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HISTORY | CRITICAL ESSAY

Photography in the boundaries of the visible. From Santiago Ramón y Cajal to Cecil Frank Powell

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Abstract: In this article, we analyze the use of photographic technologies of two renowned researchers whose investigation results would have been impossible to carry out, as occurs in Galileo a few centuries before with the use of imaging techniques, without the use of photography: Santiago Ramón y Cajal and Cecil Frank Powell, Nobel Prize winners in medicine in 1906 and in physics in 1950, respectively. These researchers were selected, first, because of their close relation with photography and, second, to clearly illustrate the gradual transgression of scientific photographic representation starting in the late nineteenth century from the visible to the invisible.

Subjects: Atomic & Nuclear Physics; Epistemology; Neurobiology; Philosophy of Science; Photography; Visual Communication; Visual Culture

Keywords: visual communication; scientific images; imaging; photography; history of science

> Quod tertio loco a nobis fuit observatum, est ipsiusmet LACTEI Circuli essentia, seumateries, quam Perspicilli beneficio adeo ad sensum licet intueri, ut et altercationes omnes, quæ per tot sæcula philosophos excruciarunt, *ab* oculata certitudine dirimantur, nosque a verbosis disputationibus liberemur (Galileo Galilei, Siderius Nuncius, 1610[1]).

1. Introduction

The use of visual elements became common practice in the scientific community from sixteenth century with the publication of the monumental illustrated works of Fuchs and Vesalius. In the spirit of faithful representation but also as objects of dialog and consensus, the use of visuals in scientific practice become usual early, as show e.g. the records of Royal Society, in which regular meetings the members decided on the most appropriate and relevant illustrations for inclusion in the articles to be published in *Philosophical Transactions*, as "a valuable way to establish, examine and share

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PUBLIC INTEREST STATEMENT

The current approach of scientific research to this expanded world is highly visual; if the current conception of the electron is so different from that of a century ago, or if timidly we begin to understand the complexity of the mind, this is undoubtedly a result of the use of technologies of visual representation of knowledge. In this article, we analyze the use of photographic technologies of two renowned researchers: Santiago Ramón y Cajal and Cecil Frank Powell, Nobel Prize winners in medicine in 1906 and in physics in 1950, respectively, to illustrate the gradual transgression of knowledge from the visible to the invisible using photographic technologies.

knowledge about a scientific object" (Kusukawa, 2011, p. 195). However, beyond the basic procedure of collective sanction to find the best way to generate the scientific knowledge, it was a process in which visual representation began to be considered as an objective reproduction of nature and soon acquired images evidentiary of solid qualities, especially from the illustrations of the Moon that Galileo did using the telescope that he had developed to demonstrate his mathematical proposals. For Descartes, in similar vein to Galileo, the use of illustrations, images, and diagrams was important to his research and an essential element to facilitate the communication of scientific truth.

In that early investigation context, illustrations resulting from the use of scientific instruments soon became common in research activity and acquired the quality of evidence, as shown, among many others, by Lüthy (2006, p. 97), who noted that: "In the case of most books, once we have read a few lines and looked at a few of the diagrams, the entire message is perfectly obvious. The rest is added only to fill up the paper." In short, the visual representation soon became by itself an autonomous epistemic object with an evidentiary nature; thereafter, this feature would be consolidated over the following centuries, especially with the invention of photography, which ended up assigning this quality of representation as *virtual witnessing*, "the most powerful technology for constituting matter of fact" (Shapin & Schaffer, 1985, p. 60).

When on 19 August 1839, the director of the Observatory of Paris, François Jean Dominique Arago, presented Daguerre's invention to the members of the Académie des Sciencies and of the École des Beaux Arts, he was justifying with vehemence its interest for its originality, relation to fine arts, its obvious practical uses, and above all, its great use in the Science. Niépcè and Daguerre expressed in a similar vein the usefulness of the new procedure that had been developed, and both wanted to record "real" nature, being eager to gradually refine their photographic techniques to reach high fidelity in their representation. Henry Fox Talbot, also, was working with identical premises when he began, ca. 1839, to develop procedures for the recording of images that he had collected in the first photographic book, *The Pencil of Nature*, published in 1844.[2] Talbot's purpose was to continue and complete new techniques for reproducing images of his invention with regard to the taxonomic work that the naturalistic Swedish philosopher Carl von Linne had begun at the end of the eighteenth century, in the wake of the monumental works that were distributed beginning in the sixteenth century.

After the public presentation of the photographic technology, scientists from different specialties soon joined in. Among the first was Ettinghausen, who was present at Arago's conference and who, on returning to his laboratory, realized the first photo of a cell under a microscope: he understood early on that photography could replace even the actual specimen for research (Thomas, 2008). By this way, from 1843, Anna Atkins started to elaborate botanical taxonomies from records on photographic paper of her collections of algae and ferns, and early, in 1855, Roger Fenton, the official photographer of the British Museum, published *Skeleton of Man and the Male Gorilla*. A few years later, Dr. Jules Luys was forced to resort to photography to save his reputation against criticisms on the lack of scientific credibility of his illustrated publication on the central nervous system of the human being, which was re-edited in 1873 and given the title *Iconographie Photographique des Centres Nerveaux*; the publication included 70 impeccable photographic images and 65 lithographs to eliminate any hint of subjectivity in the presentation of his research results.

The new technology of reproduction was definitively understood as very useful in natural science and medicine; in addition, it was not only a way to produce faithful representations but also a catalyst for further technological developments. Such was the set of chronophotographs published by Ottomar Anschütz in 1884, which represented storks taking off, flying, and landing in sequence and thereby became crucial to boosting the birth of modern aviation. The photographs showed early their supremacy for Science front illustration, and even Darwin included photographs and engravings in *Expression of the Emotions in Man and Animals*, published in 1872.

In sum, new techniques of representation immediately emerged in scientific work, and although there were a few brief years in which the illustrations coexisted with photographic reproductions, those were soon considered little more than an oddity and replaced by the new mechanical process according to the times (Tresch, 2007). Photographic techniques were expanding and being rapidly imposed as the technology for excellence in reproduction in the field of scientific activity. First, the new representational media definitely delegitimized any image or illustration that showed the slightest sign of artistry; second, its promise of fidelity made it the ideal representation to achieve the objectivity required by the scientific community at that time, initiating a path in which the representation started to acquire autonomy in relation to its referent.

Since then, the use of photography facilitated major advances in all scientific fields, such as those achieved by Robert Koch in bacteriology, which definitely strengthened the validity of microscopic images as scientific evidence. The neopositivist trend of "see and believe" (Hüppauf & Weingart, 2008, p. 11) would expand and consolidate this validity well into the twentieth century, eventually causing deep transformations not only in the way scientific work is understood but in all areas of culture.

The influence of the visual representation of scientific knowledge on the History of Science is undeniable. In addition, the new technique, as shown in recent works on photography (Nikolow & Bluma, 2008) or cinematography (Kirby, 2011), transformed forever the culture in all areas, sometimes with the invention of new techniques of representation through images, such as X-rays (or holography, but not strictly the later photographic images, such as radar, sonar, MET, PET, satellite images, etc.), or their use for testimonial purposes, as exemplified by the popular photography of Rosalind Franklin by which Watson and Crick demonstrated the structure of the DNA.

Photography, in short, opened an era in which the representation acquires evidential value, as *virtual witnessing*, which Daston and Galison (1992) called the era of "mechanical objectivity." Paradoxically, despite its attachment to reality, the representation is increasingly developing independence from its referent, even managing to turn itself into what has recently been named a *biofact* (Karafyllis, 2003), a product of the "chains of truth" that complies with the activity in our modern laboratories (Latour & Woolgar, 1979), with the ability to act as a catalyst for the development of new scientific paradigms as understood in our contemporary context (Kuhn, 1962).

In this article, and in the context of this framework, we will analyze the work of two renowned researchers whose efforts would have been impossible to carry out without the use of photographic techniques: Santiago Ramón y Cajal and Cecil Frank Powell, Nobel Prize winners in 1906 and 1950, respectively. These two eminent researchers were selected, first, because of their close relation with photography and, second, to clearly exemplify the progressive transgression of scientific representation in the twentieth century from the realm of the visible towards the invisible.

2. Classic microscopy. The visual borders of realism

Galileo designed his own microscope and made if first observation, of a bee, ca. 1609 from a previous prototype of Hansen and Zacharias Janssen. Some years later, the Dutch Antonie van Leeuwenhoek, after correcting some of the spherical and chromatic aberrations of the optics, was able to observe and accurately describe some micro-organisms, such as bacteria and sperm. *Micrographia*, by Robert Hooke, was published in 1665 with spectacular illustrations of living organisms, especially insects, observable only under the microscope. His contemporary, William Harvey, demonstrated by these dates the theory of blood circulation, also from his observation with a microscope. In spite of its proven utility, these early optical instruments were built with a simple glass lens and, besides important optical aberrations, had little capacity in terms of magnification, sharpness, and brightness. Jean Baptiste Biot, a contemporary and sometimes a rival of Arago, was the first to give news of a daguerreotype on 1 January 1839, in *Compte Rendus*, before his public presentation. He is credited with the metaphor about the camera, "rétine du savant" (Wilder, 2003). The merge of microscope and photography started to be the base for the next development of Science.

Ramón y Cajal, further for his wisdom, was known for his love of photography, which went far beyond mere entertainment, as shown from his numerous publications focused on photographic technology, from what seemed to be his first work (unpublished) on the History of Photography (1870) to his well-known book *La fotografía de los colores* (1912). Cajal understood photography as a technique that allows expanding the horizons of vision beyond human limits and, thus, reaching levels of scientific knowledge that until then had been inaccessible. He was a hard worker in general, but he tried too much to improve the processes of heliochromy that had been developed previously by Lippmann, also a Nobel laureate in 1908, about the color process without dyes based on wave interference and diffraction. Some authors even claim that Ramon y Cajal could have established the first industry for the production of photographic emulsions in Spain: "at the age of 27, he was an early visionary of instant photography, and had successfully cultivated the art to the point of producing ultrarapid gelatin-bromide plates of his own formulation, assisted by his wife Silveria Fañana's" (Triarhou & del Cerro, 2008, p. 2).

In any case, his expert knowledge of the photographic process allowed Cajal to adapt the staining method developed by his colleague Golgi, who would share the Nobel for it, for use in his histological studies of neuronal structure. Cajal learned this technique, which Golgi called "la reazione nera" and announced in 1873 without much success, from the prestigious psychiatrist Luis Simarro and, thereafter, began using it in his own laboratory.

The method was relatively simple and consisted of the immersion of fine neuronal tissue samples in different solutions of silver compounds that made neuronal cells visible by highlighting them on a yellow-orange background, in Cajal's words: "What an unexpected sight! Sparse, smooth and thin filaments or thorny black, thick, triangular, stellate, or fusiform black cells could be seen against to a perfectly translucent yellow background! One might almost liken the images to Chinese ink drawings on transparent Japanese paper [...] this is the Golgi method" (cf. De Carlos & Borrell, 2007, p. 9).

His discovery burst with authority in the dispute with Golgi himself and others on the matter and led to sorting out what the scientific community had been unable to solve until then: the question of the identity of the neuron and its functionality as a basic element of the complex brain structure. To prove this theory, Ramón y Cajal not only stained samples with his own improved Golgi method but also performed detailed schematic illustrations that were used as supporting evidence for his argumentations. His work, in that sense, is at the place where the evidential nature of the images converges with their rhetoric ability to persuade others to solve a theoretical dispute that had remained unresolved until then, with the authority of *oculata certitudine* that was formulated by Galileo centuries ago.

Cajal's cosmovision is imbued with the realism and scientific optimism typical of the early last century, and his research results have become a confirmation of the breadth of vision of "*rétine du savant*" in that they combine modern techniques of optical instrumentation and photographic recording in the service of science. It was only a question of gradually perfecting the work methodology towards achieving a technique of reproducing nature faithfully and in full detail. In Cajal's own words about color photography: "Faltaba todavía alcanzar el soñado ideal, es decir, descubrir medios prácticos para fotografiar los colores, trocando la siniestra visión de búho por la riente visión de hombre. Y este ideal, quimera inaccesible al parecer, se ha realizado al fin. Hétenos ya, gracias al maravilloso invento de Lumiere, emancipados de la intolerable esclavitud del blanco y negro."[3] Any concern about this arose from the imperfection of the research method used and even, ultimately, from lack of diligence or the tendency of human procedure to wander: "El devoto de la heliocromía no debe ser rutinario practicón atenido a recetas y formularios, al modo del carpintero que, aguijado por la necesidad, abandona la garlopa por el objetivo. Ocioso parece insistir en el vulgar argumento de que sólo acierta quien sabe. La interpretación de los resultados obtenidos y el remedio de los fracasos y accidentes, deben buscarse en la clara comprensión del mecanismo físico-químico de cada operación fotográfica"[4] (Ramón y Cajal, 1912).

In short, we are faced with a brilliant scholar and researcher who, in all his wisdom, clearly exemplified the classic scientific model of a scientist at the frontier of his epoch who, using advanced research methods and technologies, tried to solve relevant issues that may well be catalysts of a scientific revolution in the Kuhnian sense. What is noteworthy about Cajal is that his research work eventually culminated the long exploration with optical instruments began centuries ago to reach the visible boundaries of nature. As aptly expressed by Garlick (2009, p. 98), a well-known character in biological science: "we might say that biological science shares with photography an uncertain location between Romanticism and positivism. Both seek objective truth, but are haunted by something that is fundamentally unknown and unseen, and which structures the historicity of nature. Photographic vision promises to restore the meaning of nature or life, but it continually delivers only informatic residues of experience."

Ramón y Cajal was attached to reality; in fact, he could not put his vision elsewhere than according to his epoch and the foundations of his research discipline. However, this model of *faithful photography of visible reality* soon entered unknown dimensions, which, decades later, were shown critical to review the familiar position about *reality* in biological science that exemplifies our laureate wise.

3. The omnivorous retina. The photography of the invisible

Galileo was more than a microscopist and telescopist; he was more an astrophysicist than a biochemist in contemporary terms and was known for his adhesion to the heliocentric theory that was originally proposed a couple of millennia ago by Aristarchus of Samos, followed by Nicolas Copernicus and, as a transitional way from ptolemaic system to heliocentric thesis, Tycho Brahe. His disciple Johannes Kepler proved the crazy theory of heliocentrism, and after that astronomy continued to develop with the help of optical instrumentation in the hands of Huygens, Newton, Bradley, and Herschel, among many others.

Daguerre himself made the first astronomical photographs, commissioned by Arago, although success did not come until 1940, when William Draper registered the first daguerreotype of the Moon. The eminent geographer and naturalist Alexander von Humboldt, who beheld the imperfect and slightly sharper image made by Daguerre, soon became enthusiastic about the new technique; this led him to publish in 1845 his work *Cosmos*, which included photographic images.

From 1859, Robert Bunsen and Gustav Kirchoff had begun to develop methods of spectroscopic analysis, prompting a visual culture in the field of scientific research in which "spectroscopy played to significant part in establishment to dwells visually oriented science culture, remove in step with other fields, which were drawing away from to rigid textual orientation at roughly the same steal" (Hentschel, 2002, p. 14). The Swedish Angström would later show the relationship between the radiating lines and the chemical composition of the object from a spectrographic study of the presence of hydrogen in the solar atmosphere, thus inaugurating astrophysics. In 1912, the American Henrietta Leavitt designed a photographic method to estimate the distance of the stars based on the observation of some red dwarfs. Nowadays, we analyze the situation and composition by considering the Doppler effect and based on mathematical proofs, as did Edwin Hubble, who in 1929 studied in detail the photographic record of the cosmos and concluded that there are countless galaxies moving around, thereby proving that the universe is expanding at a speed proportional to its distance.

Early, at the dawn of the twentieth century, imaging technologies that would greatly revolutionize scientific research techniques and produce deep cultural transformations over the following decades were developed.[5] Thereafter, imaging technologies began to be used in practical applications in all areas, especially in military industries and medical diagnosis, starting with the development of nuclear technologies and the study of the interior of the human body through nonsurgical methods.[6]

A highly visual culture started to form and thus became the dream of many, such as the physiologist Marey, who "dreamed of a wordless science" and was conclusive in this regard: "There is no doubt that graphical expression will soon replace all others whenever one has at hand a movement or change of state—in a Word, any phenomenon. Born before science, language often is inappropriate to express exact measures or definite relations" (Daston & Galison, 1992, p. 81).

Until the emergence of these imaging technologies, the classical optical instruments had provided an extended macro- and microscopic vision, but always within the range of the visible because they did not allow magnification greater than 10 μ (10^{-6} m, a size slightly larger than the diameter of, for example, human hair, which is about 75 μ). That is to say, a resolution capability lower than it is needed to study atomic structures because the diameter of the largest of the known elements, hydrogen, is about 10^{-10} m. These limits began to be crossed with the use of techniques of X-ray diffraction and, in around 1931, with the development of the first prototype of a transmission electron microscope (TEM) by Ernst Ruska, who also earned a Nobel Prize in 1986. However, since the early twentieth century, with the discovery of X-rays and diffraction analysis techniques, physics has been at the forefront of the biological science; in this regard, no one could ever equal the contributions of skilled microscopists such as Cajal.

Those seemingly advanced photographic techniques were actually becoming less so, in the same way that this world of wise experts was beginning to become obsolete, breaking the cosmovision that was cemented in reality and in the foundations of scientific positivism. Although until quite recently, classical photographic techniques have been used to record *oculata certitudine*, such as with the famous first photographs of Earth from space obtained in 1961 by the Russian cosmonaut German Titov. Along twentieth century, the use of photographic techniques were improved to reach levels of quality difficult to imagine for the own Cajal, greatly amplifying, since his epoch, its demonstrative and rhetorical power along the century.

The images were of such shocking quality and colors that they excited scientists and society as a whole and, in addition to becoming cultural icons, became crucial to the promotion of research in remote sensing images, which are currently used as tools in the analysis of atmospheric phenomena and plant pests, fire prevention, mining and geological prospecting, and desertification studies, among many other applications.[7]

In short, visual representation with photographic images served as *oculata certitudine*, as it does nowadays, inasmuch as Galileo understood it, but its claims of independence from its referent started to be loaded with theory in the early twentieth century as it crossed over to the realm of the invisible. With these cutting-edge imaging technologies that allowed us to explore beyond the visible spectrum, we entered fully into the era of *theory-ladenness* (Hanson, 1967), in which the epistemological framework applied the aforementioned revolutionary works of the 1960s in the history and sociology of science of Kuhn or Latour, among others.

The focus of this work is not to develop a critical analysis of the objectivity of visual representation but to present our position regarding the theoretical framework that is introduced and developed throughout the text as well as the concept of *reliabilism*. The latter is a generic approach to epistemology that emphasizes the need for truth as integral to the development of all kinds of knowledge, scientific or otherwise, from the creation of favorable conditions for holding on to that belief (Goldman, 1967; Goldman & Olson, 2009), which is closely related to the social order (Shapin, 1994).

We are concerned about the importance of photography in the work of Powell, who received the Nobel Prize in 1950 for "his development of the photographic method for the study of nuclear processes and his discoveries concerning the mesons" (Lindh, 1950). A research paper that, unlike that of our beloved histologist, was already locate in our modernity, in time every time more complex research structures and technologies transgressing the borders of the visible with traditional optical instruments. With Powell we are faced not only with research methods that *extend* human vision;

rather, his use of photographic technologies exemplifies the culmination of recording techniques for the invisible, which were initiated by spectroscopists, and, overall, the irreversible claim of independence of visual representation from its referent.

4. Emulsions, emulsions. Measuring the invisible

In the early twentieth century, photography and cinematography prompted a profound cultural transformation that permeated every corner of society, including scientific research. New technological advances revolutionized the way of knowledge production, and a visual culture was imposed quickly and forcefully in all areas, determining the future evolution of the newborn century. In those years, physics research proposed revolutionary explanations of the structure of matter through the works of Boltzmann, Poincaré, Einstein, Bohr, Heisenberg, and Pauli, among others,[8] which applied an intense and extensive research strategy that was eminently visual, as shown, for example, by Miller (1984).

Since the 1920s some physicists have experimented with nuclear emulsions (Perkins, 2005); however, the efficiency of such method has not been proven, mainly due to emulsion sensitivity problems in recording various types of particles, especially the fastest moving.

In the 1930s Hideki Yukawa proposed a peculiar atomic theory using a particle, the meson, mathematically placed between protons and electrons. The existence of this subatomic particle was demonstrated in 1937 with the discovery of a kind of energy in cosmic rays that seemed to stand within a range of values but whose mass was impossible to calculate accurately. It was in this context that Powell worked during those decades, applying the technique of photographic recording, which had been used since the early twentieth century to demonstrate radioactivity but was not popular as a research methodology among nuclear physicists at that time.

By 1935, small steps had been taken towards the detection of protons; specific sensitization had been previously studied in experimental work carried out at the Ilford Laboratories and by the Russian Zhdanov, but most nuclear physicists were skeptical of the technique and preferred to conduct research on the Wilson chamber, the effectiveness of which had been tested since the beginning of the century. In the expansion chamber, or the Wilson chamber, energetic particles leave visible traces after interacting with the hypersaturated steam inside at a very low temperature, acting as condensation nuclei around which is formed a typical fog trajectory of each type of particle. In his own way, Powell, together with his research team, had been working since the late 1930s on various improvements in emulsions, optics, and registration procedures, which culminated in an accurate methodology fully developed at the late 40s and able to be used in all photographic technologies that later allowed him to prove the existence of the meson to the scientific community (Lattes, Muirhead, Occhialini, & Powell, 1947).

As previously mentioned, since the beginning of the century, the photographic recording of energetic outlines has been used with limited success in physics for detecting subatomic particles (Ditlov, 2001). However, Powell used a few advanced Ilford emulsions that were more sensitive and accurate than those available years ago; this enabled the precise measurement of the new particles, which hitherto had been only theoretical. The emulsions were exposed to an altitude of 2,800 meters at the Pic du Midi (in the French Pyrenees) and of up to 5,500 meters with the use of polyethylene balloons, allowing them to make photographic records of up to 3,000 lines of energetic particles on a surface of 3 square centimeters. The Wilson chamber, which also required photographic recording to capture in stable condensation the trace that produced these ionized particles in the gas inside, needed approximately 20,000 stereoscopic photographs to obtain about 1,600 lines useful for measurement, thus indicating the practical usefulness and economy of the new technique developed by Powell (Lindh, 1950).

Using these emulsions, Powell demonstrated the existence of different particles, including primary and secondary mesons, which he called π-meson and μ-meson, respectively, and determined their masses as 286 and 216 times superior to the electron. In 1949, thanks to the introduction of the new Kodak NT4 emulsion, his research team observed that the μ-meson disintegrated into at least two particles and discovered the existence of another particle, which he called τ-meson, with a mass greater than 1,000 times that of the electron. The problem that needed to be resolved had to do with the emulsions, which should be thin enough to be observable under a microscope and, simultaneously, sensitive enough, i.e. with a high granular density, to allow the recording of low-energy particles passing through it.

If these double conditions were fulfilled, the technique would be relatively simple: the emulsion would be exposed and revealed under precise control of the process, and the trace of the particle had struck the emulsion would be visible as a dark line formed by grains of bromide silver that had been affected in its wake. This is assuming that the distance between the grains is proportional to the velocity of the particle and that the faster particles have less power of ionization than the slower ones, just enough to measure the distance between the grains that form every outline and to release its energy and, in consequence, to determine its mass. In the words of Powell and his collaborators:

> In identifying the track of mesons we employ the method of grain-counting. The method allows us, in principle, to determine the mass of a particle which comes to the end of its range in the emulsion, provided that we are correct in assuming that is charge its of magnitude |e|. We define the grain-density on a track as the number of grains per unit length of trajectory. Knowing the range-energy curve for the emulsion, we can make observations on the tracks of fast protons to determine a calibration curve showing the relation between the grain-density in a track and the rate of loss of energy of the particle producing it. With this curve, the observed distribution of grains along the track of a meson allows us to deduce the total loss of energy of the particle in the emulsion. The energy taken in conjunction with the observed range of the particle then gives a measure of its mass. (Lattes et al., 1947, p. 694)

With his photographic method, Powell provided accurate calculations and showed what Wilson's camera could not efficiently do. Both photographic recording techniques allowed the visual study of the behavior of cosmic particles and, in the case of the method of Powell, the precise measurement of their mass in a more efficient and economic way.

The other cutting-edge technologies available at that time were of the *trigger* type, such as the Geiger counter and the scintillation counter; these took advantage of the photoluminescent properties of some materials, such as zinc, which, coupled to a photomultiplier tube, converted the energy of particles that impinged on phosphorescent light energy. To do this, physicists used a device called *spinthariscope*, which allowed observing the particles under a microscope; the *spinthariscope* was invented in 1903 by Crookes, an eminent spectroscopist who contributed, among others, to the advance of particle physics during the following decades by developing a vacuum tube that facilitated the study of electrons (Brock, 2008).

In sum, we argue that scientific research, and particularly physics, had made intensive use of cutting-edge imaging technologies in the last decades of the nineteenth century, since the invention of photography, and especially from the early twentieth century. The photographic registration method developed by Powell was merely an adaptation of known techniques, which made his research results possible, thanks to the characteristics of the new emulsions designed for the study of cosmic particles. In addition, using these photographic techniques of visual representation, Powell finally banished the idea of indivisibility of the atom and unveiled particle physics as a rich, visible subatomic universe that had hitherto been inaccessible and invisible.

The culture of knowledge had become entirely visual by the middle of the twentieth century. The area of physical research exemplifies this, as clearly shown in the language used by Powell himself and in his desire to realize a picture of the universe; in concluding his speech at the Nobel ceremony, he said:

> In the years which have passed, the study of what might, in the early days, have been regarded as a trivial phenomenon has, in fact, led us to the discovery of many new forms of matter and many new processes of fundamental physical importance. It has contributed to the development of a picture of the material universe as a system in a state of perpetual change and flux; a picture which stands in great contrast with that of our predecessors with their fixed and eternal atoms. (Powell, 1950)

However, and to finish his speech, Powell stressed the tentativeness of theories that represent the universe: "a number of widely divergent hypotheses, none of which is generally accepted, have been advanced to account for the origin of the cosmic radiation"; thus, he clearly established differences in the way research in physics is addressed in relation to other academic disciplines. This is very different from how the biological science have been understood, as evident in the words with which Ramon y Cajal, with a more totalitarian spirit, concluded his Nobel acceptance speech: "To sum up: from the entirety of the observations which we have just shown, and from many others about which we have not the time to talk, the doctrine of neurogenesis of His is clearly revealed as an inevitable postulate."

One way to address the knowledge in natural science, in which, for Cajal, the claims of absolute objectivity form a part of its own (proper) discipline, is to consider the research results in physics from a very different point of view, as Powell did.

5. Conclusion

In sum, Cajal and Powell, Natural Science and Physics, offer different approaches to research that could be understood simply as, respectively, more *bottom-up* or *top-down*. In the case of the natural science, and especially since the nineteenth century (Breidbach, 2002; from De Rijcke, 2012), this concerns the authority of the referent. By contrast, physics research, guided by creative visual imagery (Gruber & Broeder, 2005; Nersessian, 1992; Thagard & Hardy, 1992), uses heuristic strategies to develop theories that are later partially demonstrated, as it does today.

In the decades between the neurophysiological *findings* of Santiago Ramón y Cajal and the *demonstrations* of quantum theories of particle physics by Cecil F. Powell, research procedures have been greatly transformed, particularly due to the development of imaging technologies, which have been imposed in all areas, including the scientific fields, and which irreversibly formed the visual culture that now characterizes our contemporary society. Investigation procedures have also shifted from a personalized scientific research model towards a collective model of knowledge production highly technologized inside our own current laboratories that use complex visual tools designed to transgress the boundaries of the visible.

In conclusion, the visual representation of knowledge during the early decades of the twentieth century has become extraordinarily dependent on technical imaging instrumentation designed to explore the realm of the invisible; as a result, visual representation has ended up acquiring autonomy from its referent because it no longer serves as *oculata certitudine* of the visible. Whether we invent it or it is naturally out there is another metaphysical question that is not considered in this brief text; this should probably be approached from the perspective of a critique of anthropocentric modernity in the frame of postmodernity but without falling into its excesses.

In any case, the fact is that our contemporary visual culture has become ubiquitous, and the visual representation of knowledge is based on the collective reliability of assigning meaning to a complex high-tech scientific environment (Allamel-Raffin, 2011; Greenberg, 2004; Rosenberger, 2009). Since the time of Galileo, and today more than ever, scientific activity should be understood as the production of knowledge that aims to make visible, and therefore familiar (Wise, 2006), all that remains unexplained in our perceptual environment, as well as everything beyond our limited sensory experience.

The current approach of scientific research to this expanded world is highly visual; if the current conception of the electron is so different from that of a century ago (Arabatzis, 1996), or if timidly we begin to understand the complexity of the mind (Kosslyn, 1987; Mora, 1995), this is undoubtedly a result of the use of technologies of visual representation of knowledge—knowledge that today is *mapped* (Manovich, 2008; Tufte, 2006), *simulated* (Humphreys, 2009), and accessed through *interfaces* (Quaggiotto, 2012), as part of the *gaming culture* (López Cantos, 2012).

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Notes

1. "What was observed by us in the third place is the nature or matter of the Milky Way itself, which, with the aid of the spyglass, may be observed so well that all the disputes that for so many generations have vexed philosophers are destroyed by visible certainty, and we are liberated from wordy arguments," (transl. A. Van Helden, 1962, p. 62).
2. The book included six volumes with a total of 24 original talbotips ranging from landscapes and architectural views to inanimate objects, copies of engravings, stills of laces, and other similar objects that allow exploring the limits of the new reproduction technology.
3. "It was necessary still to reach the dreamed ideal, that is to say, to discover practical means to photograph colors, changing the sinister vision of the laughing owl for man's vision. And this ideal, apparently an unreachable chimera, has been realized to the end. We are at last, thanks to Lumiere's wonderful invention, emancipated from the intolerable slavery of the black and white."
4. "The devotee should not be a routine practitioner of heliochromy stuck to recipes and forms, like the carpenter who, goaded by the need, leaves the accuracy and the methodology for his goals. Idle seems to insist on the vulgar argument of only there succeeds the one who knows. The interpretation of the obtained results and the remedy of the failures and wrecks must be found in the clear understanding of the physic-chemical mechanism of every photographic operation."
5. The cultural impact of visual technologies produced significant changes, such as the derivatives of the popularization of chronophotography and its conversion in the entertainment industry, with the invention of cinematography by the Lumière Brothers and Porter–Edison. However, two imaging technologies that would provoke deep changes in the methods of scientific research were also developed and its effects accelerate transformations over the twentieth century in all cultural areas. The first of the discoveries came from Wilhelm Roentgen, who on 8 November 1895, detected a type of radiation, which he called X. Early, in 1910s, William Henry and William Lawrence Bragg used X-rays for accurate measurement of the distances between defined rows and columns of some crystal atoms, demonstrating that diffraction patterns differ depending on the materials explored. The second major scientific breakthrough that inaugurated the twentieth century was the discovery of the radioactivity of uranium by Henri Becquerel in 1896, who had developed, with Marie and Pierre Curie, the theory of radioactivity.
6. The impact that nuclear technology has had on warfare and on the design of energy policies since then is well-known, but not its influence on biological or human body research. In medical diagnostics, the use of dissection rooms in the study of living bodies has diminished with the application, first, of X-rays and, nowadays, of nuclear technologies (Pasveer, 1989). The doctor–patient relationship with regard to the diagnosis of disease has already begun to change, becoming more distant than in the mid-sixteenth century, when the body had to be dissected (Sawday, 1995). Since then, with X-ray imaging and nuclear technologies beginning to explore the dimensions of the invisible, the patient has become an object of study observable with the clinical eyes of noninvasive imaging technologies.
7. Paradoxically, classical photochemical techniques, in their greatest fullness, became obsolete with the development of the CCD device in 1969, which inaugurated the era of the sensors: "one afternoon over one of our frequent brainstorming sessions at the blackboard. We began drawing a diagram, and before it was finished, we knew we had something special. After a few weeks of work, George asked the 'shop' to make a model of our device. Somewhat to our surprise, the very first model worked as we had hoped. The first 3-bit device was born" (Boyle, 2009). The inventors of the CCD device also received a Nobel Prize; for his lecture during the ceremony, William S. Boyle chose the title "CCD—an Extension of Man's Vision," which is quite significant in that it expressed, four centuries later, the same thoughts from Galileo with which we started this paper.
8. Rutherford received a Nobel Prize in chemistry in 1908, the same year that Cajal won, for his studies of radioactivity and the disintegration of the atom, which allowed him to demonstrate the divisibility and existence of an atomic nucleus. Years later, scientific research revealed the existence of subatomic particles, including muons, the existence of which Powell demonstrated; nowadays, the world of particles is like a zoo populated with quarks, leptons, bosons, pions, kaons, etc. the relationships of which the scientific community endeavors to discover and place neatly on the particular matter cosmogony that supports contemporary physical theories.

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