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LEONARDO DA VINCI'S HOLISTIC CONCEPTION OF NATURE AND QUANTUM NON-SEPARABILITY

Abstract

At variance with some recent interpretations emphasizing the relevance of Leonardo's natural philosophy for contemporary science, the aim of this paper is neither to interpret Leonardo as a precursor of quantum mechanics nor to assimilate his conception of nature to contemporary relational interpretations of quantum theory. Rather, we argue that Leonardo's organic and holistic perspective offers an alternative to mechanistic reductionism while still preserving the epistemological distinction between observer and observed reality. Quantum mechanics, by contrast, radicalizes the crisis of separability by undermining not only the independence of physical systems through entanglement and nonlocality, but also the classical distinction between subject and object through the unavoidable interaction involved in measurement processes. Leonardo's relational and organic conception of nature should therefore not be confused with contemporary anti-realist or purely relational ontologies, since it remains grounded in a fundamentally realist and empiricist epistemology.

Key words: Leonardo da Vinci; nature; holism; mechanistic reductionism; quantum mechanics; entanglement; nonlocality; nonseparability

LEONARDO DA VINCIS HOLISTISCHE NATURAUFFASSUNG UND DIE QUANTENMECHANISCHE NICHT-SEPARIERBARKEIT

Zusammenfassung

Im Gegensatz zu einigen neueren Interpretationen, die die Relevanz von Leonardos Naturphilosophie für die zeitgenössische Wissenschaft hervorheben, besteht das Ziel dieses Beitrags weder darin, Leonardo als einen Vorläufer der Quantenmechanik zu interpretieren, noch seine Naturauffassung mit gegenwärtigen relationalen Interpretationen der Quantentheorie gleichzusetzen. Vielmehr argumentieren wir, dass Leonardos organische und holistische Perspektive eine Alternative zum mechanistischen Reduktionismus bietet und dabei dennoch die erkenntnistheoretische Unterscheidung zwischen Beobachter und beobachteter Realität bewahrt. Die Quantenmechanik hingegen radikalisiert die Krise der Separierbarkeit, indem sie nicht nur die Unabhängigkeit physikalischer Systeme durch Verschränkung und Nichtlokalität infrage stellt, sondern auch die klassische Unterscheidung zwischen Subjekt und Objekt durch die unvermeidliche Wechselwirkung, die in Messprozesse involviert ist. Leonardos relationale und organische Naturauffassung sollte daher nicht mit zeitgenössischen anti-realistischen oder rein relationalen Ontologien verwechselt werden, da sie weiterhin in einer grundlegend realistischen und empiristischen Erkenntnistheorie verankert bleibt.

Schlüsselwörter: Leonardo da Vinci; Natur; Holismus; mechanistischer Reduktionismus; Quanten mechanik; Verschränkung; Nichtlokalität; Nicht-Separierbarkeit

Introduction

In the history of science and natural philosophy, action at a distance has been among the most controversial questions, and the scientific community has repeatedly wavered between its acceptance and its rejection. Modern Galilean and Cartesian science was initially founded on the explicit rejection of action at a distance, but it was later reintroduced with Newton's principle of gravitation, rejected again with the advent of Maxwell's electromagnetic field theory, apparently definitively ruled out by Einsteinian relativistic theories, and finally reappeared in a stronger form through quantum nonlocality.

In this regard, we propose to dwell on Leonardo's holistic conception of nature, rejected by the mechanistic and reductionist views of Bacon, Galileo, and Descartes, which later became foundational for the ontology of classical physics. We argue instead that Leonardo's organic and holistic conception of nature represents a historically significant alternative to the mechanistic and reductionist ontology of classical physics. Both Leonardo and quantum entanglement suggest that reality cannot be fully understood through the decomposition of wholes into isolated and independently existing parts. Yet the analogy must not be overstated, since Leonardo's conception of nature remains grounded in a realist and empiricist epistemology fundamentally different from contemporary standard anti-realist and relational interpretations of quantum theory.

1. Leonardo's Philosophy of Nature

Discussing the relationship between Leonardo's conception of nature and some aspects of the foundations of quantum mechanics may at first appear surprising, since the role of Leonardo in the birth and development of modern science, namely classical physics, remains controversial.

There is little doubt that Leonardo's constant appeal to experience and observation as primary sources of knowledge, in opposition to bookish learning, anticipates some of the empiricist and anti-metaphysical tendencies that later became central to the Galilean and Newtonian scientific revolution. His emphasis on instruments, machines, technological devices, geometry, and experimental practice points in the same direction. Some of these same tendencies are also present in Bacon's thought, despite his substantial underestimation of the role of mathematics, which remained fundamental for Leonardo.

As concerns the role of mathematics, it must be stressed that for Leonardo mathematics is essentially geometry, or, more precisely, descriptive geometry: a branch of geometry focused on representing three-dimensional objects in two-dimensional space through projections. Such descriptive geometry was first widely applied in art to visualize spatial relationships and perspective correctly, thereby formulating a genuine "science of vision." It was later extended to architecture in order to create accurate plans and perspectives of buildings, and to engineering for the description and analysis of mechanical parts and complex structures.

In the first chapter of the *Book of Painting*, perhaps Leonardo's most philosophically structured work, he attempted to define what he meant by science: "Science is said to be that mental discourse which originates from its ultimate principles." And again: "No human investigation can be called true science if it does not pass through mathematical demonstrations." Leonardo immediately clarifies, however, that mathematics alone is not a sufficient guarantee of scientific truth. Science must ultimately be grounded in experience: "And if you say that the sciences which begin and end in the mind have truth, this is not conceded, but denied for many reasons; and first, that in such mental discourses experience does not occur, without which nothing gives certainty of itself."

Despite these aspects, the official historiography of science has generally placed Bacon's empiricist demands, rather than Leonardo's, at the center of the scientific revolution. The reason lies mainly in Bacon's celebrated principle of *dissectio naturae*, on which the reductionist and mechanistic conception of classical physics was grounded, together with the rejection of the holistic and organicist vision still characteristic of Renaissance thought.

Leonardo conceived nature not as a fragmented collection of phenomena, but as an indivisible network of transformations, where rivers echoed the veins of the body, forests mirrored the lungs, and vortices in water found their counterparts in the motion of air and even in the curling of hair. This intuition of interconnectedness — of patterns repeating across domains and scales — constitutes one of the most profound holistic insights in the history of thought. In the folio 55v of the Manuscript A, he affirms that:

"Therefore, the earth could be said to have a living soul and that its flesh is the earth; its blood is the veins of the waters; the lake of blood that surrounds the heart is the ocean sea; its breathing is the waxing and waning of the blood in the pulses." Although Leonardo was a bold builder — or at least designer — of mechanical instruments and automata, he continued to conceive nature as an organic structure rather than as a machine. In fact, in the folio 2 v of the Codex Leicester, he writes that: "Man has been called by the ancients a lesser world, and indeed the name is well given. For, as man is composed of earth, water, air and fire, so is the body of the earth."

Leonardo's conception of nature was guided by a deep sense of unity. He sought connections across different domains of experience: anatomy and geology, hydraulics and meteorology, mechanics and biology. He considered the boundaries between fields of inquiry to be artificial, viewing the world as a single organism in which patterns of form and movement manifest themselves at every level.

A striking example is his analogy between the human body and the Earth. Bones, he observed, correspond to rocks and mountains; rivers mirror veins; the ocean reflects the body's fluids; forests are akin to lungs. This was not poetic metaphor for its own sake, but rather an attempt to identify structural isomorphisms — recurring forms and processes revealing an underlying order.

His fascination with flows and vortices demonstrates the same holistic approach. Leonardo studied water currents systematically, sketching eddies, whirlpools, and spirals. He noticed how these patterns reappear in air turbulence, hair curls, and the dispersal of smoke. Nature, he believed, expresses itself through recurrent geometries. To study one domain is therefore to glimpse the dynamics of another.

This analogical method — the search for unity through correspondence — led Leonardo toward what we might now describe as a systemic and holistic conception of reality. Instead of isolating parts, Leonardo insisted on examining the relations between them rather than investigating them separately. For Leonardo, the peculiarity of nature lies not in isolated elements but in their interdependence.

In this way, Leonardo did not endorse the mechanistic reductionism that would later dominate modern science. While Descartes and Newton would define the world as a machine composed of separable parts governed by universal laws, Leonardo believed that life, flow, evolution, and pattern could not be reduced to isolated mechanisms. His "science of observation" was inseparable from his art: both sought to grasp the living wholeness of nature.

2. Bacon, Descartes, and the Principle of *Dissectio Naturae*

From a radically different perspective, Bacon's principle of *dissectio naturae* established that "melius autem est naturam secare quam abstrahere" — it is better to dissect nature than to abstract from it — and that the understanding of nature can only arise through a "most diligent dissection and anatomy."

A similar methodological principle was reformulated by Descartes in the *Regulae ad directionem ingenii* and later in the *Discourse on the Method*. According to the rule of analysis, each difficulty must be divided "into as many parts as possible and as might be necessary for its adequate solution," thereby treating phenomena separately, one element at a time.

In the *Principia philosophiae* (1644), Descartes further claimed that no natural phenomena had been omitted from his explanation, since all physical reality could ultimately be reduced to "size, figure, and motion." Nothing in bodies, he argued, is perceived by us as anything other than particular arrangements of extension and motion. Classical physics thus progressively reduced the complexity of nature to a limited number of measurable quantities capable of mathematical treatment.

One of the most important consequences of this ontological and methodological principle was Galileo's concentration on measurable mechanical concepts such as position, mass, velocity, and motion, all expressible through mathematical laws. Mathematics was no longer applied, according to Platonic and Neoplatonic traditions, to a transcendent world of ideal essences, but rather to elementary physical phenomena accessible to measurement and calculation.

The abandonment of traditional metaphysics therefore did not imply the abandonment of objective knowledge, but rather a restriction of scientific inquiry to measurable and quantifiable properties — those that Descartes would later call primary qualities. Physics was thus transformed into a new anti-essentialist metaphysics grounded in mathematical abstraction and separability.

3. Leonardo and the Science of Observation

For Leonardo too, the understanding of nature necessarily began from observation and experience. Yet the representation of nature did not occur through mathematical laws connecting a few measurable quantities, but rather through drawing and painting, where geometry served to translate the three-dimensional reality of nature onto the two-dimensional space of the page or canvas.

Leonardo attributed to painting a privileged epistemological role because it was capable of preserving together both mathematical structure and qualitative richness. As he observed in chapter 17 of the *Book of Painting*:

> Because the painter is the one who, by necessity of his art, gave birth to this perspective, and it cannot be done without lines, within which are enclosed all the various figures of bodies generated by nature, without which the art of the geometer is blind. And if the geometer reduces every surface surrounded

> by lines to the figure of the square, and every body to the figure of the cube; and arithmetic does the same with its cube and square roots, these two sciences concern themselves only with continuous and discontinuous quantity, but do not concern themselves with quality, which is the beauty of the works of nature and the ornament of the world.

For Leonardo, therefore, "seeing" was inseparable from "knowing." Painting became a universal language capable of approaching nature more directly than abstract conceptual analysis. The science of painting preserved the qualitative richness of phenomena that reductionist science progressively sacrificed in favour of predictive mathematical abstraction.

This aspect has been emphasized by Evandro Agazzi and Jure Zovko in their Leonardo Lectures at the National Academy of Sciences, Letters and Arts in Modena, both drawing attention to Husserl's analysis in *The Crisis of European Sciences*. Husserl argued that Galilean science achieved extraordinary predictive success by describing reality through measurable, separable, objective properties expressed mathematically, but at the cost of eclipsing the *Lebenswelt*, the concrete world of lived experience.

The Baconian and Cartesian principle of *dissectio naturae* ultimately gave rise to the notion of separability that underlies classical physics. This separability assumed two distinct forms.

The first is the separation between human beings and nature, between observer and observed system, and more philosophically between subject and object. According to this view, the human mind stands outside nature and investigates physical phenomena without modifying them. Observation and measurement merely detect and record pre-existing properties. One of the cornerstones of classical physics thus became the ideal of non-perturbative measurement.

This first form of separability between subject and object is also largely shared by Leonardo's philosophy of nature. Leonardo conceives nature as an autonomous and objective order that the observer must contemplate, describe, and imitate rather than transform. In this sense, the observer remains external to the observed world.

On this point, however, a profound divergence emerges between Leonardo and Bacon. Bacon conceived nature as something to be controlled, manipulated, and mastered, whereas Leonardo continued to approach it primarily through observation, representation, and analogical understanding.

Leonardo's writings also contain important anticipations of the experimental method later developed by Galilean science. He repeatedly emphasized the need for repetition and verification in experimentation. In the folio 47r of the Manuscript A, he writes that: “Before you make a general rule of this case, test it two or three times and observe whether the tests produce the same effects.” Similarly, in the folio 57r of the Manuscript M: “This experiment should be made several times, so that no accident may occur to hinder or falsify the test.”

In his scientific investigations Leonardo displayed the same patience and attention to detail that characterized his artistic practice. As an inventor and engineer, Leonardo also designed numerous instruments intended to enhance observation and measurement. He devised instruments for measuring wind speed and humidity, various forms of odometers, and several improvements to clock mechanisms. He also constructed experimental devices for observing the behaviour of fluids under controlled conditions, including glass chambers and transparent containers that allowed him to visualize currents, vortices, and flow patterns.

These experiments reveal an extraordinary capacity to combine empirical observation, technical ingenuity, and visual representation. Yet Leonardo’s experimental attitude remained fundamentally different from the reductionist orientation that later characterized classical physics. His investigations sought not merely to isolate elementary measurable variables, but rather to preserve the complexity, continuity, and qualitative richness of natural phenomena.

Leonardo’s refusal to reduce nature to isolated measurable entities anticipates a conception of knowledge grounded not in fragmentation but in relation, continuity, and structural correspondence. In Leonardo’s view, understanding emerges through the capacity to perceive analogies, recurrent forms, and dynamic interdependencies across different domains of reality. Knowledge is therefore neither purely deductive nor exclusively quantitative, but arises from the encounter between empirical observation, visual intuition, and the recognition of order within complexity.

From this perspective, Leonardo’s philosophy of nature acquires renewed significance within contemporary debates on the limits of reductionism. Although entirely external to the conceptual and mathematical framework of modern physics, his thought nevertheless reminds us that scientific intelligibility cannot always be exhausted by the decomposition of phenomena into elementary parts. The qualitative unity of processes, the continuity between forms, and the irreducible complexity of natural organization remain dimensions that resist complete abstraction.

In this sense, Leonardo stands at the crossroads between art, science, and philosophy. His "science of vision" sought not merely to measure nature, but to comprehend its living coherence. The resonance with certain conceptual tensions emerging in twentieth-century physics lies therefore not in any anticipation of quantum theory, but in a shared awareness that reality may exceed the explanatory capacities of strictly mechanistic and separable models.

Leonardo's legacy thus remains profoundly contemporary. His work invites us to reconsider the relationship between observation and representation, quantity and quality, analysis and totality. Far from constituting an alternative physics, Leonardo's holistic conception of nature offers a broader epistemological horizon within which scientific inquiry may once again confront the complexity, unity, and living dynamism of the natural world.

4. Two Forms of Separability Challenged in Quantum Mechanics

The classical notion of ideal measurement — understood as the passive recording of a pre-existing objective property of a physical system — found one of its most famous formulations in Laplace's demon: an intelligence capable, from the exact knowledge of the position and momentum of every object in the universe, of predicting the future and reconstructing the past with absolute precision.

This conception was radically challenged by quantum mechanics. With Planck's quantum of action, every process of observation and measurement came to involve an unavoidable interaction with the observed system through the exchange of at least one quantum of action h. Observation no longer merely records reality but inevitably perturbs it.

From this point of view, Leonardo's philosophy of nature still remains substantially compatible with the realist framework of classical physics. Like classical science, Leonardo assumes an epistemological distinction between observer and observed reality. Nature exists autonomously, while the observer seeks to understand and represent it without altering its essence.

The second, and even more fundamental, form of separability concerns the relations between physical objects themselves. According to classical physics, the properties of an object must be definable independently of the existence or state of other objects. We may call this principle locality, even though the term itself emerged only much later during the debates on the foundations of quantum mechanics surrounding the EPR argument.

This form of separability is in some respects more fundamental than the separation between subject and object, since it would remain valid even if the observer could not be fully separated from nature.

The history of classical physics oscillated continuously around this problem. Newtonian gravitation reintroduced a form of action at a distance, since gravitational attraction propagates instantaneously between distant bodies. Yet this interaction decreases rapidly with distance and remained conceptually problematic even for Newton himself, who famously refused to formulate hypotheses concerning its underlying cause.

By contrast, Cartesian physics entirely rejected action at a distance in favor of direct mechanical contact. Later classical field theories, particularly Maxwell's electromagnetic theory, replaced distant interaction with local electric and magnetic fields. Finally, Einstein's theory of relativity established an insuperable limit to the propagation of physical interactions through the principle of the constancy of the speed of light.

Quantum mechanics radically transformed this situation once again. Through entanglement and nonlocal correlations, physical systems can no longer be fully described as independent and separable entities. Bell's theorem and the experimental violations of Bell inequalities showed that no local hidden-variable theory can reproduce quantum predictions.

Conclusion

Quantum mechanics therefore challenges both forms of classical separability: not only the epistemological distinction between observer and observed system through the unavoidable role of measurement interaction, but also the ontological separability between physical objects through quantum nonlocality.

Leonardo's philosophy of nature occupies an intermediate position in this historical trajectory. Leonardo rejected the mechanistic fragmentation of nature and conceived the universe as a living network of interconnections. Water currents, air flows, the branching of trees, geological structures, and the human body were all understood as manifestations of common organizational principles.

Yet Leonardo's holistic conception of nature did not eliminate the distinction between observer and observed reality. Unlike certain contemporary relational or anti-realist interpretations of quantum mechanics, Leonardo maintained a fundamentally realist and empiricist conception of knowledge. The observer remains external to the observed world, even while recognizing the deep interconnectedness of natural forms. In this sense, Leonardo's conception of nature differs profoundly both from the mechanistic reductionism of classical physics and from the stronger forms of non-separability introduced by quantum mechanics.

Leonardo's philosophy of nature does not anticipate quantum mechanics in any literal scientific sense. Nevertheless, it represents a historically significant alternative to the mechanistic and reductionist ontology that later became dominant in classical physics.

Whereas Baconian and Cartesian science progressively grounded physics upon the principles of decomposition, separability, and mathematical abstraction, Leonardo continued to conceive nature as an organic and interconnected whole whose qualitative richness could not be reduced to isolated measurable components.

Quantum mechanics, in turn, radicalized the crisis of separability by undermining not only the independence of physical systems through entanglement and nonlocality, but also the classical distinction between observer and observed system through the unavoidable and incontrollable interaction involved in measurement processes.

Leonardo therefore occupies a singular position in the history of ideas. His holistic conception of nature remains fundamentally realist and empiricist, yet at the same time it offers an important alternative to the reductionist paradigm that shaped modern classical science. The resonance between Leonardo's organic vision and quantum non-separability is thus not genealogical or anticipatory, but epistemological and conceptual.

References

- Bacon, F. (1620/2000). *Novum Organum*. Cambridge: Cambridge University Press.
- Calosi, C., Fano, V., & Tarozzi, G. (2011). Quantum ontology and extensional mereology. *Foundations of Physics*, 41, 1740–1755.
- Capra, F. (2023). *Leonardo da Vinci: lo scienziato della vita*. Sansepolcro: Aboca.
- Capra, F. (2008). *The Science of Leonardo*. New York: Anchor Books.

- De Muynck, W. M., & Van Stekelenborg, J. T. P. M. (1986). Discussion of a proof given by Selleri and Tarozzi of the nonlocality of quantum mechanics. *Physics Letters A*, 116, 420–422.
- Fano, V. (ed.) (2014). *Gino Tarozzi, Philosopher of Physics: Studies in the Philosophy of Entanglement on His 60th Birthday*. Roma: FrancoAngeli.
- Kemp, M. (1981). *Leonardo da Vinci: The Marvellous Works of Nature and Man*. London: Dent.
- Pedretti, C. (1995). *Libro di pittura: Codice Urbinate lat. 1270 nella Biblioteca Apostolica Vaticana*. Critical transcription by Vecce, C. Firenze: Giunti, 2 voll.
- Rovelli, C. (1996). Relational quantum mechanics. *International Journal of Theoretical Physics*, 35, 1637–1678.
- Selleri, F., & Tarozzi, G. (1981). Quantum mechanics, reality and separability. *Rivista del Nuovo Cimento*, 4(2), 1–54.
- Taglialagamba, S. (2026). *La scientia per Leonardo*, in Carannante, S. (ed.), *Metafore della natura dal Rinascimento all'età moderna*. Firenze: Edifir (forthcoming).
- Taglialagamba, S. (2017) *Leonardo e i quattro elementi. I 100 disegni più belli di Leonardo dalle collezioni di tutto il mondo.* Edizione nazionale dei disegni e dei manoscritti. Presentazione di Pedretti, C. e Galluzzi P. Firenze: Giunti-Treccani.
- Tarozzi, G. (1981). 'Local realism and Bell's theorem without the hidden variable hypothesis.' *Memorie Accademia Scienze Torino*, 108, 119–124.