

The Sciences as Processes: Gaston Bachelard, the Public Communication of Sciences and *Total Museology*

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ABSTRACT

Part of Gaston Bachelard's extensive work has been applied in many areas of philosophical and humanistic research; however, his contribution to the field of public communication of science and museology is brief. The main objective of this ESSAY is to present the convergence of some of the ideas expressed by Bachelard with respect to the sciences: their historical study, their teachings and learnings, with recently enunciated proposals for museums and science centers. Bachelard's words have, in particular, many parallels with Jorge Wagensberg's *total museology*, developed in the last decades of the 20th century, and, as it is intended to demonstrate, can form a useful foundation for current museological thinking.

KEYWORDS

Gaston Bachelard; communication of the sciences; scientific knowledge; museology; museums; science centers

INTRODUCTION

Gaston Bachelard's¹ work entitled *The Poetics of Space* (1965), published in 1957, has contributed thought-provoking ideas to the realms of museological design, the search for a better use of spaces, and curatorial work, to promote mean-

¹ Gaston Bachelard; Bar-sur-Aube, Champagne, 1884-París, 1962.



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Intervención

JULIO-DICIEMBRE 2020
JULY-DECEMBER 2020



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ingful experiences among visitors.² However, in the world of museums, there is still little recognition for this author's perspective on the sciences and the way in which they are communicated and taught, despite the fact that, as I will argue in this ESSAY, the French philosopher's extensive works have many points of convergence with contemporary museological research and constitutes fertile ground for the construction of useful reflections for museums, specifically those dedicated to the public communication of the sciences.

Jorge Wagensberg's *total museology* (2015) and other contemporary proposals bet on a dynamic exhibition of the sciences, based on their methods and on the dialogue between objects, phenomena and metaphors. Like Wagensberg, Bachelard for his part, maintains that the sciences are unfinished processes or forms of knowledge that include a critical attitude, creative subjects, forms of experimentation and scientific instruments, in short, activities whose progress is defined by the intervention of institutions and communities over time (Rheinberger, 2010, p. 25).

The main objective of the following sections is to highlight the convergence of some of the ideas expressed in Gaston Bachelard's work with new or recently enunciated proposals for museums and exhibitions aimed at the public communication of science, and even, to identify approaches in Bachelard's ideas that could contribute to the redefinition of museums and science centers as relevant institutions for today's world.³ I shall take one event in particular as my starting point: Bachelard's lecture at the Palais de la Découverte in Paris in 1951. There, Bachelard stressed the importance of portraying science as an enterprise under construction, whose progress is the result of a complexity of actions and decisions over time. In the first part of this piece I will present some of the central arguments in the philosophical study of the sciences from Bachelard's works, with a view to identifying their links with 21st century museology. Museums with a scientific vocation, known as museums or science centers, tell their own story (Espinosa, 2016, p. 208), but even though their transformations are evi-

² The Museum of Modern Art in New York (MOMA) adopted Bachelard's ideas in an event aimed at reflecting on the effect of museum spaces on our experience as visitors (MOMA, 2018).

³ The International Council of Museums (ICOM) has set out to construct a new *museum* definition. During 2019 it opened a call for proposals to shape a new definition that would be voted on at its 25th General Assembly in Kyoto, Japan, in September of that year. The task is complicated, since the intention is to integrate a definition that includes the social and cultural demands of today's world. An agreement among the voting members is expected to be reached by 2022 in Prague, Czech Republic.

Intervención

JULIO-DICIEMBRE 2020
JULY-DECEMBER 2020



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dent, the demand to update and remain up to date grows stronger every day: visitors must “understand science”, not just admire or see it. Perhaps Bachelard’s words on the natural and experimental sciences will illuminate part of the path our museums must follow.

GASTON BACHELARD

Conference in a museum

Paris, 1951. As the second half of the 20th century began, Western discourses were filled with reflections on the great artistic and technological feats of the major European powers, both on the possibilities of overcoming the harsh aftermath of war conflicts and on the ambivalent conception of the experimental sciences⁴ which were seen as synonymous with progress and destruction (Rheinberger, 2010, p. 19). One of the most appropriate places to meditate on these issues, and possibly one of the most emblematic for the sciences in France, was the Palais de la Découverte, which since its design and construction in 1897, and its inauguration as a science museum in 1937, had the exhibition of economic, industrial, political and technological advances in the civilized world as its main vocation.⁵

Originally, the Palais de la Découverte was conceived as a creative and dynamic space, with exhibitions that allowed its visitors to assimilate concepts and ideas, and to understand the sciences (Espinosa, 2016, p. 28). Neither contemplation nor the transmission of knowledge were among its objectives. Despite the adverse conditions and the destruction of part of its halls during the Second World War (Bergeron & Bigg, 2015, p. 203), the Palais de la Découverte has been, and continues to be, an institution that aims to reveal the background of the exact and natural sciences, to motivate curiosity among visitors, to inspire scientific vocations, to highlight the role of the sciences in society, and to reflect on the challenges of the modern world.⁶

Thus, with a strong social responsibility, in 1951 this museum integrated a series of weekly conferences to its program of activ-

⁴ Mainly, physics and its new developments.

⁵ The Palais de la Découverte opened its doors on May 24, 1937 in the context of the *International Exhibition of Arts and Techniques in Modern Life*, supported by the University of Paris (La Sorbonne). As a museum, it was mainly inaugurated with the participation of Jean Perrin, Nobel Prize for Physics in 1926, and André Lèveillé, an industrial designer with great talents in management and organization, both of whom were concerned with French scientific research in the inter-war period (Bergeron & Bigg, 2015, p. 190; Eidelman, 1985).

⁶ Official website of the Palais de la Découverte: <http://www.palais-decouverte.fr/fr/accueil>

Intervención

JULIO-DICIEMBRE 2020
JULY-DECEMBER 2020



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ities. On the first Saturday of each month, a scientist, philosopher or historian, be it French or foreign, whose professional career allowed him to share their scientific or technological expertise, would be presented. In a list of 79 talks, we can find the names of many famous, such as Georges Canguilhem, Alexandre Koyré, Sophie Piccard and, of course, Gaston Bachelard (Colnort, 1962, p. 87).⁷

A postal service officer, a soldier in the Great War, a physics professor and a leading philosopher of science at the Sorbonne, Bachelard gave the fifth lecture in this series organized by the Palais de la Découverte. The title of the series, *L'actualité de l'histoire des sciences* (*The present day of the history of sciences*), was described by its author as “a true anachronism”, for focusing more on facts of the past than on the imperious modernity of science exhibited in the museum’s spaces (Bachelard, 2015, p. 129). However, the implications of Bachelard’s words during his lecture and, more broadly, of his philosophical statements are significant in the realms of museums dedicated to the communication of the sciences.

Although the presence of a specialist in the history of science in an act destined to the scope of science in modern times is paradoxical, in reality Bachelard intended to discuss the relevance of the history of science in contemporary scientific thought. That is, beyond simple and idle curiosity, why should it be necessary to integrate a historical approach into a science museum? What would be the relevance and possible effects of presenting, with all its difficulties and errors, the past? The conference began with this statement:

In many ways, today’s science can be considered through its revolutionary discoveries as a *liquidation of a past*. Here are discoveries that bring immediate history back to the rank of prehistory. Thus, the past of science could, in certain cases, be revived merely out of historical curiosity...

[...]

Then we find ourselves before the heroic dialectic of the scientific thought of our time, before the dialectic that separates natural curiosity and scientific curiosity where the former wishes to see, the latter wishes to *understand*.

⁷ These conferences dealt with a wide variety of topics: anatomy, astronomy, geographical charts, crystallography, pharmacopodia, geometry, universal gravitation, parasitology, natural selection, zoology, among others. All of them were published in a series of booklets entitled *Histoire des Sciences* (*History of the Sciences*) in the collection *Conférences du Palais de la Découverte* (*Conferences at the Palais des Découvertes*) (Colnort, 1962, p. 87).

Intervención

JULIO-DICIEMBRE 2020
JULY-DECEMBER 2020



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In my opinion, this dialectic is the very philosophy of the Palais de la Découverte. Indeed, a visitor should not enter the Palais de la Découverte merely to see, he should come here, and come often, to understand. The Palais de la Découverte is not a museum for voyeurs. One should not walk around it on a rainy day, simply to pass or kill time. They should come to work. To work on their spirit. By understanding science in its novelty, one comes to make a new spirit for oneself [Bachelard, 2015, p. 129].⁸

The dialectic between natural curiosity and scientific curiosity, between ordinary knowledge and scientific knowledge, between “wanting to see” and “wanting to understand” creates a game of interest for the Palais de la Découverte and for any space that wishes to exhibit scientific content. As visitors, we can ask ourselves about our motives for visiting a museum, about our objectives and about the benefits obtained. As creators and scholars of museums, the questions are: how do we best convey science? How do we overcome natural curiosity and offer experiences that allow and promote the appropriation of knowledge among visitors and, in Bachelard’s words, for them to “work” and “understand science”?

REFLECTIONS ON SCIENCE

The ancestral temporality of questions about science, its structure and evolution in time, makes us think that the probability of reaching easy answers is reduced. Hot debates and captivating arguments have filled pages and answered queries over centuries, long before Gaston Bachelard appeared on the scene. Defining science as a knowledge enterprise is a task that escapes from our grasp, because of the amount of questions that appear in a sequential way and because of the differentiated approaches that authors have given in answering each one of them.

Various theoretical schools across many parts of the world have addressed similar questions about scientific knowledge. While the Vienna Circle, represented by Moritz Schlick, Rudolf Carnap, Pierre Duhem and Otto Neurath, among others, advocated a renewed positivism,⁹ in France things took a particular direction, one centered around the leading role of history and time. The works of authors such as Bachelard himself, Georges Canguilhem and

⁸ Editorial translation from the Spanish version.

⁹ This philosophical movement was called *logical positivism*, *neo-positivism* or *logical empiricism*.

Intervención

JULIO-DICIEMBRE 2020
 JULY-DECEMBER 2020



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Michel Foucault are examples of an epistemology based on historical analysis, the study of (dis)continuities and the consideration of the material and social conditions that frame the construction of knowledge. The philosophy of French science in the 20th century, in many ways opposed to the vigorous existentialism of its compatriots, openly fought against scientific dogmatism and affirmed that the generation of knowledge cannot be reduced to fixed systems of relationships and methods, but is a complex process of elaboration and verification of hypotheses, and of struggles for power.

In general, the numerous philosophical approaches to the sciences could be studied in three categories: 1) Positivist, which defines the exact and natural sciences as valid knowledge, based on empirical experience (Sánchez & Tagüeña, 2011, p. 85); 2) critical or Kantian, which sees the different sciences as providers of first-rate knowledge, and 3) metaphysical or ontological, which promotes access to philosophical truths that are independent and superior to any science. The empiricist perspective includes the works of Ernst Mach in Germany and Henri Poincaré in France, who soon received strong criticism from neo-Kantians, such as Bachelard. Finally, the ontological line included the phenomenology of Husserl, the existentialism of Heidegger and Merleau-Ponty, and the poststructuralism of Deleuze (Gutting, 2005, pp. 1-2).

Then, during the first part of the 20th century the philosophy of science in France became defined by the intense activity of scholars attached to a neo-Kantian philosophy which, like Bachelard, defended an “applied” or “committed” rationalism, which placed reason as the axis of knowledge, but inserted it into specific social contexts that were accompanied by individual experience.¹⁰ Logical positivism maintained the belief that the exact sciences form the only system of knowledge that has managed to escape from relativism and achieve universality, as well as the truth about the world (Descolá, 2013, p. 61). Their approaches, however, lose sight of both historical contexts and scientific practices across classrooms, field work, laboratories and workshops, and the communicating vessels between the sciences and other forms of cultural production. Bachelard’s philosophy, on the other hand,

¹⁰ Although Bachelard sought to transcend positivism, it is undeniable that much of his work focuses on epistemological aspects that do not register the relevance of the external or social aspects of science. Undoubtedly, it will be seen that already in the 20th century authors such as Thomas Kuhn and, recently, Bruno Latour will manage to question the Kantian division between nature and society in order to integrate another type of analysis to the studies of science. For instance, in his *Actor-Network Theory*, Latour (2005, p. 97) suggests increasing the list of actors operating in science and recognizing that objects also participate in the course of action of social relations.

Intervención

JULIO-DICIEMBRE 2020
JULY-DECEMBER 2020



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fought for a historicized definition of scientific knowledge, where perfection and certainty are only rare and whimsical exceptions (Knorr-Cetina, 1981, p. 2).

More than three decades before Thomas Kuhn moved the world with his ideas about scientific revolutions and paradigm shifts, Bachelard had already proposed a philosophical approach that would show “under what conditions —both subjective and objective— certain general principles lead to particular outcomes, to diverse fluctuations; and also, under what conditions particular outcomes suggest generalizations that complete them, dialectics that produce new principles” (Bachelard, 2009, p. 11). Bachelard presents a “philosophy of no”, understood as a particular form of open Kantism, functional Kantism or neo-Kantism, that thinks of the rationality of the sciences in a dynamic way and as activities that always seek to go beyond the initial clarities, that try to overcome the immediate realism of sensitive knowledge and that fight against closed epistemic frameworks that prevent meaningful change in research.

Retaking Bachelard’s words at the Palais de la Découverte, his reflections on science were aimed at looking “behind the scenes”, at conceiving reason as the support of science, but always in terms of the unpredictable issues that we face in everyday life and that science, as a great human enterprise, has faced and overcome on more than one occasion. Visitors to a science museum can achieve a new spirit —the scientific spirit— when we give importance to the progress of the past, the memories of the study of a subject, and the memory of heroes and geniuses¹¹ (Bachelard, 2015, p. 140).

The study of sciences as processes

The qualification of Bachelard’s perspective as “applied rationalism” has a very broad background behind it. On the one hand, as mentioned previously, it refers to the prominence given to external conditions (historical and social) in the construction of scientific knowledge, but consequently, also to the dialectic between reason or idealism and technical work and its material aspects.

¹¹ New directions in science studies recognize it as a situated, embodied and material phenomenon. This means that science is seen as a human adventure involving people and communities that do not always stand out as “heroes”, but whose participation in the construction of knowledge is vital. Women and members of lesbian, gay, bisexual, transgender, queer, intersex and asexual (LGBTQIA) communities well deserve a space in the study of science as subjects who provide unique perspectives and raise different research questions, but also as a sector that since Hypatia of Alexandria in the fourth century and Hildegard von Bingen in the 12th century, have actively participated in all areas of knowledge.

Intervención

JULIO-DICIEMBRE 2020
 JULY-DECEMBER 2020



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In scientific research, experience and observation cannot be detached from theory, just as theory cannot be detached from experience. Therein exists a reciprocal dialectic that allows Bachelard to speak of a solidarity between mathematics and experience. This reciprocity and solidarity mean that in science, one cannot speak of the imposition of one point of view over another; hence the proper epistemological attitude behind a philosophy of science is, that of an *applied rationalism* equally distant from extreme realism and extreme idealism, and in which every theory is ready to receive and integrate any novelty that may surface from experimentation [...] [Martínez, 1992, pp. 94-95].¹²

In this sense, scientific knowledge is not just a configuration of concepts and statements, nor is it the direct result of mere experience: it is an intermediate configuration resulting from the negotiation between the two. According to Bachelard, the sciences are the product of the relationship between theory, practice and phenomenon, which he summarizes in one of the most discussed and important concepts in his work: *Phenomenotechnics*.¹³

When the researchers of the Large Hadron Collider in Switzerland, one of the largest and most important scientific instruments in the world, make observations aimed at confirming the existence of atomic particles and their characteristics, they undoubtedly require a set of theories and practices that will allow them to understand the phenomenon in question; furthermore, such practices require equipment and a complex computer system that will facilitate the flow of necessary data. Even though Bachelard did not live to see this ambitious project, the concept of *phenomenotechnics* has an easy application in this context, where knowledge does not arise from direct experience with reality or from a set of theoretical ponderings, but is a construction that derives from the relationship between the subjects (scientists), the practices and use of instruments and the phenomena or objects of study. Although many scientists and those within logical positivism defend that the starting point in research is the observation of “raw facts” or “immaculate” perceptions, for Bachelard, the construction of scientific knowledge is a function of the theories that frame it, the coherence of the research project in play, the practices and reasoning capacity of the subjects and the use of instruments and time.

¹² Editorial translation from the Spanish version.

¹³ *Phénoménotéchnique*, a neologism with which Bachelard describes modern science as a form of production or a process of construction of phenomena.

Intervención

JULIO-DICIEMBRE 2020
 JULY-DECEMBER 2020



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The epistemological traditions close to logical positivism were, according to Bachelard, adequate responses to the 19th century sciences; however, those of the 20th century needed a new philosophical approach, one that renounced thinking about scientific objects as if they were independent from the subjects of knowledge (*knower*). Physicist Neils Bohr argued that measurement procedures had an enormous influence on the definition of the physical quantities in his work; Bachelard agreed and thought that the only possible way to do scientific research was through technical work and experimental apparatuses (Chimisso, 2008, p. 142). The atomic science of the 20th century cannot be understood without paying attention to the links between knowledge and action, that practical dimension that does not limit itself to describing phenomena, but rather, that produces them (Gómez, 2013, p. 68).

Phenomenotechnics is the combination of intellect, practical skill or *tecnia* (τεχνη), and the phenomenon of study itself (φαινεσθαι). That is why science has an unavoidable creative component and sometimes lengthy processes where scientists measure, record, test and use the instruments that allow them to produce, choose, (un)organize, filter, purify and place information. It is impossible to separate data from its method, because the sciences are shaped by human intervention, practices, and material specificities; they are activities located in time and space around subjects, techniques, tools, and phenomena. Therefore, Bachelard's rationalism is based on the dialectic relationship between the subjects and the objects of research through the relationship between working processes and material conditions; that is, in the dialectic relationship between the phenomena and theories through technique and technology. The concept of *phenomenotechnics* characterizes the sciences as creative processes that go beyond the simple observation and collection of data and highlights the role of hypotheses, preconceptions, predictions, provisional representations and conceptual frameworks, models, instruments and technologies. "Phenomenotechnics expands phenomenology. A concept becomes scientific in the proportion that it has become technical, to the extent that it is accompanied by a realization technique" (Bachelard, 2000, p. 74). At no time is the guidance of reason in the sciences questioned, but scientific knowledge results from a necessary dialogue between reason and the empirical world: nothing is given, everything must be constructed (Chimisso, 2008, p. 143).

A perspective such as the one proposed by Bachelard and several other of his contemporaries —and even of course in more recent positions— regarding the study of science, allows us to iden-

Intervención

JULIO-DICIEMBRE 2020
 JULY-DECEMBER 2020



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tify the process through which the sciences have been built and reconstructed, over and over again. In other words, Bachelard's perspective and the concept of phenomenotechnics lead to a specific way of studying the history science and the formation of the scientific spirit, as well as to specific guidelines for its communication and teaching.

With respect to the history of science, Bachelard emphasizes the importance of understanding its current progress set against the background of its practices, the very subjects and instruments that have, over time, formed an infinite chain of successes, errors and rectifications.¹⁴ In his 1951 lecture, Bachelard pointed out: "In fact, my project is to search with you, in what conditions and in what way the history of science can play a positive role on the scientific thought of our time" (Bachelard, 2015, p. 130). Bachelard's argument seeks to position the history of science as an epistemological perspective that is valuable for contemporary societies, one that emphasizes the sciences as activities in permanent construction. That is, that they are not; they happen —they are possible.

The indirect relationship between reason and the natural world's phenomena presents certain drawbacks and assumes a series of errors and imbalances in the process of constructing scientific knowledge. Consequently, a history of the sciences conceived from Bachelard's rationalism implies emphasizing the dialectic between objects and research subjects and conceiving the splendor of modern science from the everyday drama of everyday study, "[which] will make us describe the rivalry and cooperation of theoretical effort and experimental research, will put us at the center of that perpetual conflict of methods that is the manifestation character, the tonic character of contemporary scientific culture" (Bachelard, 2015, p. 37).

Therefore, Bachelard pointed out that the study of the history of science is, in fact, the study of "epistemic obstacles": attitudes and ideas that limit or condition the progress of scientific understanding (Bachelard, 2000, p. 15). This means that we cannot defend a naive or immediate empiricism, because the development of the sciences shows a series of constant attempts to overcome different types of obstacles that hinder the formation of the scientific spirit. The notion of an *epistemic obstacle* calls for the abandonment of natural curiosity and ordinary knowledge —limited by

¹⁴ In that respect, Bachelard's proposals coincide with those of Karl Popper, in maintaining that scientific theories are always hypothetical or approximations to the truth. However, Popper did not take into account historical and social conditions to prove the falsity or validity of a hypothesis.

Intervención

JULIO-DICIEMBRE 2020
JULY-DECEMBER 2020



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culture and other individual prerogatives— and the adoption of a critical attitude that is not satisfied with “seeing” the splendor of modern science but rather, is capable of “understanding” its complexity.

Although on many occasions scientific knowledge affirms phenomena and facts that contradict everyday knowledge —atomic physics is, once again, a good example (Sánchez & Tagüeña, 2011, p. 85), the formation of the scientific spirit will only be possible by abandoning previously held ideas, breaking with natural curiosity and replacing a rigid state of thought with a state that is free of inductive interests and detached from immediate experience (Bachelard, 2000, pp. 11-12).¹⁵

A notation must here be made. In the historical approach to science, we must be careful not to fall into the pitfalls of narrating the “history of bad students in mathematics” or the chronicling of the incorrect, since that does not lead us to think of science as a path of growth: “Either it narrates growth, or it has nothing to say” (Bachelard, 2015, pp. 132-133). The history of contemporary science must be “the history of progress of the rational connections of knowledge”; this means that it must be a history which encapsulates all the discoveries that have passed from being in an originally empirical state to a rational one. Bachelard proposes that the sciences are processes of resistances, difficulties, and advancements that lead to the great progress of humanity, and “The historian of the sciences, while marching through a dark past, must help the spirits to become aware of the profoundly human value of today’s science” (Bachelard, 2015, p. 142).

PUBLIC COMMUNICATION OF SCIENCE IN MUSEUMS

Public understanding of research

The gap in time is not a sufficient impediment to being able to identify links between Bachelard’s work and some of the most recent approaches to the public communication of science and contemporary museology. After all, the ideas of authors such as Bachelard, Canguilhem, and Foucault have flourished in other cultures and have been widely considered in the development of the humanities and social sciences. It would not be far-fetched to assume that

¹⁵ Bachelard maintains that the formation of scientific spirit implies the transition through three rational and soul states: 1) Concrete state with a childish soul motivated by naive curiosity; 2) Concrete-abstract state with a professorial or dogmatic soul, and 3) Abstract state detached from basic experience and a soul in a trance of abstraction or “quintessence” without experimental support (Bachelard, 2000, pp. 11-12).

Intervención

JULIO-DICIEMBRE 2020
 JULY-DECEMBER 2020



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research in science communication and museology has been influenced by such a philosophy of science, one that is close to history, social structures, human skills, and multiple perspectives.

The study of scientific practice has flourished in recent decades, mainly thanks to works from authors such as Thomas Kuhn (2013), Paul Feyerabend (1986), Bruno Latour (1992), Latour and Steve Woolgar (1986), Karin Knorr-Cetina (1981) and Andrew Pickering (1995) among many others, who are committed to the prosperous growth of the sociological and anthropological influences on the sciences. Likewise, there has been an increased trend in the public communication of science, one centered around practice and the conjunction of the whole set of aspects that form the processes of knowledge construction.

Although it does not always occur, it is not uncommon for us to be left with a bittersweet taste in our mouths after visiting a museum or reading popular science magazines, since we celebrate new findings and discoveries but we preserve the image of a true and unquestioned science. Nowadays, one of the most frequent criticisms of public communication projects in science, is that scientific knowledge is usually presented as a homogeneous, concluded enterprise, with final products and famous authors devoid of controversy or conflict. The so-called *showcase effect* (Roqueplo, 1983, p. 127) has dominated communicative practice for over a century, and across most mainstream media the sciences have been presented as valuable enterprise solely by virtue of its results. Could we communicate a more humane, every day, living image of the sciences?

The man of science, of so hard and ardent thought, of such living thought, is conceived as an abstract man. Little by little, all values of the studious man, of the industrious man, fall into disrepute. Science is but a small adventure, an adventure in the chimerical regions of theory, in the dark labyrinths of artificial experiences.

[...]

If a philosopher speaks about knowledge, he wants it to be direct, immediate, intuitive. One ends up making of naivety a virtue, a method. [...] And it is professed that the first awakening is already full in light, that the spirit is born with an original clarity [Bachelard, 2015, p. 35].¹⁶

¹⁶ Editorial translation from the Spanish version.

Intervención

JULIO-DICIEMBRE 2020
JULY-DECEMBER 2020



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However, “Science is only understood once one has vigorously committed oneself unto it, when one loves the tension of study, when one has recognized that it is a model of spiritual progress, one that allows us to be the actors of great human destiny wherever the modesty of research may place us” (Bachelard, 2015, p. 43). To understand the sciences is to approach their “process of elaboration”, to the times when it was still a “science that does not yet know” (Latour, 1992, pp. 3-7), mixed with polemics, uncertainty, pending tasks, pending analysis and the participation of scientists as “practical reasoners” (Knorr-Cetina, 1981, p. 5).¹⁷

As a result, and in an attempt to distance themselves from a deficit model,¹⁸ new proposals have emerged that focus their attentions on research, promoting a controversial, dynamic and participatory image of scientific knowledge (Field & Powell, 2001). For the communication of the sciences in the 21st century, “there is a great need for the public to understand that research is in a state of progression; to consider what the social, ethical, and political implications of new findings are; and to recognize the importance of continuous support for both basic and applied research” (Knorr-Cetina, 1981, p. 421).

Bachelard’s heritage in projects that portray science as processes is tangible, especially for museums and science centers which see the importance of presenting the plurality of the sciences not from successful results or products, but from their methods and challenges as social institutions with strong historical and social components, as human and, therefore, “artificial” constructions (Roqueplo, 1983, p. 141), as something unfinished and in continuous process.

Concepts such as: *Public understanding of research, unfinished science* (Durant, 2004; Farmelo, 2004) and *Science-in-the-making* (Shapin, 1992) underline the importance of scientific work, its methods and values, but also emphasize the need, not only to communicate and teach the sciences but to achieve the more ambitious goals of the public communication of science: to create a scientific culture and provide societies with the tools for the con-

¹⁷ Although Bachelard concentrates on historical study and the new proposals in the study of sciences that defend the everydayness of its practices, in this section I intend to highlight the idea of science as a living, dynamic and changing process.

¹⁸ In the public communication of science, the deficit model reproduces a unidirectional or vertical scheme of the communication process, understood as the transmission of information from someone who has certain knowledge —the scientist—to another who lacks it —the layman. Furthermore, it assumes that it is possible to modify the perceptions and attitudes of the receivers on certain subjects from the communication of scientific information or from a process of “alphabetization” (Cortassa, 2012, p. 27).

Intervención

JULIO-DICIEMBRE 2020
JULY-DECEMBER 2020



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struction of knowledge, that is, to empower them as groups of individuals capable of applying, exploring, understanding, debating, and innovating. In short, to develop a scientific spirit in the world's population.

Bachelard considered that the ultimate goal of communication and science education is to elevate the human spirit, to unsettle it. By knowing the interweaving nature of scientific knowledge, of its methods and history, we can make society thirsty for knowledge, and also capable of questioning and of strengthened critical thought. The public communication of the “unfinished” sciences coincides with Bachelard's criticism of the importance of forming a scientific spirit that

prevents us from having an opinion on issues that we do not understand, on issues that we do not know how to formulate clearly. Above all, it is necessary to know how to pose problems. And whatever you may say, in scientific life, problems do not appear by themselves. It is precisely the sense of a problem that is the hallmark of the true scientific spirit. For a scientific spirit, all knowledge is an answer to a question. If there was no question, then there could be no scientific knowledge. Nothing is spontaneous. Nothing is given. Everything is constructed [Bachelard, 2000, p. 16].¹⁹

Total museology and other perspectives

Public communication of the sciences in the context of museums acquires unique characteristics, such as the informal environments in which free choice prevails and visitors conduct their learning at different rates and according to their interests and needs (Sánchez & Tagüeña, 2011, p. 86). Discussions surrounding the role of these institutions and the most effective way of displaying scientific content are comprehensive. Some of Bachelard's ideas re-emerge in today's debates, mainly where he argues that museums and science centers must overcome the one-way discourse from experts to apprentices, and communicate a historicized image of science, full of all its ups and downs (Sánchez, 2018, p. 21).

These are not recent reflections. For several decades now, museums and science centers, as well as exhibition spaces devoted to the communication of social sciences and humanities, have sought new ways to promote an active, direct, playful, and lively

¹⁹ Editorial translation from the Spanish version.

Intervención

JULIO-DICIEMBRE 2020
 JULY-DECEMBER 2020



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relationship with their visitors through the manipulation of objects, experimentation, and the application of non-directive pedagogies (Hernández, 1998, p. 214). They have also sought to produce exhibitions that simultaneously entertain and educate, generating curiosity for scientific knowledge and fostering in visitors a kind of critical thinking that allows them to exit the museum convinced of pronouncing the phrase “I know how to know” (Pedretti, 2002, p. 10). However, it is not surprising that most museums around the world maintain the traditional rules where “science presented to the public is usually simplified into a series of demonstrated principles or ‘summarized facts’ that the public reads as truths and not as a process under construction with tentative results” (Sánchez, 2018, pp. 23-24).

The different proposals put forward aimed at revitalizing museums include, to a greater or lesser extent, a strong recommendation to present science more as a process than as a product, and to encourage visitors to engage in exercises of inquiry and discussion similar to those that have strengthened the scientific spirit for centuries. With respect to scientific education, Peter Heering (2017) argues a shift from the question “What do scientists know?” to the question: “How do scientists know?” Instead of transmitting the contents of the sciences as solid bodies of knowledge, projects focused on scientific education should refer to the understanding of the sciences in terms of human processes and activities, developed in historical contexts and based on precise objectives (Heering, 2017, pp. 401-402).

Most museums related to the natural and experimental sciences—including the Palais de la Découverte— have, among their aims, the mission of contributing to the formation of scientific culture. Bachelard said that in order to maintain interest in the sciences, it is necessary to integrate them into the general culture and history of human beings (Bachelard, 2015, p. 140). Although the controversies regarding the concept of *scientific culture* are vast, in general terms, it relates to the task of making people understand both the contents of science including its methods and processes, and its effects and commitments to society. It is therefore essential to reflect on the curatorial discourses in our museums and science centers, so that they go beyond the mere communication of data and formulas, instead providing their visitors with tools, skills, attitudes and values (Reynoso, 2018, p. 217). In museums,

Information must be current and accurate, with a greater emphasis on processes over mere data; it must show how sci-

Intervención

JULIO-DICIEMBRE 2020
 JULY-DECEMBER 2020



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entists know what they know, that is, how they come to form the knowledge and strategies that they use throughout their process. It must stop showing a finished, uncritical and de-contextualized end product science; instead presenting it as a social product and one whose knowledge is under continuous construction [Reynoso, 2018, p. 226].²⁰

Transforming museums into social forums and open learning spaces is still a work in progress, one that overcomes the notion of the *epistemic obstacles* proposed by Bachelard and integrates every day and trivial experience as essential to science. Albert Einsiedel Jr. and Edna Einsiedel (2004) have marked a distinction between exhibitions that present products and objects (data, evidence, models, theories) and those that highlight processes and practices (creation, experimentation, use of instruments): the former focuses on a traditional museology with passive collections and audiences, while the latter places interactivity as the main communication resource. Likewise, Erminia Pedretti (2002) argues that scientific museums have identified the social demand for a profound transformation that motivates and involves visitors, so one possibility for change could be to adopt and exhibit a more authentic notion of the development of scientific knowledge, one that recognizes its provisional nature and the negotiations involved (Pedretti, 2002, p. 9). Pedretti's proposal, called *critical exhibitions*, highlights at least three tasks: *a)* To describe contexts and frames of reference from which scientific knowledge is generated and applied; *b)* To highlight the bridges between science and society; and *c)* To explore the contributions and dialogues between the sciences and the diverse communities from which they are born. Although Pedretti focuses on the exhibition of controversies in scientific communities, between them and society, her proposal is relevant because it accentuates a set of moments contained by the general process of the construction of scientific knowledge.

Thus, the open laboratory at the Deutsches Museum (2020, "Open Research Laboratory") in Germany, the Darwin Centre at the Natural History Museum (2020) in London, the introductory room to the archaeological zone at the Pueblo Grande Museum (2020) in southern United States, and the Science Balcony and laboratories at the Musée de l'Homme (2020) in Paris, are just some valuable examples of the effect and expansion of these proposals. Interaction with scientists, their tools and discourses change the

²⁰ Editorial translation from the Spanish version.

Intervención

JULIO-DICIEMBRE 2020
 JULY-DECEMBER 2020



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perception of science, but also stimulates and invites visitors to build more knowledge and go beyond the obvious, transforming them in the process. The sciences are not, as has been said, finished products; they are paths full of deviations, labyrinths, hard work, effort and emotion (Delicado, 2007).

Finally, most of these proposals are synthesized as *total museology*, a perspective named after Jorge Wagensberg (2015) who, based on his experience at the CosmoCaixa science museum in Barcelona, listed some statements aimed at transforming museums into agents of social change and into true creative spaces. First of all, the aim of science museums is no longer education, training or popularization; the priority is to stimulate visitors, to leave them with a new attitude towards science and life in general after visiting the museum (Wagensberg, 2005, p. 311). The guiding principle of every museum should be to provide stimuli for knowledge.

The second principle of total museology is that museums should not limit themselves to only displaying objects or phenomena through interactive designs. The only way to stimulate visitors is to show reality, that is, the conjunction of objects that are spread across space and of phenomena that occur in time (Wagensberg, 2015, p. 37). Additionally, museums must use models, graphics, or simulations: exhibition metaphors that facilitate the display of objects and invisible phenomena or those of gigantic scale. Bachelard said, in the case of atomic physics, the fact that the scale is not visible to the naked human eye poses an epistemological obstacle, since people find it difficult to understand something they cannot see. Museums, in that sense, require the creative production of instruments for communication and, as exhibition-design solutions, models that encourage “visitors to actively participate in the understanding of complex subjects” (Sánchez & Tagüeña, 2011, p. 99).

Some of the first science or natural history museums invested all their efforts in the exhibition of specimens, instruments and machines; later in time, it was discovered that it was necessary to promote manual, intellectual and emotional interactivity, by communicating concepts and phenomena. Total museology, however, proposes that these entities take reality as their raw material —with all that it implies.

Finally, without wishing to detail an exhaustive account of Wagensberg’s work, the task of stimulating and transforming visitors is only possible if we stop showing results and communicating answers and instead, promote controversy, discussion, paradoxes, and abandon the dictatorial rhetoric where someone “more intel-

Intervención

JULIO-DICIEMBRE 2020
JULY-DECEMBER 2020



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ligent” and better trained will speak for others or decide what visitors to a museum should or should not know.

A good science museum not only offers a selection of spectacular scientific results. It must also show the process followed to obtain them, and comment on their reliability and validity. [...] The greatness of science is that it recognises its ignorance (that, precisely, is why research exists), that the concept of error is not a singular negative fact but our daily bread, the necessary episode from which we learn the most. [Wagensberg, 2005, p. 312].

Throughout Bachelard’s work —and to the extent to which I have been able to refer to it— the recurring mentions of epistemic obstacles as contradictions between ordinary immediate knowledge and scientific knowledge, is indirect yet fruitful (Bachelard, 2000, p. 19). Like Wagensberg, Bachelard defended the importance of communicating and teaching the sciences by agitating the spirit beyond its nature and any general idea that paralyzes thought, by replacing closed and static knowledge with open and dynamic knowledge. However, it is necessary to emphasize that more recent studies of science and positions such as Wagensberg’s do recognize with greater clarity, the importance of common experience and social factors in the development of science and visitors’ experience with it.

In sum, as spaces of meeting and dialogue, museums and science centers have the opportunity to inspire citizens in the same way that any scientist is inspired: with a reality full of objects and phenomena to understand, and with an enormous amount of doubts to answer (Wagensberg, 2001, p. 23). Museums are privileged communication spaces because they manage to immerse their visitors in a specific environment and transmit a message through multisensorial means. It is a question of taking advantage of the benefits of museums and their different specializations to maintain interest in scientific thought, and to communicate it in an intimate way that is always related to the future and destiny of humanity.

FINAL REFLECTIONS

In its most recent definitions, public communication of science is presented as a set of tools aimed at bringing scientific knowledge to society, generating social awareness, promoting interest in sci-

Intervención

JULIO-DICIEMBRE 2020
 JULY-DECEMBER 2020



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ence, encouraging dialogue between different social sectors and achieving a greater understanding of scientific enterprise. How can this be achieved? Few would dare, at least in theory, to question the potential of museums and science centers to achieve the above-mentioned objectives. Offering information and data is possible through many channels, but museums have the capacity to provide unique experiences and generate surprising results in the process.

In contemporary museology there is no longer a crossroads between the age-old defense of perfection in scientific knowledge and the words of scholars who have long presented the sciences as vulnerable and humane enterprises. What path to follow? In this work I present a series of philosophical premises that converge with those who are concerned with the social relevance of science museums and their optimal performance. Gaston Bachelard, in particular, generated an extensive theoretical framework regarding the importance in understanding the sciences as something more than a finished and resplendent product. To see the sciences is to accept a beautiful gift. To understand them and develop a scientific spirit is to unwrap that gift and immerse ourselves with the set of practices that form its very existence so that we may advance them in the building of new stories.

We go to museums to observe and to be moved, but also to understand and to question, which means adopting a museological perspective that, like that of Wagensberg, converges with the ideas developed by the French philosopher at the beginning of the 20th century, one that is centered around a dynamic image of the sciences. So, what can we expect? A socially relevant museum will seek to contribute to the formation of a conscious society, one with the capacity of making decisions, a population whose spirit does not culminate in specific cases or in immediate experience, but which understands the world we inhabit today in greater depth. Beyond the intriguing correspondence of Bachelard's proposals on recent museological research, it is fundamental to conclude that museums dedicated to the public communication of science require a renewed effort. The main purpose of discovering and exhibiting the history of modern science and revealing the procedures, practices, and instruments that participated in its construction, as well as the relationship between theory and phenomena through the dexterity and rational capacity of the subjects in the research, is to promote a better understanding of science as a collective achievement.

Intervención

JULIO-DICIEMBRE 2020
JULY-DECEMBER 2020



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Intervención

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JULY-DECEMBER 2020



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Intervención

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Intervención

JULIO-DICIEMBRE 2020
JULY-DECEMBER 2020

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