say about atoms and radioactivity. Furthermore, many frugal innovations (low cost sophisticated products) among which stand out clay refrigerators, bamboo microscopes and palm-sized DNA sequencers require that the designers have a strong background in science and technology. “This is because these innovations have been realized *by research and development* (R&D) teams in academy and/or industry where the knowledge-base … needed … is accrued typically through advanced degree programs … (Rao, [24], p35). And even those like Vermaas, who are reluctant to admit the standard view on the count that it limits the work of the engineers to that of the designer forced to apply the knowledge previously developed by scientists, is ready to admit that “very recent developments, for example in the fields of nano-technology and biotechnology, cannot be understood in isolation from fundamental scientific knowledge” (2011: 56).[14]

However, if in the process of designing devices, or in the use of certain techniques, we can find implicit scientific knowledge and an intuitive understanding of the laws of science (i.e., since every technological device must function according to certain physical restrictions that we must intuit) there is still a sense (even if it is deflationary), in which we can insist on identifying technology with applied science, namely: every technological device is the result of, among other things, applying, at least implicitly, the principles and laws of science that we may not even know because they have not yet been discovered. This

[12] A coordination compound consists of a metal or metal ion (central atom or coordination nucleus) surrounded by atoms or ligands.

[13] These valences have a geometric structure, e.g., the coordination compounds with number 6 have an octahedral structure.

[14] In the same vein, [4]; critics of *the standard view*, admit that “the electrical industry constitutes an exception (to the view that technology is not applied science) since its birth and development were a direct consequence of scientific investigations […] the key event was the practical demonstration of electromagnetic induction performed by Michael Faraday in 1831: a short time after this they built electromagnetic generators for sale to the public” (p. 893).

amounts to saying that there is a meaning in which it is legitimate to claim that technology is a sort of applied knowledge, one in which we take advantage of the principles and laws of nature –for our own sake. In other words, technology can also be understood as the right use of the principles of nature for practical purposes. The requirement that principles and laws of nature must be perfectly known before any attempt at using them for the design of artifacts (or other practical ends) is too demanding and embodies a strong characterization of the relationship between science and technology that prevents all sorts of identifications between them. But it is far from obvious that our discussion of this relationship has to abide to such characterization or that it provides us with the right understanding of the way we can take advantage of forces, rules, relations and processes that we do not fully understand but that we are able to put at work.

Analogically, in the same way that arguing well presupposes applying correctly the principles of logic, even if we do not know them explicitly, a good design or device does imply the right application of the principles and laws of nature, even if they have not been explicitly formulated in natural sciences. In other words, a condition of possibility to design technological devices is to comply the restrictions imposed by nature.[15]

For instance, in a steam engine that transforms thermal energy into mechanical energy, the law of thermodynamics occurs, implying that energy is not created or destroyed but transformed, and there is no reason to worry about the fact that in the process of his invention and design, James Watt did not know the theory that explicitly stated these laws. The same applies to windmills as well. Windmills convert the energy that comes from the motor force—either wind or water—into mechanical energy. Additionally, the mill's blades move by following the same scientific principle that explains airplanes (or sailing): Bernoulli's principle, which was explicitly developed centuries after the invention of a windmill. Similar reasoning can be used for the use of the pigment technique. Alchemists and artists mixed a series of elements with astonishing precision to make pigments and dyes, and in doing so, all the chemical reactions that took place were possible by the laws of conservation of matter and defined proportions, among other scientific principles, albeit they were not explicitly known then.

## 3. Conclusion

To the question: "Is technology (still) applied science?" we give a positive answer that accounts both for the instances of technological designs developed long before the principles and laws of science that explain their functioning were available, as well as for those cases of technological realizations that were the conclusion of previous theoretical work. Since we hold that technology is still applied science regardless the arguments on the contrary, it becomes crucial to reiterate the deflated sense of *the standard view* that we endorse. We can do this, by recurring to the ideas of some realists [18,19] who follow the particular construal of empirical science famously advanced by Popper [20,21]. Popper explained at length, that empirical science starts with problems, searches by tentative solutions to those problems and tests those solutions against experience to adjust or discard them according to the outcomes of the tests. The method that makes progress possible is the tireless formulation of conjectures followed by merciless criticisms (refutations) or put it in a more familiar way: the method of trial and error. Such method guides not only the search for practical solutions but the quest for theoretical explanations and, in the long run, the hunting of scientific laws. This theory of science shows that technology and science share methods and ends. It also helps us to understand the nature of their relationship: they are mutually beneficial in the sense that just an intuitive understanding of the principles and laws of science is enough to produce noteworthy technological advances and that a full comprehension of such principles and laws leads to practical realizations (not to mention that the more profound our understanding of those principles is, the better our practical designs become). A deflationary interpretation of *the standard view* of the relationship between technology and science allows us to claim that technology is still applied science due to the give and take relation between them. The case studies posited by Skolimowski and others do not endanger this view in the same way that the multiple examples of technological devices designed only after the background scientific knowledge was fully available are not enough to prove, conclusively, the classical standard view. For this reason the deflated interpretation of technology as applied science needs to recognize both types of cases and allow for a mutual, dynamical and never ending relationship between technology and applied science.

Last, but no least, we contend that we should not be impressed by the historical evidence appealed to by the enemies of *the standard view* (unless we are ready to give the same attention to the cases studies that seem to support the very *standard view*). A good engineer –*qua* skilled designer– can be compared to a clever and insightful reasoner who using the natural powers of her mind can argue successfully without knowing the principles of logic. If we do not hesitate to recognize the special qualities of a natural reasoner who applies naturally the rules of logic that she is unable to formulate or explain in detail (a task of the logician), why would we doubt that the engineer can apply (intuitively) the principles and laws of science which explicit formulation is a task of the natural scientist?

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[15] One of the anonymous reviewers notices that the contention that artifacts are subjected to the constraints of natural laws (which is a part of our argument) is trivial. Put in this way he is right, it is trivially true that artifacts as well as natural objects behave according to the natural laws. Taking this criticism, we have revised our argument and replaced by another, quite different. To the thesis that technology is not applied science because there are some technological realizations achieved long before the discovery of the theories, laws and principles that govern their functioning we reply: (1) there are also some artifacts which invention was possible only after a working knowledge of the scientific principles that explain them; and even in those cases in which it seems the contrary, we can adjudicate to the designers an intuitive understanding of those principles. This answer, supplemented with a realist and analogical perspective can show that a deflationary interpretation of *the standard view* is preferable. To make this clear we can escape a similar criticism to our view, by the fact that, while Skolimowski believes that identifying technology with applied science requires that we know in advance all the scientific principles which explain and govern the functioning of every technological device ever designed (i.e. the explicit formulation of scientific theories and laws is a condition *sine qua non* of design), we hold that technology is still applied knowledge: technology is a sort of knowledge, one in which we apply sciences and use the laws of nature based in an intuitive understanding of them every time we lack their complete formulation in basic science.

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