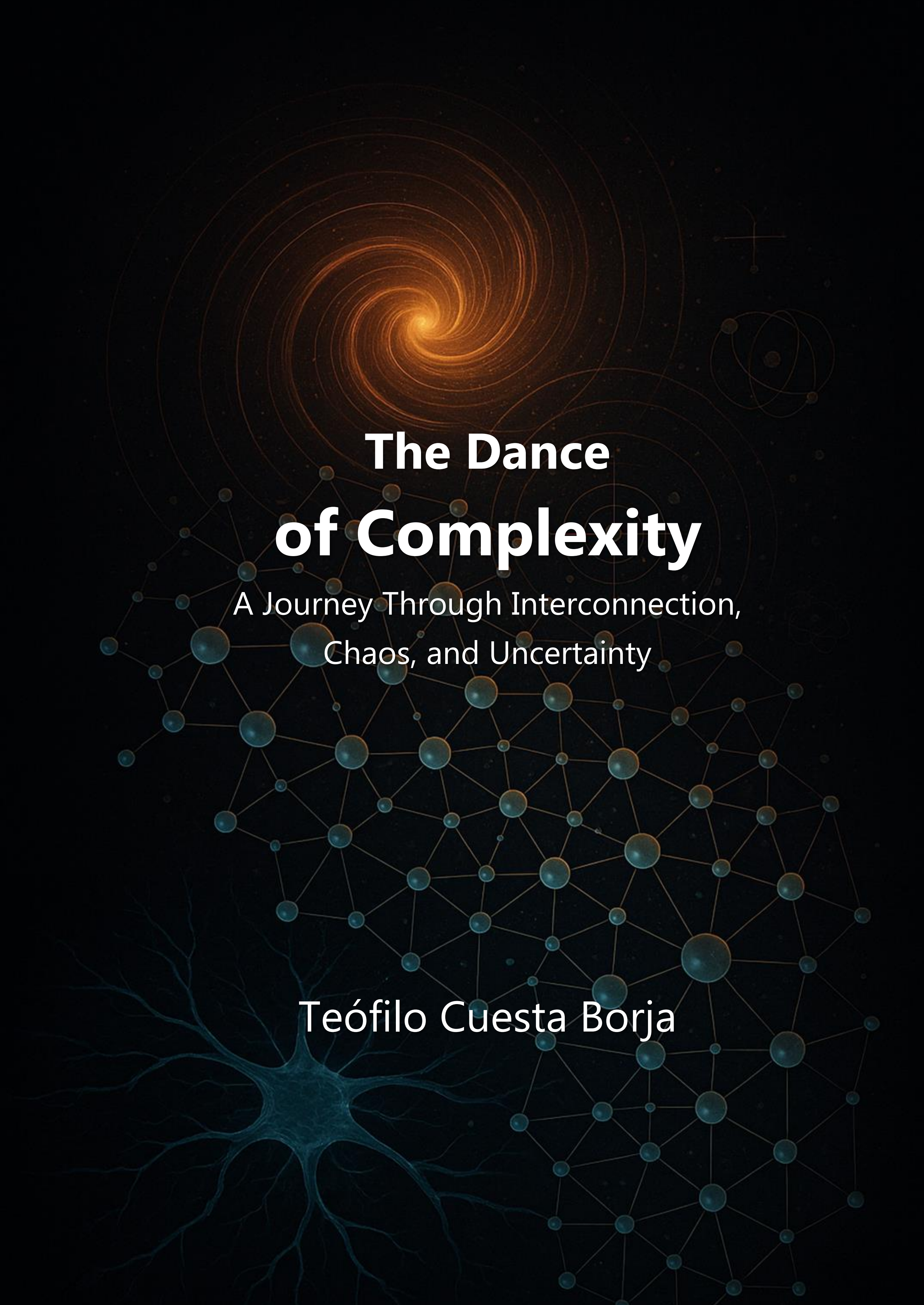

The Dance of Complexity

A Journey Through Interconnection, Chaos, and Uncertainty

Teófilo Cuesta Borja

About the Author

Teófilo Cuesta-Borja was born 51 years ago in the heart of a small village called Vegaez, in the municipality of Vigía del Fuerte. This fertile corner of the Antioquia department in Colombia, where the river and jungle seem to whisper ancestral secrets, shaped his deeply inquisitive soul and profound connection to the land. This connection led him to study Agricultural Engineering at EARTH University, an international institution located in the Republic of Costa Rica dedicated to cultivating knowledge and a deep love for life. Driven by a genuine commitment to nature and humanity, he deepened his expertise through a specialization in Environmental Management at the National University of Colombia, Medellín campus. His searching spirit took him beyond conventional sciences into the mysteries of interdependence and wholeness, specializing in Complexity Sciences at the Multiversidad Mundo Real "Edgar Morin" in Mexico.

His academic journey continued with a Master's degree in Sustainable Development and Environment at the University of Manizales, Colombia, where he strengthened his integrative vision of development and life. He received his first doctorate (PhD) in Regional Development from AIU in the United States and later earned a second doctorate (PhD) in Complex Thinking at the Multiversidad Mundo Real "Edgar Morin" in Mexico. He is currently pursuing a third doctorate (PhD) in Economics and Finance at UIIX University in Mexico.

Beyond his academic titles, Dr. Cuesta has generously shared his knowledge for over 15 years as a university professor at institutions such as the National University of Colombia, Universidad Lasallista, University of Chocó, and the Technological Institute of Antioquia, leaving a mark on the minds and hearts of those privileged to hear him. His vocation for service has led him to hold significant leadership positions, including President of the National Association of Regional Autonomous and Sustainable Development Corporations (ASOCARS), General Director of CODECHOCÓ, Secretary of Agriculture and Environment of Chocó, Deputy Director of Research at the Pacific Environmental Research Institute "Jhon von Neumann," and President of the organization ECOFUTURO Colombia. He has carried out these roles passionately both in Colombia and internationally, including Costa Rica, Brazil, Mexico, the United States, Sweden, and Portugal.

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A Journey Through Interconnection, Chaos, and Uncertainty

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Dedication

I dedicate this work to my mother, Teofilina Borja Campo (R.I.P.), to my father, Severiano Cuesta Rentería, to my beloved wife, Sorleidy Moreno, to my children Jefer, Juan Camilo, Kaia Juliana, Kaiter Jacob, and Kiara Juliana, and to my siblings Luis Arnobio, Olga María, Manuel Enrique, Mirlenis, Reinaldo, Luis Enier (R.I.P.), Luz Marina, Luz Evedilde (R.I.P.), and Nievelina. Family is undoubtedly my main inspiration and my only stronghold, my refuge, my everything in life. I love them passionately.

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To the Advanced Complexity Thinking Center TRAMASUR, to the organization Ecofuturo Colombia, and to the Sotec Polytechnic Institute for their technical and financial support in making this work a reality.


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Foreword

In a world marked by dizzying transformations, where certainties dissolve as quickly as new questions arise, there emerges a pressing need to rethink our ways of understanding reality. The Dance of Complexity: A Journey Through Interconnection, Chaos, and Uncertainty is more than a book; it is a profound and challenging invitation to abandon the linear paths of simplistic thinking and to venture into the fascinating territory of the complex. This work is more than a reflection on complexity; it is, in itself, a complex exercise, a cartography crafted by Teófilo Cuesta Borja after decades of rigorous, critical, and transdisciplinary exploration.

Teófilo Cuesta is far from a newcomer to the world of Complex Thinking and complexity sciences. His academic trajectory has been characterized by a steadfast resistance to reductionism, an openness to multiple forms of knowledge, and a passion for the emergent and the uncertain. His work has significantly contributed to the development of systems thinking, transdisciplinary epistemology, and a deep understanding of the nonlinear processes that characterize life itself, society, and knowledge. Throughout his career, he has successfully built bridges among diverse disciplines, from philosophy to environmental sciences, from biology to sociology, illuminating fertile intersections for critical thinking at all levels.

He is a researcher, educator, and transdisciplinary thinker recognized for his contributions to the study of complexity, critical epistemology, adaptive systems, and for more than 25 years of academic work and deep reflection across the intersections of social sciences, natural sciences, and philosophy. He has taught at various universities in Latin America and has been an invited speaker at international forums on systems thinking, social transformation, and emerging epistemologies.

Those familiar with Cuesta's work will recognize in these pages the maturity of a thought forged at the crossroads of multiple traditions, nourished by constant dialogue, and guided by an uncommon intellectual integrity. Those encountering him for the first time will discover a lucid and rigorous voice, deeply committed to the transformation of knowledge and life.

As the author of numerous essays and academic articles, Cuesta has decisively contributed to the dissemination of Complex Thinking and the sciences of complexity, promoting a critical and engaged vision that addresses the ethical and political challenges of the contemporary world. His approach combines analytical rigor with humanistic sensitivity, offering tools to inhabit uncertainty without falling into nihilism or naivety.

In The Dance of Complexity, he offers much more than a theoretical exposition; he invites us into a profound and exquisite experience of critical thinking. This book describes complex systems and embodies them in its structure, its narrative style, and its constant dialogue between order and chaos. Readers will find here a polyphonic text, where ideas flow like a carefully woven choreography, yet remain open to the improvisation demanded by every genuinely transformative journey.

One of the great merits of this work is its ability to show that complexity, rather than being a property of certain objects of study, is an inherent condition of reality itself. In this sense, Cuesta proposes a reading of the world that avoids simplification and renders it more intelligible in its richness and multiplicity. His approach is profoundly pedagogical, as it teaches us to think differently, to live with uncertainty without becoming paralyzed, and to recognize patterns without falling into the illusion of total control.

Alongside its conceptual depth, this book stands out for its ethical and political sensitivity. Recognizing complexity also entails embracing the radical interdependence among human beings, institutions, ecosystems, and technologies. In this context, Teófilo Cuesta poses uncomfortable questions about how we attempt to manage disorder and warns us about the dangers of simplistic thinking in contexts where life itself is at stake.

In these pages, the reader embarks on a transdisciplinary journey unfolding like a choreography among disciplines, theories, and human experiences. The work weaves together knowledge from physics, biology, social sciences, philosophy, chaos theory, and cybernetics, all stitched together with sensitivity and rigor. Complexity serves as the epistemological horizon structuring the perspective, the pulse animating each reflection, and the rhythm through which ideas unfold.

From the notion of open systems and interconnected networks to the emergence of unforeseen patterns and the inherent unpredictability of dynamic processes, this book offers conceptual tools to understand contemporary phenomena that resist logics of control, prediction, and fragmentation. Beyond an accumulation of concepts, what is offered to the reader is a way of thinking and feeling: a complex sensitivity capable of perceiving the interdependence of elements, the ambiguity of processes, and the openness of becoming.

The proposed journey is neither linear nor conclusive. It is a spiral journey, where each chapter points to a distinct yet always interwoven dimension of the human condition, of knowledge, and of historical and ecological becoming. Like a dance, there are steps forward and backward, moments of pause and acceleration, of order and apparent chaos, in which the reader is invited to participate actively, to be affected by the questions, the paradoxes, and the invisible threads that connect different planes of reality.

The Dance of Complexity speaks to both the academic and the curious, to the scientist and the artist, to the educator and the citizen, because it is written from an ethical commitment to critical thinking, openness to uncertainty, and the search for new ways of inhabiting the world. Without dogmas or definitive answers, it invites us to follow paths of exploration that remind us that a deep understanding of the world requires humility, imagination, and a constant willingness to learn.

At a time when the fragmentation of knowledge and instrumental logic threaten to reduce the human to algorithms and the living to mechanisms, this work rises as an act of intellectual and poetic resistance. It is a commitment to complexity as a vital language, as a compass for navigating uncertainty, as the art of weaving connections amid apparent disorder.

Anyone who delves into these pages will not emerge unscathed, for thinking in a complex way is also an act of transformation. It is to allow oneself to be touched by that which cannot be fully understood, by that which escapes our categories, by what pulses between the cracks of established knowledge. In this sense, this book proposes a new way of reading the world and a new way of being in it.

This foreword cannot, nor does it intend to, anticipate all the richness of the chapters that follow. Rather, it invites the reader to enter this journey with an open disposition, with patience, and with full attention. It is not an easy read, yet it is a necessary one. As Cuesta aptly notes, understanding complexity is very different from mastering it: it is about learning to live with it, to listen to it, to let ourselves be transformed by its incessant dance.

The Dance of Complexity represents a mature synthesis of his intellectual and life journey. It is an urgent call to rethink our ways of knowing, acting, and coexisting in an increasingly interconnected and uncertain world.

I am convinced that this book enriches the field of Complex Thinking and the sciences of complexity. It expands, reconfigures, and sets it dancing.

Reinaldo Cuesta Borja
Doctor in Territorial Studies
Associate Professor and Researcher
Dean, Faculty of Administrative, Economic and Accounting Sciences
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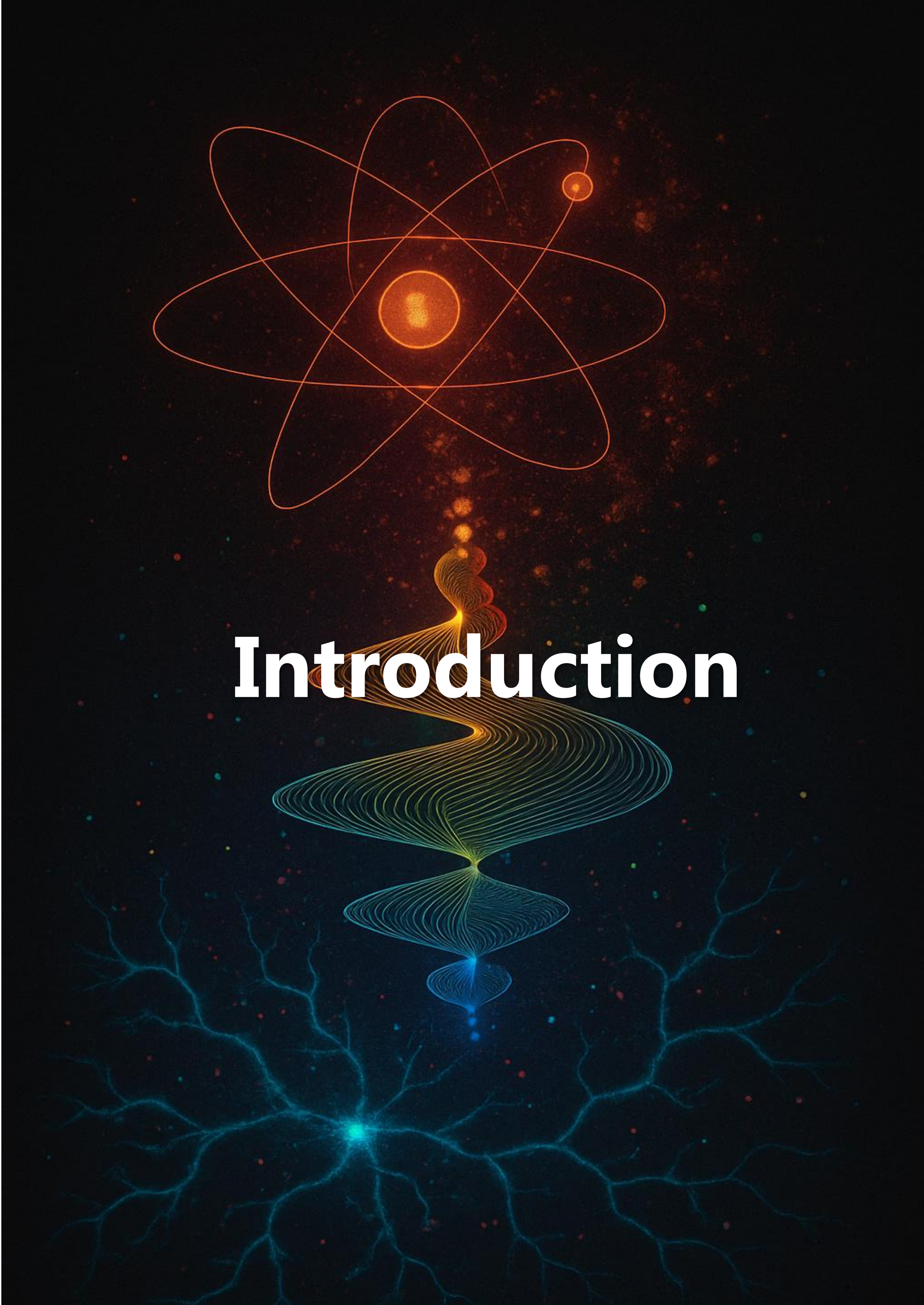
Introduction



Introduction

We live in an era characterized by radical uncertainty. The climate crisis, technological disruption, geopolitical conflicts, structural inequalities, pandemics, and ecological collapse configure a web of interrelated phenomena that challenge traditional ways of understanding reality. The idea of an ordered, stable, and predictable world has been surpassed by evidence of chaotic, nonlinear, and deeply interdependent systems. In this context, the deterministic paradigm, which dominated scientific thought since modernity, proves insufficient to account for the complexity of the contemporary world.

Since the scientific revolution of the 16th and 17th centuries, modern science built its foundations on reductionism, linear causality, and the objectivity of the observer. This model, articulated through Newtonian physics, Cartesian rationalism, and Aristotelian logic, enabled enormous technological and scientific advances. Its epistemological hegemony also produced a fragmented view of the world: it broke reality into isolated parts, marginalized the subjectivity of the knowing subject, and excluded uncertainty as a legitimate category of analysis (Capra & Luisi, 2014; Prigogine & Stengers, 1984). The emergence of complex thought, driven mainly by Edgar Morin, represents a rupture with this tradition. Without denying the achievements of modern science, it seeks to relocate them within a broader, critical, and self-reflective rationality. Morin proposes a reform of thought that recognizes the autopoietic, contradictory, emergent, and situated nature of knowledge. Reality is understood as a dynamic network, where order and disorder, certainty and uncertainty, intertwine in a constant becoming.

Classical determinism, in its teleological, mechanistic, and causalist versions, postulated a universe governed by universal laws that explained and predicted the behavior of all phenomena. Throughout the 20th century, quantum theory, thermodynamics, systems biology, chaos theory, and complexity sciences revealed the limits of this rationality. The impossibility of knowing a system's state with absolute certainty, the emergence of unpredictable patterns from small initial variations, and the active participation of the observer in the construction of knowledge dismantled the aspiration for absolute knowledge (Heisenberg, 1927; Lorenz, 1963; Maturana and Varela, 1994).

Complex epistemology thus proposes a radical shift: knowing is different from representing an external world with total objectivity. It means interacting with it from a situated, affective, and ethical position. This perspective implies recognizing that all knowledge is partial, historical, and conditioned, and therefore must be assumed with responsibility. As Nicolescu (2008) points out, complexity, beyond being a property of the object, is an attitude toward knowledge. Thinking in a complex way differs from merely accumulating data. It involves learning to navigate uncertainty, inhabit contradiction, and articulate disparate knowledge while respecting its diversity.

This book is inscribed within that horizon of transformation. It proposes an epistemological journey from the deterministic paradigm toward the paradigm of complexity, understood as an open and transdisciplinary matrix that allows us to rethink our ways of knowing, educating, governing, and coexisting. Through a rigorous exploration of the historical roots of deterministic thought and the ruptures that destabilize it, the conceptual foundations of Complex Thinking are presented, along with its applications in diverse areas such as environmental education, geopolitics, economics, spirituality, and epistemic resistance to technocracy.

Each chapter of this work constitutes a node in this web of knowledge: from the deconstruction of the causal-mechanistic model to the articulation of a complex ecotheology. From the critique of biodiversity agreements to the proposal of a resilient agroecosystem. From the analysis of the trade war between global powers to the vindication of ancestral and community knowledge, the book unfolds an intellectual cartography that, rather than imposing answers, seeks to enable pertinent questions in times of crisis.

The very structure of the book reflects its epistemic commitment: it avoids a linear sequence of contents and instead presents them as a dance. A vital metaphor evoking the meaningful and arrhythmic movement of complex systems. This dance, as Morin (2000) notes, does not dream of dominating chaos but seeks to learn to coexist with it. For this reason, this work is also a manifesto: an ethical and political declaration that addresses the reader as a subject implicated in the construction of meaning.

The work invites a metamorphosis of thought: to abandon the security of absolute certainties and to embrace fragility, ambiguity, and interdependence as conditions of knowing. In a world that appears increasingly unstable and conflictive, Complex Thinking avoids offering prefabricated solutions, instead providing a more lucid, integrative, and committed rationality. In times when simple solutions fail in the face of present challenges, thinking complexity is a form of resistance against simplification, an act of love for knowledge, and a declaration of hope. Because it is still possible to think differently, feel differently, live differently.

The book unfolds an organic structure that evokes an intellectual ecosystem in constant metamorphosis. Each chapter functions as a node that drives connections, inviting the reader on a journey where reason converses with sensitivity and science intertwines with philosophy. In the first station, determinism is addressed from its ancient roots to its modern consolidation. It shows how humanity forged a mechanistic vision of the universe, reducing reality to predictable gears. This journey reveals the epistemological fissures that emerged when quantum physics and chaos theory appeared to evidence an unpredictable and creative cosmos. Through rigorous analysis, it proposes overcoming reductionism, suggesting a mode of thought that embraces the coexistence of order and disorder as vital pulses of existence.

In the second stop, the epistemological and theoretical perspectives supporting the emerging paradigm of complexity are developed. The transition from linearity toward a rhizomatic vision of knowledge is explored, where disciplines interweave and boundaries dissolve. This section vindicates transdisciplinarity as an act of resistance against the fragmentation of knowledge and as a vital tool to face the planetary crisis. The role of the situated subject is highlighted, aware of their historicity and deep bond with the world, as the epicenter of a committed and sensitive way of knowing.

The third chapter delves into scientific research through the lens of complexity. The aspiration to absolute objectivity is questioned, proposing instead an embodied, reflective, and ethical science. This section invites us to conceive research as a living process, permeated by uncertainty and constant feedback. It defends the need for a flexible method that embraces contradiction and accepts provisionality as a condition of knowing. Here, the scientist is redefined as a navigator moving through turbulent seas, attentive to invisible currents shaping phenomena.

In the fourth chapter, environmental education emerges as fertile ground to cultivate complex thinking. The urgency of transcending mere content transmission toward the formation of critical consciences sensitive to the living fabric of the biosphere is emphasized. This section connects pedagogy with ecology, promoting an education that fosters empathy, creativity, and the ability to articulate multiple forms of knowledge. The goal is to form citizens capable of inhabiting the planet with responsibility and gratitude, aware of the interdependence that sustains life.

The following segment analyzes governance systems and international negotiation, showing how complexity transforms political and diplomatic strategies. It becomes evident that relations between states are configured in a network where interests, values, and narratives are in constant friction. This chapter underscores the importance of embracing ambiguity and plurality as fundamental conditions for building sustainable and adaptive alliances.

Next, the trade conflict between the United States and China is examined from the perspective of complexity. It illustrates how global economic disputes act as chaotic ecosystems where political, cultural, and financial forces interact. This analysis reveals that global tensions express unpredictable dynamics that challenge linear calculations. Understanding these disputes involves accepting surprise as a structural feature and designing strategies based on adaptability and multilateral cooperation.

Later on, environmental negotiation and biodiversity are explored as scenarios where complexity acquires an unavoidable ethical force. International agreements aimed at halting ecological deterioration are examined, highlighting tensions between economic growth and the preservation of life. A perspective is suggested that prioritizes reciprocity and ecological justice, placing the sacredness of ecosystems and the need to reconfigure global policies with planetary sensitivity at the center.

In "Knowledge That Sprouts," the richness of ancestral and community knowledge is celebrated as sources of living wisdom. It is recognized that indigenous and peasant epistemologies offer worldviews that integrate spirituality, subsistence, and care. This chapter vindicates the coexistence of multiple rationalities and emphasizes the urgency of protecting traditional knowledge as invaluable cognitive heritage. The coexistence of different ways of understanding the world strengthens cultural resilience and offers keys to facing the contemporary civilizational crisis.

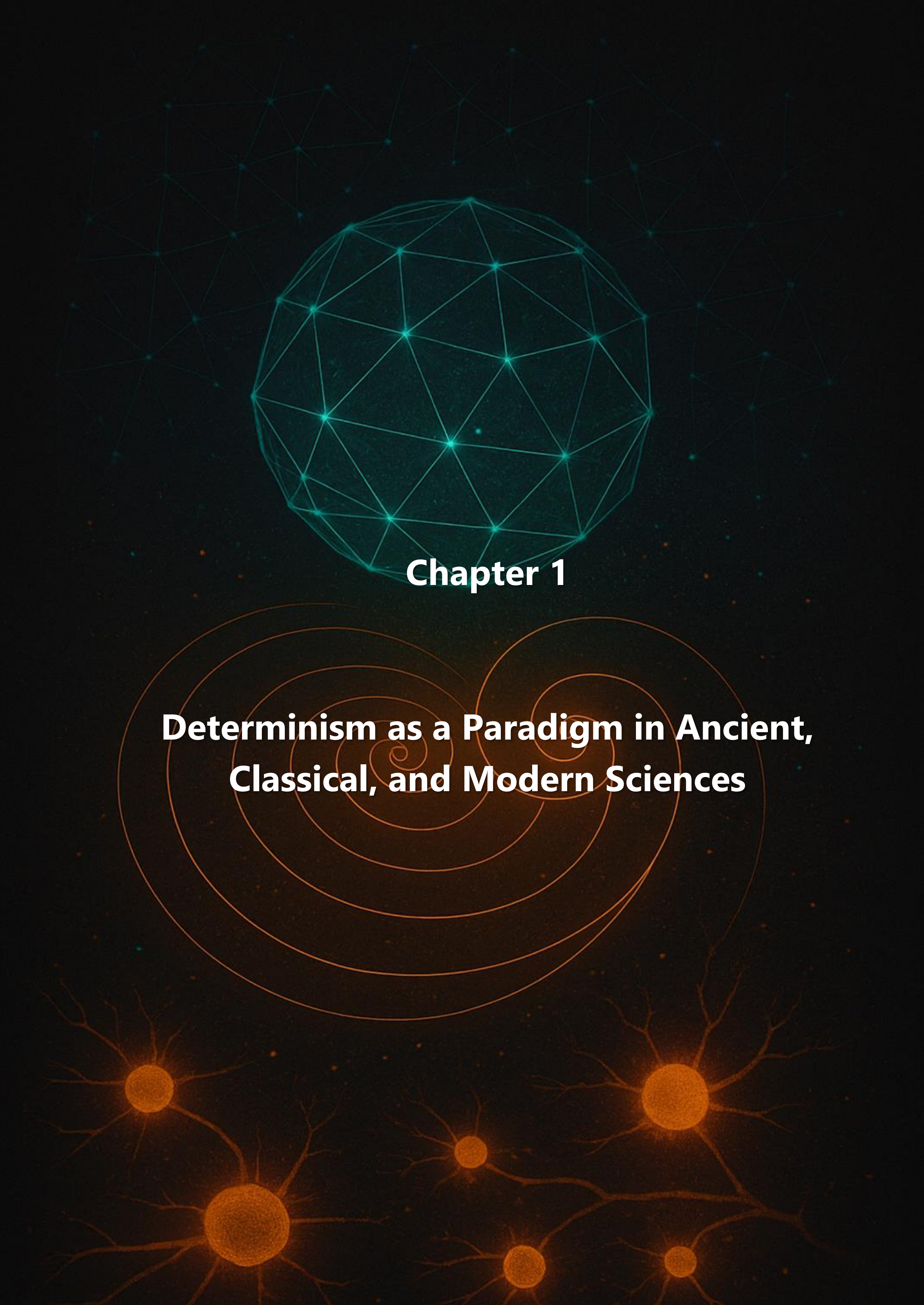
The exploration of the symbolic contradiction of the Vatican's white smoke becomes a space to reflect on spirituality and tensions between dogma and openness. A complex spirituality is proposed, one that embraces ambiguity and renounces paralyzing truths. This chapter inquires into the possibility of a faith that dialogues with science and uncertainty, cultivating an inclusive and transformative ethos.

The chapter focused on tariffs and trade wars connects with a reflection on economic complexity. It exposes the dynamics underlying global competition and reveals how economic systems function as adaptive networks subject to constant disturbances. The economy appears as a living organism, whose stability depends on cooperation and creative solidarity.

Modern agriculture is examined from a perspective that underscores the importance of integrating biodiversity, food sovereignty, and respect for vital cycles. A regenerative agriculture is presented, capable of revitalizing soils, preserving seeds, and strengthening the connection between communities and territories. This chapter presents agroecology as an essential paradigm for sustaining the continuity of life.

Local economic development is addressed as a complex process that articulates cultural values, local knowledge, and appropriate technologies. Progress is proposed to be measured in terms of integral well-being and harmony with the environment, beyond quantitative accumulation. This chapter suggests pathways for building resilient and equitable economies, based on mutual respect and cooperation.

The final reflections constitute an urgent call to transition toward a complex rationality, committed to life and collective becoming. This epilogue calls for the intellectual courage and ethical bravery necessary to face global challenges. As a whole, the work stands as a song to the possibility of a way of thinking that embraces uncertainty and celebrates interdependence as the vital core of the human condition.



Chapter 1

Determinism as a Paradigm in Ancient, Classical, and Modern Sciences

Determinism as a Paradigm in Ancient, Classical, and Modern Sciences

The history of science is closely linked to three major periods: antiquity, classical science, and modernity. Throughout these eras, the deterministic current has influenced various epistemological conceptions aimed at explaining the causes of phenomena. In its most common formulation, determinism refers to a causal relationship among three elements: "A" (the subject), "B" (the cause), and "C" (the action). According to Salcedo (2010), this structure implies that “A” is determined by “B” to perform “C,” establishing an inevitable causal relationship based on prior causes. Thus, it is held that cause "B" irrevocably determines the action "C" of subject "A," thereby nullifying their freedom.

Within this framework, strict determinism is conceived as a form of predeterminism: the belief that human action is determined by prior causes beyond the subject’s control (Abbagnano, 1963). Ferrater Mora (1988) reinforces this view by stating that everything that has happened, is happening, or will happen is predetermined, in accordance with a strict causal order.

It is essential to distinguish between different forms of determinism. A distinction has been made, for instance, between determinism as causalism and as teleologism or finalism. Both currents agree that phenomena obey a rigorous causal chain that excludes freedom. The original conception was teleological: phenomena were explained in terms of ends. Aristotle, one of its foremost exponents, asserted that natural beings tend to realize their essence, which implies a causality oriented toward a goal. In this model, chance is excluded. Nature pursues an essential purpose.

This approach contrasts with later mechanistic conceptions, such as those of Descartes and Newton, who discarded final causality. Instead of ends, they proposed an explanation based on mathematical laws regulating the behavior of interacting particles. From this perspective, the universe functions like a predictable machine: knowing the initial conditions and the laws governing phenomena, it is possible to anticipate their evolution.

The Cartesian-Newtonian thought transformed the notion of causality, replacing finality with quantifiable causality. Descartes and Newton imagined a universe governed by precise laws, whose interactions could be calculated. This model had a profound impact on modern science, consolidating determinism as a fundamental principle.

This mechanistic paradigm faces epistemological limitations. Although it allowed for highly precise explanations of phenomena, the idea of a completely predictable universe was challenged in the 20th century with the theory of relativity and quantum mechanics. Both introduced limits to predictability. Relativity suggested that physical laws lack absolute character, and Heisenberg's uncertainty principle demonstrated the impossibility of simultaneously knowing the exact position and velocity of a particle, thus challenging classical determinism.

Chaos theory also eroded the idea of absolute predictability. In nonlinear systems, small variations in initial conditions can produce enormous differences in outcomes. Although these systems remain deterministic in principle, the practical impossibility of knowing the initial conditions with exactitude prevents precise predictions. This suggests a complexity that transcends classical predictive frameworks, without fully reaching absolute indeterminism.

Determinism, therefore, is a concept that allows for nuances. From Aristotelian teleology to contemporary models, it has taken various forms depending on epistemological, ontological, and methodological contexts. The debate about determination and freedom remains central, especially in social sciences, where economic, cultural, or biological determinisms are discussed in relation to human agency. Complex thought, following Edgar Morin's line, proposes overcoming linear and reductionist explanations, suggesting a more holistic and dynamic vision of reality.

Consequently, determinism has evolved in response to new scientific discoveries and epistemological shifts. The current challenge is to articulate a framework that recognizes the interaction among causality, probability, freedom, and complexity, without losing sight of the inherent limitations of human knowledge in the face of a multifaceted and ever-changing universe.

Causal Determinism and Its Limits

Modernity introduced a crucial ambiguity into deterministic thought. On one hand, it consolidated the causal-mechanistic model, which sought to explain even human behavior through strict laws. On the other, the figure of the autonomous subject endowed with free will emerged, generating a tension between scientific predictability and individual freedom. Descartes (1977 edition) asserted that human will was so vast that he could not imagine a more perfect one, disconnecting it from understanding. This view was gradually questioned by modern science, which demanded more objective, quantifiable, and predictive models.

Within the mechanistic framework, the idea emerged that human behavior could be anticipated through exhaustive analysis of its causes, reducing its ethical, cultural, and historical richness to mere variables. The human being thus came to be conceived as a calculable entity within a closed and predictable universe governed by unbreakable laws.

The limitations of this approach became evident with scientific advances. The impossibility of considering all the factors involved in human processes led to the development of more nuanced theories, such as causalism. Although initially aimed at more accurate predictions, it was soon recognized that the human mind lacks the capacity to encompass all determining variables. From this arose the figure of an ideal intellect, like Laplace's "demon," capable of knowing all the forces and states of the universe at a given instant and foreseeing the past and future with certainty (Popper, 1994).

This hypothesis revealed its own limits. Neither the human intellect nor any known intelligence has succeeded in encompassing such complexity. This recognition weakened the idea of perfect prediction and questioned the validity of absolute determinism. The notion that human mind and action could be governed by immutable causal laws became increasingly unsustainable.

Modernity replaced teleology with more than pure causalism by introducing the modern subject as an entity capable of deliberating and acting according to free will. According to Descartes, "I feel within me a will so great that I do not conceive another more perfect" (1977), thus asserting self-determination. Human actions are influenced by causes, although these prove insufficient to explain them entirely. Freedom manifests in the capacity to choose despite conditioning factors.

This approach was strongly criticized for its metaphysical basis and for the growing demand for more objective and verifiable scientific explanations. Science tended to privilege mechanistic models even in fields such as psychology and social sciences, seeking to explain human behavior within deterministic frameworks. This paradox highlighted the conflict between subjective freedom and a scientific model that, by definition, tends to negate it.

The conception of the human being as completely predictable was challenged by epistemological currents that recognized the complexity and indeterminacy of human systems. Although causalism was presented as a more realistic alternative, it also proved insufficient to adequately explain all the factors involved in human action, especially due to its inability to predict with certainty behaviors conditioned by multiple levels of reality.

Duality Between Freedom and Determinism in Modernity

Modernity introduced a fundamental ambiguity by establishing a double epistemological movement. On one hand, it consolidated the causal-mechanistic model, which sought to explain all of reality, including human behavior, through a deterministic lens. On the other, it exalted the figure of the autonomous subject, capable of deciding by their own will.

Descartes (1977) asserted that human will was so vast that no more perfect one could be conceived, disconnecting it even from the limits of understanding. This conception was progressively questioned by a science demanding objective, measurable, and predictive explanatory models.

The idea that human behavior could be anticipated through exhaustive analysis of causes and conditions was central to mechanism. This vision reduced the subject to a calculable entity, stripping it of its ethical, cultural, and historical complexity. Thus, a paradigm was imposed that conceived both the universe and the human being as closed systems governed by immutable causal laws.

Scientific Determinism and the False Perception of Total Control

A theory is deterministic when it holds that every phenomenon obeys universal laws, implying that any event is predictable if its causes are known. This approach reached its peak in the 17th century, when science formulated mathematical laws capable of precisely describing terrestrial and celestial movements. Analytical mechanics and celestial mechanics emerged, offering a vision of an ordered and predictable universe.

Paradoxically, many founders of this science were deeply religious. Descartes believed in an eternal, immutable, and omniscient God, creator of matter and guarantor of motion. Newton, for his part, affirmed that the solar system could only have originated through the work of an intelligent being (Cohen, 1971; Cohen & Koyré, 1972).

This “hypothesis” of divine intervention gradually lost relevance. When Napoleon questioned Laplace for not mentioning it in his work, the scientist replied: “Sir, I had no need of that hypothesis” (Woodward, 1891). And to Lagrange, who considered it a “beautiful hypothesis,” Laplace responded: “Yes, though it does not allow us to predict anything” (Simmons, 1996).

This shift marks an epistemological milestone: science emancipated itself from the theological framework and consecrated itself to total predictability. This confidence was eroded in the 20th century by discoveries that revealed the uncertain, unstable, and emergent character of many phenomena.

The transition from the classical to the complex paradigm represented a radical change in the notion of knowledge. The focus shifted from predicting or controlling to understanding, integrating, and intervening in contexts marked by uncertainty. This new rationality recognizes that absolute prediction is an illusion, full objectivity is an ideal, and that knowledge must incorporate the subject, their context, values, and reflexivity.

Authors such as Ilya Prigogine, Stuart Kauffman, Gregory Bateson, and Humberto Maturana have decisively contributed to this transformation. Prigogine (1980) showed that even in physico-chemical systems far from equilibrium, self-organized and unpredictable structures can emerge: the “dissipative structures.” Kauffman (1995) argued that in biological systems, emergence is a structural, not accidental, property. Maturana and Varela (1994) introduced the concept of autopoiesis to describe how living beings self-organize in interaction with their environment. These perspectives converge in Edgar Morin's proposal for a complex rationality that rejects reducing scientific knowledge to a closed framework and inscribes it in a broader and self-critical perspective, capable of embracing error, contradiction, and the incompleteness of human knowledge.

Genealogy of Determinism

One of the most common mistakes in understanding determinism consists of treating it as a univocal and homogeneous category. Under this notion coexist deeply different, and even contradictory, philosophical traditions. For this reason, it is necessary to clearly distinguish between the teleological, mechanistic, and causalist versions of determinism in historical and epistemological terms.

1. **Teleological Determinism: Finality as an Ontological Principle**

Classical Greek thought, especially in Aristotle, conceives reality as oriented toward immanent ends. The final cause constitutes an essential explanatory principle, rather than a mere complement. In his Physics and Metaphysics, Aristotle asserts that every being naturally tends to actualize its potential, that is, to realize its essence. This finality is constitutive: the seed tends to become a tree, the eye to see, the human being to live virtuously. This conception implies profound epistemological and ethical consequences: to know is to understand the end, and to act well consists in realizing it according to reason. Aristotelian science is therefore a science of meaning. Although it was displaced by modernity, this framework persists in various normative visions of the world.

2. **Mechanistic Determinism: Reduction to Efficient Causes**

The scientific revolution of the 16th and 17th centuries broke with teleological ontology. Galileo, Descartes, and Newton replaced final explanations with efficient causes. The shift from "for what purpose?" to "how?" represents the transition from teleological to mechanistic thinking. Descartes conceived the world as a machine governed by invariant laws. Newton translated these laws into mathematics, establishing physics as the paradigm of knowledge. Causality became linear, quantifiable, and reversible; in this scheme, the universe is an automaton whose highest rational expression is prediction.

This implies the displacement of the subject and freedom: reality becomes a closed system, completely determined by prior conditions. As Laplace formulated, an intelligence that knew all laws and initial states could predict the future with exactitude. This vision influenced physics and disciplines such as economics, psychology, and pedagogy, where human behavior was modeled as a programmable system.

3. **Causal Determinism: Between Necessity and Probability**

In response to the limits of mechanism, causal determinism emerged. This current holds that there are causal laws, though many are expressed in statistical terms. The idea of absolute determination is abandoned in favor of observable regularity subject to margins of uncertainty; authors like Popper (1994) and Hempel reconstructed scientific explanation through probabilistic models. Science directs its effort toward the formulation of falsifiable hypotheses, subjected to empirical testing, rather than seeking perfect prediction. This approach proves more suitable for sciences such as biology, psychology, or social sciences, where regularities are less universal than in classical physics.

Tensions Between Paradigms

Far from representing a linear progression from false to true theories, the history of scientific thought reveals a dispute between paradigms with incompatible ontologies, methods, and values. The replacement of teleology by mechanics was more than a technical improvement. It was an epistemic shift that transformed the objects of study, the role of the subject, and the meaning of knowledge.

The Aristotelian world was qualitative, animated, and purposive. The Newtonian world, quantitative, inert, and devoid of meaning. The expulsion of telos entailed the neutralization of meaning, while the exclusion of the subject led to the objectification of knowledge, reducing its interpretative dimension and transforming it into a mechanical object of study. The logic of efficiency replaced that of the good. Therefore, the contemporary critique of determinism is technical, ethical, and political: What kind of world does a science produce that excludes finality, uncertainty, and subjectivity?

The deterministic paradigm intensified the dilemma of free will by questioning whether freedom is possible in a universe governed by physical laws. Kant proposed a solution by separating the phenomenal world, dominated by causality, from the noumenal world, where moral freedom resides. This response, metaphysical in nature, remained beyond the reach of science, leaving the problem unresolved from an empirical perspective. Spinoza took determinism to a deeper level by suggesting that freedom arises from understanding the inherent necessity of the universe. In his Ethics, he asserts that "the free man is the one who acts according to reason," which implies accepting and aligning oneself with the natural laws. For him, freedom is understood as the capacity to recognize and act in harmony with the structure and rules governing existence (Spinoza, 1677/2008).

In the scientific realm, thermodynamics and evolutionary theory introduced significant nuances. The second law of thermodynamics, by postulating entropy, challenged the vision of a completely predictable universe. Darwin, for his part, replaced biological finality with statistical selection: there are random variations and differential survival, without predetermined ends. These advances preserved the core of mechanistic determinism, although they significantly modified its conceptual foundations. The duality between freedom and determinism in modernity reveals a persistent tension between the aspiration for total control through knowledge and the inherent limits of human understanding. While science sought a predictable universe, philosophies of freedom attempted to reclaim agency in the face of closed systems. This tension continues to fuel contemporary debates about the autonomy of the subject and the possibilities of knowledge.

From Scientific Determinism to Chaos Theory

During the 20th century, the deterministic paradigm inherited from classical science began to erode. New theoretical frameworks such as quantum mechanics and chaos theory questioned the pillars of the Newtonian-Cartesian model: linearity, reversibility, predictability, and the separation between subject and object. This transformation preserves determinism, reformulating it within the context of complex, dynamic systems characterized by nonlinear interactions.

David Bohm, a heterodox physicist, proposed a vision of the universe as a totality in constant flux. In Causality and Chance in Modern Physics (cited in Stewart, 2001), he argues that order can emerge from apparent chaos through combinations that generate coherent structures. Chance, far from negating law, may be its condition of possibility. Thus, chaos is presented as a generative matrix of order, far from signifying an absence of meaning.

Chaos theory, developed by Edward Lorenz, Ilya Prigogine, and others, introduced a radical form of unpredictability. In nonlinear systems, small variations in initial conditions provoke divergent effects, making it impossible to predict their long-term evolution. This phenomenon, known as "sensitivity to initial conditions" or the "butterfly effect," reveals the complexity of determinism, showing laws that govern the system without ensuring absolute control over its outcomes. This perspective discredits Laplace's illusion of an intelligence capable of predicting everything from initial conditions. Science abandons the obsession with absolute prediction and shifts toward understanding probabilistic patterns in unstable dynamic systems.

The Quantum Revolution and Indeterminacy

Quantum mechanics introduced Heisenberg's uncertainty principle, according to which it is impossible to know both the position and the momentum of a particle simultaneously with precision. This indeterminacy arises from an ontological characteristic of subatomic reality, beyond any technical limitations. The subatomic world is composed of systems where measurement influences the phenomenon, rather than being composed of objects with defined properties independent of the observer.

Heisenberg demonstrated that, in the microscopic realm, defined trajectories are replaced by wave functions which, according to Schrödinger's model, represent probabilities. This probabilistic description reveals an intrinsic indeterminacy in the nature of being. Thus, concepts such as strict causality, predictability, and continuity are profoundly questioned as foundations of classical determinism.

The quantum revolution introduces an epistemological shift in which the observer is integrated into the process, leaving behind the notion of neutrality and externality. Knowledge becomes the result of an interaction between the knowing agent and the phenomenon, constructing reality in the very act of measurement. This raises the need for a relational epistemology that contemplates this interdependence.

Chaos theory expanded the scope of unpredictability to include macroscopic systems. Although they maintain a deterministic structure, these systems display dynamics highly sensitive to initial conditions. The so-called butterfly effect, popularized by Lorenz, illustrates how small alterations can generate divergent paths, complicating any precise prediction in fields such as climate, financial markets, or ecosystems. "The flap of a butterfly's wings in one part of the world may cause a hurricane in another."

Both the quantum revolution and chaos theory transformed the traditional vision of science. Instead of a fully predictable universe, they propose a rationality that incorporates uncertainty as an essential element of knowledge. This approach recognizes the inherent limitations in controlling and predicting dynamic and constantly evolving systems.

Determinism persists, though without offering an absolute guarantee of certainty. It is redefined as a contextual regularity dependent on local and specific dynamic conditions. Ilya Prigogine emphasizes that contemporary science focuses its efforts on achieving clarity within the unstable, the transitory, and the emergent, rather than seeking eternal truths. This shift evidences a transition from the paradigm of simplification toward a science oriented toward understanding complexity.

From Myths to Reason

In Antiquity, natural knowledge combined rational observation with mythical elements. Cultures such as the Egyptian, Indian, Babylonian, and Chinese developed valuable empirical knowledge, though it was in Greece where this knowledge was philosophically systematized. Aristotle (384–322 BCE) proposed a teleological vision: every being tends to realize its form. Knowledge arose from observation and inductive generalization, though he rejected experimental validation. Thus, he claimed that heavier bodies fall faster, without empirically verifying it.

The Aristotelian model dominated for centuries. With Copernicus (1473–1543) and his heliocentric revolution, the geocentric paradigm began to be questioned. This transformation was also epistemological: common sense as a criterion of truth was displaced, and the subject was marginalized in favor of an idealized objectivity. With the Enlightenment, this exclusion of the subject was consolidated. Reason had to be clear, universal, and free of all affectivity or value. Thus, a separation was established between knowledge and life, between cognition and morality, which would later be criticized by Complex Thinking in the 20th century.

Classical Period: Rationalism, Empiricism, and the Universal Machine

During the 16th and 17th centuries, the ancient legacy was reformulated by European thinkers. Francis Bacon proposed an empirical science based on observation and induction. Kepler replaced Pythagorean spheres with observable elliptical orbits.

Cartesian rationalism, with its "I think, therefore I am," introduced a dualistic vision: res extensa (the physical world) and res cogitans (the thinking subject). The Cartesian

project ultimately excluded the subject from the scientific process by reducing the world to objects governed by efficient causes.
Empiricism countered that reason without experience is insufficient. This debate marked the evolution of modern science. With Newton, the paradigm reached its peak. His physics described a mechanical universe regulated by mathematical laws. Although Newton believed in a divine order, his method was based on experimentation and deduction.

This model excluded subjectivity, values, and sensitivity, consolidating the hegemony of reason and a science based on measurement and prediction. However, this absolute confidence would be questioned by the discoveries of the 20th century, which revealed a universe less stable and more unpredictable than previously believed.

The 20th Century: Crisis of the Classical Paradigm

Philosophers such as Karl Popper and Thomas Kuhn questioned the foundations of the traditional scientific method. Popper criticized inductivism and proposed falsifiability as a scientific criterion: a theory is valid if it can be empirically refuted.

Kuhn introduced the concept of “paradigm” as a common framework adopted by a scientific community. According to his perspective, science advances through ruptures that profoundly transform the worldview, rather than through the linear accumulation of truths. Paradigm shifts respond to cultural dynamics and collective transformations rather than deriving exclusively from logical proofs.

Paul Feyerabend took this critique to the extreme by proposing “methodological anarchism,” asserting that knowledge is constructed through multiple pathways. For him, scientific advances arise from challenging and transgressing established rules. This critical atmosphere coincided with the advances of relativistic and quantum physics. Relativity showed that time and space are relative to the observer. Quantum mechanics introduced an ontological indeterminacy. The observer ceases to be neutral, and their presence configures the phenomenon.

These theories reconfigured scientific epistemology. Absolute objectivity was replaced by an awareness of the limits of knowledge. As Edgar Morin (1999) pointed out, “all knowledge is a reconstruction by a subject situated in time and culture.”

The Need for a New Paradigm

The epistemological shift driven by complexity sciences demands overcoming the mechanistic model that has dominated Western thought since the 17th century. Based on the analogy of the universe as a perfect machine, this paradigm fostered great technological advances, though it also imposed severe theoretical and practical limitations. Reductionist, linear, and deterministic logic has shown its limitations when addressing interconnected, dynamic, and emergent phenomena characteristic of living and social systems.

The urgency for a new paradigm is more than theoretical: it responds to a cultural, political, and ecological necessity. Today's crises climatic, health-related, economic, social reveal the insufficiency of fragmentary, one-dimensional, and technocratic approaches. Facing these challenges requires a profound transformation in our ways of thinking, knowing, and acting.

The complexity paradigm proposes a fundamental change in the way we understand phenomena. In contrast to the classical model based on separation, simplification, and control, Complex Thinking emphasizes articulation, contextualization, and openness. This approach integrates uncertainty as an essential part of knowledge and privileges a situated, critical, and responsible understanding, moving away from the aspiration to omniscience.

Edgar Morin stands out as one of the main proponents of this transformation. His Complex Thinking transcends the limitations of closed theories and rigid methodologies, presenting itself as an epistemological orientation that invites us to reexamine all dimensions of knowledge. This approach encompasses everything from ontology to politics, including biology and pedagogy. According to Morin, knowledge must overcome the tendency to dissociate interconnected elements and to simplify the intricate. Reintegration of complexity at the core of knowledge is essential to adequately address the challenges facing the contemporary world.

From Scientific Complexity to Lived Complexity

Complexity encompasses much more than physical or biological systems, becoming an ontological dimension of human existence. Human decisions, relationships, and institutions are deeply marked by uncertainty, ambiguity, and multiplicity. For this reason, Complex Thinking extends beyond the scientific domain, significantly impacting ethics, education, politics, and knowledge management.

Morin emphasizes that complexity is more than a mere perspective on the world. It represents a different way of inhabiting it. This approach entails a profound reform of thought, a transformation of rationality, and the incorporation of an ecology of action.

Thinking in a complex way implies understanding that complex problems require integral solutions, while phenomena are immersed in networks of interaction and feedback. This approach embraces contradiction as an essential feature of reality: the coexistence of order and disorder, life and death, individual and society, reason and emotion.

From this perspective, knowledge transforms into a space of dialogue, care, and responsibility, moving away from its conception as an instrument of domination. The epistemic subject ceases to be a conqueror and assumes the role of an inhabitant conscious of their fragility and their interdependence with all living beings. Rationality acquires a new meaning, defined by its capacity to understand, connect, and transform in a way that respects the integrity of the environment and the beings that inhabit it.

This epistemological transformation implies an ethical transformation. Complex Thinking is oriented toward a commitment to life, diversity, and cognitive justice. Morin proposes an "anthropo-ethics" based on recognizing the human condition as shared, finite, uncertain, and relational. Instead of imposing universal rules, this ethics proposes reflecting on the consequences of actions, the bonds that constitute us, and the limitations inherent in knowledge.

In a globalized world, where local actions generate planetary repercussions, knowledge needs to consciously consider its effects. Science, technology, and education must converge in an ethical perspective that values and respects the complexity of life. Only then can an authentically humanistic rationality be built, capable of responding to the challenges of the 21st century and learning from the mistakes of the past.

The transition from classical determinism to Complex Thinking is more than theoretical. It is a historical necessity and a condition for a new way of inhabiting the world. It is also an invitation to rethink how we know, act, and coexist. In Morin's words: "The intelligence of the world requires the intelligence of the complexity of the world. And this intelligence requires the reform of thought" (Morin, 2000).

Critiques of the Classical Scientific Method

The scientific method, understood as a systematic and empirical procedure for producing knowledge, has for centuries been the standard of research. Precisely codified since the 17th century, it is based on the principles of empiricism, quantification, replicability, and reason. In its classical form, it adopts a hypothetico-deductive model: from observations, hypotheses are induced, from which predictions are derived and tested against experience. If they hold true, the theory is reinforced; if not, it must be revised or discarded.

This cycle of validation was considered unquestionable for a long time. From the mid-20th century onward, critiques emerged targeting its philosophical, epistemological, and ontological foundations. One of the most influential came from Humberto Maturana, who argued that all observation depends on the observer. According to Maturana (1994), "reality is generated in the relationship between the observing system and the observed." From this perspective, science describes the world as it is experienced from a specific cognitive position, rather than offering an absolute and independent representation.

Gregory Bateson, from another perspective, criticized the scientific method's tendency to treat descriptions as explanations. According to his approach, natural laws represent systematizations based on repeated observations, without guaranteeing that they explain the causes of phenomena. This tendency, Bateson argued, exposes science to the risk of transforming its linguistic constructions into ontological entities, losing sight of the fact that all knowledge is an interpretative representation of the world (Bateson, 1972).

Paul Feyerabend radicalized this critique by rejecting the existence of a universal method for advancing knowledge. In Against Method, he argued that major discoveries arose by breaking established rules. He proposed an "epistemological anarchy" that, without denying the value of science, questions its methodological dogmatism and champions freedom, creativity, and heterodoxy as engines of progress (Feyerabend, 1993).

Thomas Kuhn, for his part, highlighted the instability of scientific development. According to his thesis, science is organized around paradigms that define theories, relevant problems, forms of validation, and modes of observation. When a paradigm is worn out due to the accumulation of anomalies, a scientific revolution occurs that transforms and reconfigures the field. The history of science is characterized by its discontinuous and conflictive nature, rather than by linear or cumulative progress (Kuhn, 1971).

The classical scientific method, formulated in modernity by Galileo, Descartes, Newton, and Bacon, consolidated itself as the core of scientific rationality. Founded on hypothetico-mathematical deduction, controlled experimentation, and empirical observation, it became the emblem of an objective, universal, and cumulative science. Toward the end of the 20th century, various approaches began to deconstruct this hegemony, pointing out its theoretical, cognitive, and ethical limits.

One of the central criticisms targets objectivity. The positivist tradition assumed that scientific knowledge faithfully reflected an external and independent reality. Since the 1960s, this conception was profoundly questioned by authors such as Kuhn, Feyerabend, and especially Maturana and Francisco Varela. Their theory of the observer, based on autopoiesis, holds that all knowledge is an internal construction. The subject accesses the world through their operational, structural, and historical construction.

Maturana argues that “objectivity is the illusion that descriptions can be made without an observer.” This assertion deeply challenges the supposed scientific neutrality. Knowing implies creating more than representing, since knowledge arises from an experience constructed by a situated, embodied, and emotionally involved observer. This perspective introduces an ethical component into scientific practice: mediated by a subject, all knowledge entails responsibility for its effects, applications, and the exclusions it generates.

Bateson questions the logical reductionism characteristic of the classical scientific method. In his work Steps to an Ecology of Mind (1972), he argues that scientific laws merely describe regularities, leaving aside deep explanations. For Bateson, explaining requires developing a theory of context, a relational logic that contemplates patterns and interactions. For this reason, he proposes an “ecological epistemology” that integrates knowledge with the living processes it seeks to understand.

Feyerabend takes this critique to the extreme. In Against Method, he asserts that methodological rules have served more to exclude alternative knowledges than to understand reality. In his view, great advances occurred when scientists disobeyed methods, guided by imagination, intuition, and contingency. He defends an epistemological pluralism where knowledge advances through the coexistence of multiple rationalities, paradigms, cultures, and perspectives.

This perspective is taken up by Edgar Morin, who, from the standpoint of complex thought, argues that the classical method suffers from a "paradigmatic blindness." It has separated what is united, reduced the multidimensional to the univariable, ignored uncertainty, and eliminated contradiction. According to Morin (2008), this logic has been effective but has obscured the intelligibility of the complex world in which we live. For Morin, the classical scientific method is structured around four problematic pillars:

- **Reductionism:** the belief that the whole can be understood solely through its parts.
- **Disjunction:** the separation between subject and object, between natural and human sciences, between knowledge and ethics.
- **Determinism:** the assumption that every phenomenon obeys necessary and predictable causes.
- **Universalism:** the idea that scientific laws are valid in all contexts and systems.

From the Mechanistic Paradigm to the Paradigm of Complexity

In recent decades, scientists and intellectuals have reopened the debate on the need to transform thought and knowledge. In this context, the general systems theory, proposed by Bertalanffy in the 1950s, introduced conceptual and methodological tools to understand reality as an organized, dynamic, and interrelated whole.

This approach marked an epistemological rupture with the classical analytical vision and gave rise to "systemics," a new way of doing science. Toward the end of the 20th century, the systemic paradigm consolidated itself as a solid alternative, establishing the foundations of the complexity paradigm (Ferrer, 1998).

This new paradigm brings together scientists from diverse disciplines who emphasize the urgency of constructing more integrative theoretical, methodological, and epistemological models. By developing theories more closely aligned with reality, it seeks to intervene more effectively in social, political, economic, and ecological contexts, challenging the fragmentary rationality that has historically dominated both the natural and human sciences.

This transformation combines the analytical vocation of science with the transdisciplinary and critical attitude of philosophy. Thus, a convergence is articulated between Complex Thinking and the sciences of complexity (De Rosnay, 1996; Morin, 1992).

Birth of Complexity

In the 1960s, notions of computational complexity began to be formalized. In 1965, Hartmanis and Stearns introduced the first metrics for time and space as functions of input size, proving hierarchy theorems. That same year, Jack Edmonds proposed that an algorithm is efficient if its execution time is polynomial, leading to the definition of the classes P and NP. In 1967, Manuel Blum established axioms to measure complexity and formulated the speed-up theorem, providing a formal foundation for the field.

Among the decisive promoters of the complexity paradigm, Edgar Morin holds a central place. Philosopher, sociologist, and epistemologist, he has developed a vast and transversal body of work that spans from natural sciences to politics. His project culminates in Method, where he formulates the principles of a new rationality: complex thought.

Morin proposes an open, critical, and articulation-oriented epistemology, instead of a closed system. His approach integrates contradiction instead of eliminating it, incorporates uncertainty instead of imposing certainties, and connects knowledge instead of fragmenting it. As he himself states: "Complex Thinking attempts to articulate, without reducing them, dispersed knowledge, separated knowledges, antagonistic logics." (Morin, 1990).

This thought emerges as an alternative to the limitations of classical rationality, which operates under the logic of disjunction: subject or object, order or chaos, reason or emotion. This logic, based on the principle of non-contradiction, has generated clarity in certain aspects, though it has also fostered a cognitive blindness that makes it difficult to address the contradictory, the ambiguous, and the emergent. With this, Morin proposes a logic of conjunction: subject and object, order and disorder, rationality and affectivity. This dialogical logic integrates tensions, considering them essential elements of knowledge. For this reason, the reform of thought he proposes transcends mere technical improvement, promoting an ethical and ontological transformation in our relationship with knowledge.

Complex Thought

Complex Thinking emerges as a response to the limitations of the classical paradigm of modern science, characterized by fragmentation and reductionism. Throughout the 20th century, various scientific, philosophical, and epistemological currents demonstrated the insufficiency of this model to explain dynamic, interdependent, and multidimensional phenomena. Complex Thinking presents itself as an open epistemological attitude, incorporating uncertainty, contradiction, emergence, and self-organization as fundamental principles of knowledge, moving away from closed theoretical structures.

Key Milestones in the Evolution of Complex Thought

Cybernetics and systems theory (1940–1950): Norbert Wiener (cybernetics) and Ludwig von Bertalanffy (general systems theory) introduced the idea that systems are organized wholes, emphasizing feedback and interconnection among their parts. This laid the foundations for a more holistic view of processes.

Chaos theory and nonlinear systems (1960–1970): Edward Lorenz and Ilya Prigogine showed how complex systems can generate order out of chaos. Prigogine introduced the concept of "dissipative structures," explaining how disorder can give rise to organized forms.

Consolidation of the complexity paradigm (1980 onwards): Edgar Morin systematized these advances in his work Method, articulating principles such as dialogics (unity of opposites), recursion (causes and effects that feed back into each other), and hologrammaticity (the part contains the whole). Morin argues that thought must always be contextual, relational, and interactive.

Transdisciplinarity and social complexity (1990–present): Complex Thinking expands into the social and human sciences and connects with transdisciplinarity, seeking to integrate scientific, social, philosophical, and spiritual knowledge to address problems that are unsolvable from a single discipline.

Complex thought, developed primarily by Edgar Morin, criticizes the insufficiency of traditional approaches based on fragmentation and linear causality, for example, Taylor's scientific management models (1911). These approaches reduce reality to simple causal relationships, ignoring the complexity of the interrelations among the different elements that make up systems. Morin's proposal seeks to overcome this mechanistic and linear vision of science, recognizing reality as a complex, open, evolutionary, and nonlinear whole.

New Epistemological Approaches and Emerging Paradigms

Since the 1980s, new approaches such as autopoiesis, complex adaptive systems, chaos theory, and fractal geometry (proposed by Mandelbrot in 1975) have begun to shape the field of complexity sciences. These theories have helped to better understand nonlinear phenomena and the interaction among parts of a system, while questioning the classical model of universal laws and determinism. In the words of Kuhn (1962), we are experiencing a paradigm shift in the understanding of science.

Complex epistemology builds upon the contributions of researchers such as Gell-Mann (1994), Prigogine (1984), Kauffman (1995), Holland (1995), Arthur (1995), Morin (1995, 2000b, 2002a), and Maturana and Varela (1994), who have helped to rethink the nature of knowledge, the role of transdisciplinarity, and the processes of emergence in complex systems.

The Seven Principles of Complex Thinking According to Edgar Morin

1. **Systemic principle:** The whole is more than the sum of its parts. Each system possesses emergent properties that cannot be deduced solely from individual components. Understanding a system requires considering its interactions and context.

2. **Hologrammatic principle:** Each part contains information about the whole. Like a hologram, each component reflects the totality, similar to a cell that carries all the genetic information of the body.

3. **Feedback loop principle:** Effects can feed back into causes, creating a cycle of self-regulation within systems. This is fundamental for understanding processes of self-regulation, learning, and adaptation in complex systems.

4. **Recursivity principle:** The products of a system are also producers, creating a continuous cycle of self-organization and coevolution. Humans, for example, are products of their social systems and, in turn, produce them.

5. **Self-eco-organization principle:** Living systems self-organize, but always in interaction with their environment. The autonomy of a system depends on its capacity to adapt to its context and maintain balance with it.

6. **Dialogical principle:** Reality is full of tensions and contradictions that are resolved through integration. Order and disorder, reason and emotion, individual and society must be thought of together, never separately.

7. **Principle of reintroducing the subject:** All knowledge is produced by a situated subject, culturally and affectively conditioned. Knowledge lacks neutrality and is always influenced by the observer's perspective.

Complex Thinking proposes a new way of approaching science and knowledge, grounded in the integration of multiplicity and contradiction, and in the recognition of interdependence among systems. This approach rejects the pursuit of unique or simplified truths, prioritizing a deeper, more ethical, and responsible understanding of phenomena. In the face of contemporary challenges such as climate change or social crises, Complex Thinking provides tools for more inclusive and contextual reflection, capable of addressing the complexity of these problems.

Towards a Complex and Transdisciplinary Rationality

Complex Thinking challenges dispersed knowledge. Morin warns that extreme specialization leads to organized ignorance: details abound, but the vision of the whole dissolves. The reform of thought promotes knowledge capable of assembling detail and horizon, objectivity and lived experience, scientific rigor and everyday life. This way of knowing demands situated precision, dialogue among disciplines, and awareness of the bias introduced by any simplification. Morin (1999) reminds us that "all knowledge carries the risk of error and illusion." Intellectual lucidity demands critical vigilance and continuous examination.

Its projections are vast. In research, it opens multiple scales of analysis; in education, it fosters collaborative learning connected to life; in politics, it stimulates plural deliberation based on epistemic diversity. Rather than a closed system, the complex approach guides decision-making in uncertain and plural environments.

For decades, the word "complexity" described systems with abundant elements and unpredictable behavior. Morin conceives it as a provocation to cognitive acts and a call to think with multiplicity, contradiction, and emergence. This shift goes beyond merely adding knowledges or applying advanced models. It proposes transforming mental frameworks, opening a critical reason that connects science, ethics, and politics. Morin calls this process the "reform of thought" (1999): it questions inherited divisions and projects an integrative reason. From this perspective, connections, networks, and situated contexts are valued. The transdisciplinary attitude redefines knowing through the lived experience of shared problems. Complexity thus emerges as a flexible cognitive strategy, aware of its limits and open to revision.

Health, ecological, economic, and social crises demand integrative visions. These challenges exceed linear responses. They require systemic intelligence capable of recognizing interdependencies and fostering cooperation. The COVID-19 pandemic highlighted this need. A purely biomedical perspective proved insufficient for a phenomenon with epidemiological, social, and economic implications. Complex Thinking enables relational mappings, anticipates unforeseen effects, and supports adaptive strategies.

In the environmental sphere, the idea of the socio-ecosystem expresses the interaction between human and ecological health. This perspective includes marginalized knowledges, such as indigenous knowledge, and strengthens just and sustainable policies. In education, the complex paradigm promotes pedagogies centered on uncertainty, critical thinking, and the articulation of knowledges. Morin (1999) proposes forming reflective subjects, capable of questioning what they have learned and acting with ethical responsibility in ambiguous situations.

Institutional management and social leadership also benefit from this approach: organizations are understood as living systems in permanent renegotiation of meanings. Conflicts are interpreted as expressions of vitality, leadership becomes distributed, and innovation emerges from context.

Complex Thinking transcends the theoretical plane. Instead of offering recipes, it guides ethical understandings that transform relationships with knowledge, with others, and with the environment. Morin promotes a transformation of the cognitive act. Teaching involves awakening awareness of the assumptions that guide reasoning, opening judgment to critique, articulating dispersed elements, and embracing uncertainty as a constitutive trait.

This perspective establishes a metacognitive pedagogy: it invites reflection on one's own mental frameworks, their scope, and their effects. Knowledge is no longer seen as neutral accumulation but is redefined as a situated, historical, ethical, and committed construction. The transformation begins in childhood through experiential learning: curiosity, questioning, connecting knowledges, accepting error, and recognizing the bond between subject and world.

Inherited educational models segment content and apply quantitative evaluations. This logic impedes the circulation of knowledge and hinders integral interpretation. Morin proposes an ecology of knowledge that reconnects dispersed fields and demands curricular transversality. Topics such as ethics, chance, death, or the human condition cross all areas.

Thus, biology examines cellular structures and reflects on the concept of life. Mathematics introduces probability, chaos, and statistics applied to social realities. The ultimate goal is to forge subjects capable of thinking in networks and generating meaning within complexity. Complex pedagogy invites us to inhabit ambiguity with lucidity. Its aim is to form individuals who act with critical consciousness and contextual sensitivity. Learning involves emotion, body, history, identity.

Thinking from complexity means embracing this human dimension. Teaching becomes an act of care and listening. Ethics is exercised through cooperation, dialogue, and relational creativity. Morin synthesizes this horizon with the term "anthropo-ethics": forming beings aware of their interdependence with the planet and community.

In the face of ecological degradation, cognitive fragmentation, and loss of meaning, the school takes on the challenge of acting as a space for cultural emergence. Educating means promoting understanding and care for the common good. This purpose requires redesigning the figure of the teacher as a mediator of meanings and facilitator of complexity. Evaluation evolves into a reflective practice that accompanies processes and stimulates critical autonomy. For Morin, teaching Earth, error, the human condition, and planetary identity constitutes an essential cultural imperative.

Paradigm of Complexity and Transdisciplinarity

Transdisciplinarity stands as a pillar of complex thought. Faced with extreme specialization, a cognitive ecology emerges that articulates diverse modes of knowledge and fosters the circulation of meaning.

Basarab Nicolescu (2008) describes this path as a journey between, across, and beyond disciplines. It recognizes multiple levels of reality and the need for bridges between science, philosophy, art, spirituality, and oral tradition. Morin highlights the urgency of embracing complexity in challenges such as climate change, inequality, automation, or cultural collapse. This perspective drives a transformation of perception and an integrative reason.

Complex and transdisciplinary convergence shares the same critique of reductionism and encourages an articulating intelligence that is sensitive to context. More than acquiring data, the challenge lies in cultivating a reflective disposition and committed dialogue. In this framework, transdisciplinary knowledge promotes complementarity and acknowledges the value of ancestral knowledges, sensitive intuitions, and spiritual practices.

The complex paradigm proposes a recursive epistemology that incorporates error, contradiction, and ambiguity. Its goal, far from definitive explanation, seeks meaningful understanding and a science committed to the fundamental challenges of the 21st century.

Morin observes that humanity stands at a historical threshold: it possesses unprecedented technical power yet lacks equivalent ethical and cognitive criteria. Instrumental rationality has generated extraordinary advances and planetary devastation. The complex paradigm proposes a regenerative rationality that incorporates responsibility, sensitivity to uncertainty, recognition of errors, and openness to the unknown.

This way of thinking redefines science, revitalizes democracy, reimagines education, and reconstructs vital meaning. Morin’s vision points toward a complex humanism based on shared vulnerability, radical interdependence, and reconciliation between reason and emotion, technology and poetry, analysis and compassion.

In light of the limitations of the traditional scientific method, a complex rationality is proposed that integrates knowledges, engages in dialogue with other forms of knowledge, and addresses problems from multidimensional perspectives. Transdisciplinarity expands the reach of science by including dimensions and questions that transcend its usual framework (Nicolescu, 2020, p. 33).

In this sense, the scientific method is broadened and enriched, maintaining its utility while incorporating other modes of knowledge, such as narrative, cultural, and experiential approaches, especially in addressing socio-environmental and human problems. Critiques of the scientific method from Complex Thinking and the sciences of complexity point to the need to overcome the monopoly of the scientific method as the only valid path to knowledge production. Instead, an ecology of knowledges is proposed that recognizes epistemic plurality and promotes dialogue among science, ethics, philosophy, art, and ancestral knowledges.

Complexity, Method, and the Crisis of Instrumental Rationality

Complex thought, as a meta-epistemological standpoint, transcends merely describing the world as complex and demands an approach that delves into the complexity of the act of knowing itself. In this sense, Morin (2008) denounces the pathology of hyper-specialization: fragmented knowledge, dissociated from context and ethical aims, produces understandings blind to the global web of which they are part. This instrumental rationality, which dominates contemporary technoscience, is efficient yet blind: it can maximize short-term benefits while generating ecological, social, or existential disasters.

Complexity is more than a phenomenon of the object; it is a condition of the knowing subject. The method must become reflexive, aware of its own limitations and assumptions. This implies overcoming the paradigm of exteriority, according to which the observer is separated from the observed system. From quantum physics to contemporary anthropology, it has been shown that all observation transforms the observed phenomenon and that absolute neutrality is an operational myth.

Morin proposes an "ecology of action," emphasizing that every action transcends its initial intentions when it enters a network of interactions that can amplify, divert, or neutralize its effects (Morin, 2004). Therefore, Complex Thinking goes beyond merely integrating disciplines, demanding a reform of thought that connects knowledges, contextualizes phenomena, embraces uncertainty, and recognizes the active participation of the subject in the cognitive process.

This approach is especially pertinent when addressing contemporary global problems such as climate change, pandemics, or migration crises. All of these share characteristics of complexity: multiple intertwined dimensions (economic, ecological, health-related, cultural), nonlinear dynamics, feedback loops, and emergent effects. Applying a linear, specialized, and isolated thought process to these phenomena leads to ineffective or even counterproductive policies.

Table 1: ***Milestones in the Evolution of Complexity***

Decade	Main Contribution	Key Contribution
1940–50	Cybernetics and systems theory	Norbert Wiener · Ludwig von Bertalanffy introduce feedback and systemic interconnection, establishing a holistic perspective.
1960–70	Chaos theory and nonlinear systems	Edward Lorenz · Ilya Prigogine demonstrate the generation of order from chaos. Prigogine formulates dissipative structures.
1980–	Systematization of the paradigm	Edgar Morin · *Method* formulates the principles of dialogics, recursion, and hologrammaticity. Emphasizes the contextual nature of knowledge.
1990–present	Transdisciplinarity and social complexity	Integrates natural sciences, social sciences, and cultural knowledges to address problems irreducible to a single discipline.

Source: Author's own elaboration

The Epistemological Contribution of Edgar Morin: An Open and Regenerative Reason

Complex Thinking transcends criticism of the modern paradigm or the mere compilation of scattered heuristic principles. At its core, it constitutes an integral epistemological proposal aimed at regenerating Western rationality through its expansion. Morin reclaims reason, broadening it to include dimensions that modernity sidelined such as uncertainty, the subject, contradiction, meaning, and life recognizing them as essential elements of knowledge.

This proposal entails a profound transformation in ways of thinking. The epistemology of complexity goes beyond the idea of being a new discipline; it represents a mutation of the cognitive regime, where the contents of knowledge, its structure, its purpose, and its relationship with existence are reorganized integrally.

Morin questions the logic of disjunction, which separates subject and object, mind and body, nature and culture, as the foundation of a fragmented, technical, and disconnected knowledge. In place of this fragmentation, he proposes a logic of articulation that turns tensions into a space for constructive dialogue.

In Method (1977–2004), Morin designs a cognitive architecture that spans five levels: the knowledge of knowledge, of life, of organization, of complexity, and of the human being. This structure reflects knowledge conceived as a living system, feedback-driven, inseparable from context and subject. Epistemology thus transforms into cognitive anthropology: to think about knowledge implies thinking about oneself as a knowing subject, in a metacognitive exercise that displaces the classical distance between observer and object.

From this perspective, knowing involves actively participating in a reflective and situated practice, far from merely reproducing certainties. Epistemology transforms into a critical awareness of the very process of knowing, ceasing to be an external discourse about science. This metacognition forms the foundation of an ethical and political rationality, capable of questioning its own premises, objectives, and consequences.

Reintegrating Life into Knowledge

One of the most innovative contributions of Morin's thought is his emphasis on returning life to the core of knowledge. Modern science, by prioritizing objectivity, eliminated the subject, stripped knowledge of corporeality and emotions, and reduced life to meaningless mechanisms. For Morin, every act of knowing is vitally implicated, as knowledge is woven with affect, the body, history, and culture. This perspective turns complex epistemology into a bio-epistemology, an approach that recognizes thought as embodied, situated, and committed.

This vision has a transformative impact on pedagogy. Teaching is conceived as an invitation to experience knowledge as something alive, beyond the mere transmission of information. Learning, in this context, is understood as an existential practice, a way of inhabiting the world, understanding it in its depth, and acting in it with ethical lucidity. Morin synthesizes this proposal by affirming that "all true knowledge is committed knowledge," challenging the objectivist tradition of the classical paradigm.

Complex Thought, Social Sciences, and Knowledge Management

The principles of Complex Thinking have particular resonance in the social sciences, where phenomena characterized by ambiguity, multicausality, and meaning defy reductionist approaches. Human societies are configured as dynamic constellations integrating biological, symbolic, historical, and structural factors. Understanding these complexities requires a rationality that articulates multiple levels of analysis and recognizes the active participation of the researcher in the frameworks from which they interpret.

Morin proposes replacing the illusion of neutrality with a self-reflective epistemology, aware of the constructed and narrative character of social knowledge. Science ceases to be understood as a simple objective accumulation of data and is assumed as a symbolic practice, imbued with values, traversed by ethics, and guided by the desire to understand.

In the field of organizational management, this perspective replaces mechanistic and Taylorist models with a more complex vision. Organizations are understood as living systems, interacting with their environment. Human relationships, emotions, shared meanings, and emerging learning form a dynamic and unpredictable web. Knowledge, in this context, is generated, transformed, and constructed collectively.

This requires moving beyond the logic of control and efficiency toward a strategic intelligence that combines reflection, creativity, and ethical sensitivity. Organizations must learn to inhabit uncertainty, adapt without losing coherence, and innovate without uprooting. Complex epistemology thus reveals itself as an operative guide for more conscious leadership and for decisions oriented toward the care of life.

An Ethical and Political Reason

Morin's thought presents a direct critique of the supposed axiological neutrality of modern knowledge. Behind the claim of objectivity often lie power relations, epistemic exclusions, and forms of cognitive colonialism. Science, as a social construction, is traversed by interests, values, and political consequences.

Against this structural blindness, Morin proposes an ethical rationality conceived as an intrinsic necessity of the complexity of lived reality. Every act of knowing implies choosing a vision of the world, orienting desire, and configuring a relationship with otherness. Therefore, knowledge carries a dimension of responsibility. To know also means to transform, to affect, and to commit.

This "ecology of knowledge" proposed by Morin confronts any form of knowledge that reduces, instrumentalizes, or destroys. Instead, it promotes knowledge that listens, dialogues, and remains open to being challenged. It proposes a careful epistemology, willing to embrace diversity, the unexpected, and difference. In times of civilizational collapse, this perspective becomes urgently relevant, as rethinking ways of knowing becomes inseparable from reimagining ways of inhabiting the world.

One of the most disruptive contributions of Complex Thinking is the decisive reintroduction of ethics at the very center of the cognitive act. In opposition to the scientific model that separates knowledge and value, Morin asserts their interdependence: all ethics needs knowledge, and all knowledge entails an ethics. This reciprocity requires a critical awareness of the place from which one knows, the limits of knowledge, and the consequences of its application.

Science, in this framework, must avoid remaining depoliticized. It must recognize its performative power and open itself to dialogue with other rationalities: local, ancestral, symbolic, and spiritual knowledges. Knowledge production should be guided by criteria of cognitive justice, ecological sustainability, and human dignity.

To know, from the ethics of complex thought, means to understand, to care for, and to establish bonds, rather than to dominate or control. It is a profoundly human act that requires subjectivity as a basis for meaningful understanding. Complex rationality incorporates emotion, intuition, and uncertainty, integrating them into an epistemic approach that recognizes its own finitude with humility.

Thinking in a complex way thus becomes a form of education for life. It means forming subjects capable of living with ambiguity without falling into cynicism or dogmatism, acting with clarity amidst chaos, and constructing meaning without depending on absolute certainties. The pedagogy of complex thought, in its essence, is a pedagogy of living.

Complex Thinking offers a profoundly democratizing perspective on knowledge. By challenging epistemic hierarchies between experts and laypeople, centers and peripheries, formal sciences and experiential knowledges, Morin proposes a plural cognitive ecology. In this framework, diverse ways of knowing scientific, technical, ancestral, popular, and experiential dialogue on terms of epistemic equity. This openness reshapes criteria of rationality based on interdependence, critical dialogue, and complementarity among different cognitive traditions.

Morin seeks to foster co-constructive relationships between science and alternative knowledges. This perspective aligns with proposals such as Boaventura de Sousa Santos's "epistemology of the South" and with intercultural approaches applied in fields like health, education, and the environment. The aim is to expand reason toward more inclusive and dialogical forms, especially in contexts of epistemic and cultural diversity, where Eurocentric models face limitations in addressing complex and conflictive realities.

The notion of "cognitive democracy" articulates two simultaneous movements: decentralizing the production of knowledge by recognizing multiple legitimacies, and creating spaces for deliberation where these knowledges can meet, confront, and mutually transform. This logic, coherent with the paradigm of complexity, breaks with epistemic verticality and favors horizontal processes of collective learning.

Morin's Proposal Beyond the Epistemic Realm

Morin's proposal transcends the epistemic realm. It projects itself into a praxis guided by the awareness of uncertainty, non-linearity, and the unforeseen consequences of every intervention. Confronting the classical ideal of rational planning, he proposes a notion of strategy understood as reflective action capable of real-time adaptation, integrating feedback, and improvising with situated intelligence.

This approach promotes more lucid and ethical interventions in fields as diverse as public policy, organizational management, education, or social activism. Complex praxis avoids illusions of absolute control and faces with clarity the plurality of variables, the ambiguity of contexts, and the dynamics of open systems. Instead of imposing linear solutions, it explores tentative paths, sensitive to the emergent and to the relationships that shape each situation.

The challenge projected into the future transcends technical innovation and the efficiency of public policies. The main challenge consists in promoting a profound transformation of thought. This metamorphosis requires shifting a reason trapped in its automatisms toward a relational intelligence, open to the unexpected, which embraces diversity as a source of meaning and integrates multiple dimensions of experience.

This rational shift demands a fully conscious cultural will, a deep transformation in educational processes, and the emergence of intellectual communities willing to question established dogmas. Thinking differently requires weaving together knowledges historically kept separate such as science, art, spirituality, technology, and politics. This transformation of reason demands a committed engagement with new ways of knowing and a more inclusive vision of the lived world.

A Regenerative Reason for a Humanity in Transition

The rationality proposed by Morin envisions an ethical and political transformation of knowledge. Its goal is to develop the capacity to navigate chaos with lucidity, attend to unforeseen effects, and foster dialogue with diversity. Complex Thinking acts as a compass that guides and suggests open paths, avoiding rigid or predetermined trajectories.

Thinking in a complex key transforms knowledge into an engaged practice. Rationality ceases to be conceived as an instrument of domination and becomes an exercise of care, a bond with the living, a way of assuming the consequences of knowing.

This metamorphosis of reason arises from a critical awareness that recognizes the limits of knowledge, avoids closure, and embraces contradiction as an inherent part of the vital process. Within this awareness lies the possibility of a transformation that encompasses the cultural, the cognitive, and the existential.

Facing the technocratic hollowing of thought, the complex paradigm reclaims the richness of experience, the power of the unexpected, and the responsibility to intervene without totalizing aspirations. In times of civilizational crisis, this way of thinking becomes a necessity for imagining livable futures open to diversity and conscious of the fragility that unites us.

The Sacrilegious Computational Complexity

Computational complexity theory consolidated its conceptual structure in the 1970s with the identification of NP-completeness, a milestone that transformed the understanding of the limits of computation. In 1971, Stephen Cook demonstrated that the Boolean satisfiability problem (SAT) belongs to the class NP-complete, establishing that the existence of an efficient algorithm to solve it would imply efficient solutions for all problems in the NP class. Simultaneously, Leonid Levin achieved equivalent results in the Soviet Union.

In 1972, Richard Karp extended this idea by showing that various combinatorial problems such as the traveling salesman problem, the Hamiltonian cycle, and graph coloring are also classified as NP-complete. This development posed one of the most fundamental and challenging questions in theoretical computer science: Is P equal to NP?

During that same period, other fundamental classes emerged, such as PSPACE (polynomial space), which includes problems solvable with a polynomial amount of memory, and EXPTIME (exponential time), which encompasses those requiring exponential time. These distinctions precisely mapped computational resources and established operational boundaries for algorithmic knowledge.

During the 1980s and 1990s, the theory expanded with probabilistic models like Rabin's algorithms, which gave rise to classes such as BPP (bounded-error probabilistic polynomial time) and RP (randomized polynomial time). Interactive proof systems were also developed, culminating in 1992 with Adi Shamir's proof that

IP equals PSPACE, meaning that problems solvable with polynomial space can be verified through structured interaction.

In parallel, quantum computing emerged as a promising field. David Deutsch and Andrew Yao formalized the quantum Turing machine model, and in 1994 Peter Shor presented a polynomial-time algorithm for integer factorization, which led to the definition of the class BQP (bounded-error quantum polynomial time) and reframed the classical distinction between tractable and intractable problems.

The encounter between computational complexity theory and the Complex Thinking developed by Edgar Morin arises from a structural affinity: both perspectives confront the internal margins of rationality and propose reformulating the categories through which reality is understood, especially when facing unstable, contradictory, and multidimensional systems.

1. **Limits of Knowledge: Computational Uncertainty and Unfinished Reason**

The classes NP and PSPACE transcend their technical character to become expressions of epistemic zones of indeterminacy. The famous question "Is P = NP?" poses a challenge that goes beyond algorithmic efficiency; it questions the reach of reason in the face of complex problems. This enigma resonates with Morin's thought, who argues that complexity emerges when acknowledging the finitude of knowledge: instead of closing off, it opens to new possibilities. Rather than offering rigid certainties, it encourages problematization.

Thus, computational complexity theory manifests in the mathematical domain what Morin articulates from philosophy: the absence of absolute certainties invites a deeper exploration of the limits and possibilities of human knowledge.

2. **Dialogics Between Order and Disorder: Structural Chaos in Computational Logic**

NP-complete and PSPACE-complete problems inhabit a realm where logical order is stretched to the point of becoming unmanageable. From Morin's perspective, disorder intertwines with order in dynamic processes of organization. These computational classes demonstrate how even mathematically defined structures contain elements of chaos and uncertainty that challenge complete resolution.

The computational space appears as a scenario of active tensions between the possible, the unresolved, and the uncertain. This dialogics between order and disorder reflects the intrinsically complex character of formal systems, where stability and indeterminacy coexist as constitutive parts of the same reality.

3. The Involved Observer: Interaction and Co-construction

The equivalence IP = PSPACE shows that the interaction between verifier and prover has as much power as an autonomous computational strategy of high complexity. This relationship displaces the image of an external and inert observer. For Morin, all knowledge involves participation: knowing emerges from the relationship between the cognizing subject and the observed object. The interactive logic of IP connects with the relational logic of complex thought, where knowing implies intervening, communicating, and transforming.

4. Transdisciplinarity: Integration of Formal and Human Knowledges

Computational complexity theory dialogues with disciplines such as cryptography, artificial intelligence, quantum physics, and network theory. Its implications transcend the technical field. Morin warns against the fragmentation of modern knowledge and proposes a transdisciplinary rationality capable of articulating scientific, ethical, cultural, and symbolic knowledges. Questioning the limits of the computable also leads to questioning the limits of cultural, social, and political knowledge. Deciding what is solved and how that resolution is interpreted constitutes a situated construction.

5. Complexity as Awareness of Incompleteness

In computation and epistemology, complexity points toward a rationality that remains open. Undecidable problems, the indeterminacy surrounding P vs NP, and the expansion of classes like BQP show how technical knowledge reaches limits that demand a broader and more flexible approach. Morin invites us to conceive complexity as a mode of thought that embraces contradiction, contingency, and instability as essential components of knowledge, avoiding absolute closures.

During the 21st century, computational complexity theory has found applications in fields such as bioinformatics, game theory, and social network analysis. These areas are marked by nonlinear, unpredictable dynamics deeply influenced by context. Advances such as the optimization of PCP theorem proofs and new connections between computational classes, along with the inclusion of the P ≠ NP conjecture among the Millennium Problems, underscore the global importance of these issues.

Beyond evaluating algorithmic efficiency, this theory raises questions about the role algorithms play in organizing social life. In facing this challenge, Complex Thinking offers critical, ethical, and political tools to address it in depth.

Computational complexity and Morin's Complex Thinking converge in a common intellectual project that recognizes the limits of knowledge as a starting point for constructing an expanded, relational, and committed rationality. Classes such as NP, PSPACE, IP, and BQP draw logical boundaries that reflect how reason explores and questions its own finitude.

From Morin's perspective, this recognition demands deepening thought, humanizing it, and orienting it toward an ethics of knowledge that is conscious, critical, and transformative.

Critique of Complex Thought

Despite its conceptual richness and the growing influence it has exerted across multiple contemporary fields of knowledge, Complex Thinking has been subject to significant criticism. Edgar Morin presents it as an epistemology capable of integrating fragmented knowledges and fostering an inclusive rationality oriented toward the challenges of the planetary era. Various authors have identified theoretical and practical limits that merit careful reflection.

One of the most frequent criticisms targets the discursive style adopted by Morin. His writing, characterized by an essayistic, hybrid tone with a strong lyrical component, has been considered by some as an obstacle to the operational translation of his proposals. Critics such as Mario Bunge have pointed out a proliferation of concepts and metaphors that, in their view, lack the degree of formal precision and empirical verification required by the scientific domain. From this perspective, the poetic power of his ideas appears insufficient in the face of demands for clear validation criteria, especially in contexts such as experimental sciences.

Another critique concerns the difficulty of converting the principles of Complex Thinking into concrete methodological protocols. Although Morin conceives it as a transdisciplinary orientation rather than a closed method, this openness has generated uncertainty in areas where defined procedures and evaluable criteria are required. The lack of specific tools has restricted its institutional incorporation in fields such as applied social sciences or public policy formulation, where direct applicability and rigorous operationalization are highly valued.

Key concepts such as "emergence," "auto-eco-organization," or "hologrammaticity" present ambiguities due to their lack of clear delimitations and precise empirical operationalizations. This has led to vague or decorative uses that, far from deepening the complexity of phenomena, risk aestheticizing it and emptying it of theoretical density, reducing its scope to a repertoire of conceptually prestigious terms without real analytical impact.

An additional concern arises regarding the possibility of falling into excessive holism or a form of epistemic relativism. Although Morin has expressed reservations toward absolute relativism, the impulse to connect all elements can dilute boundaries between fields, scales, and levels of analysis, generating conceptual inflation where explanation loses discriminative capacity. The dialogical logic, one of the core axes of his proposal, could become counterproductive if it omits the establishment of clear criteria for integrating tensions. Treating every opposition as complementary risks obscuring concrete conflicts or neutralizing the power asymmetries that shape many social processes.

From a pedagogical standpoint, Complex Thinking proposes a comprehensive reform grounded in transdisciplinarity, contextualization of knowledge, and the connection between knowledge and ethics. Traditional educational systems, organized around fragmented disciplines and standardized evaluation schemes, show deep resistance to this change.

This tension has generated discontent among educators who, although they agree with Morin’s diagnosis, face material and institutional limitations that hinder the implementation of significant transformations. Education conceived from Complex Thinking requires conditions that allow overcoming these obstacles, enabling more integrative, critical pedagogical practices oriented toward the challenges of the contemporary world.

From a critical epistemological perspective, some thinkers from the Global South have pointed out that, despite its integrative vocation, Complex Thinking continues to operate within a Eurocentric matrix that privileges Western philosophical traditions. From this viewpoint, integrating knowledges demands much more than connecting academic disciplines: it requires embracing ancestral knowledges, situated experiences, popular practices, and marginalized epistemologies. As Boaventura de Sousa Santos argues, expanding science demands decolonizing knowledge.

These critiques seek to contribute to the enrichment of complex thought, recognizing its potential to become a relevant rationality in the 21st century. To achieve this, it is essential to expand its epistemic and political horizon, integrating conflicts, marginalized memories, and insurgent forms of knowledge creation.

Adopting this perspective demands a profound transformation in ways of thinking and an authentic openness toward epistemic diversity and cognitive justice. This approach fosters a more inclusive and plural dialogue, capable of addressing contemporary challenges from a broader understanding committed to equity and diversity.

Some analysts have also questioned the viability of Complex Thinking in the field of scientific research. They argue that the absence of criteria such as falsifiability and methodological reproducibility makes its integration difficult in contexts where these standards are central. Although Morin has acknowledged the tensions involved in formalizing his proposal, there remains an expectation for greater methodological precision that facilitates its concrete and evaluable implementation.

The objections extend to the educational field. Teaching from a complexity perspective, in contexts dominated by compartmentalized logics and reductionist approaches, faces multiple institutional barriers. In many cases, its introduction has remained at the declarative level without producing real transformations in pedagogical practices. Nevertheless, there are experiences that demonstrate its transformative potential: environmental education, critical pedagogy, global citizenship education, and participatory action research offer examples of applications that have succeeded in articulating complex principles with situated, open, and collaborative practices.

Rather than invalidating its value, these critiques help better understand the tensions, ambivalences, and challenges faced by this evolving paradigm. Its strength lies precisely in its decision to remain open to debate, willing to be revised, and permeable to new forms of rationality. Morin avoids offering definitive answers. His approach proposes a guideline for thinking more contextually, critically, and committedly. His proposal presents itself as an epistemological gesture that stimulates constant inquiry, distancing itself from rigid structures. It is a bet on a rationality that prioritizes humility, reflexivity, and ethics in the act of knowing, fostering an open and responsible attitude toward the complexity of the world and of knowledge.

This journey from classical determinism to Edgar Morin's Complex Thinking reveals more than a linear succession of paradigms: it traces a constant tension between the longing for certainty and the experience of uncertainty. The history of science unfolds between the drive to control and the growing awareness of the limits of knowledge. In this oscillation, Complex Thinking emerges as a radical opening: the possibility of thinking about reality without reducing it, of knowing with lucidity about one's own involvement, and of acting with the understanding that every intervention is inscribed in networks that exceed prediction.

Morin proposes an ethics of thought that invites us to approach knowledge as a practice sustained by humility, critical attention, vital connection, and active commitment. In a world characterized by interdependence, fragility, and constant change, this epistemic attitude presents itself as a path to sustain and enrich life through lucidity and solidarity. In this way, Complex Thinking transcends its epistemological character, becoming a pedagogy of meaning and a politics oriented toward coexistence, capable of responding to contemporary challenges from an integrative and transformative perspective.

From this viewpoint, the challenge lies in learning to inhabit the complexity of the world: to think with it, to act from it, to transform oneself within its movement.

The trajectory of scientific thought, from its classical roots to its current expressions, can be interpreted as a process of progressive awareness of complexity. From Aristotelian telos, through Newtonian mechanism and Cartesian rationality, to the ruptures introduced by quantum physics, chaos theory, and systems biology, a fundamental shift becomes evident: from the ideal of absolute prediction to the acceptance of uncertainty as a constitutive feature of the world.

This shift transcends the theoretical plane; it also transforms the civilizational horizon. Modernity, sustained by a fragmentary and reductionist rationality, today faces a structural crisis, evidenced by ecological, social, health, and cultural phenomena that demand new ways of understanding. Faced with this demand, Morin's Complex Thinking offers a coherent, critical, and constructive response.

Throughout this text, it has been argued that complexity transcends its character as a theoretical alternative. It emerges as a demand of our time, proposing a way of thinking that challenges the assumptions of the classical paradigm: disjunction, unidimensionality, and separation. This approach introduces an articulating, contextual logic open to uncertainty. Its principles systemic, hologrammatic, recursive, retroactive, self-eco-organizing, dialogical, and subjectivizing offer tools for a profound revision of scientific, educational, political, and existential practices.

The challenges faced by this perspective have also been analyzed: its conceptual density, integrative ambition, and rejection of simplification can lead to inoperability if they lack clear methodologies, pedagogical disposition, and openness to dialogue with other knowledges. The complex paradigm must be sustained as an active and embodied epistemological practice, capable of inhabiting the intermediate spaces between rigor and uncertainty, between systematicity and openness, between calculation and experience.

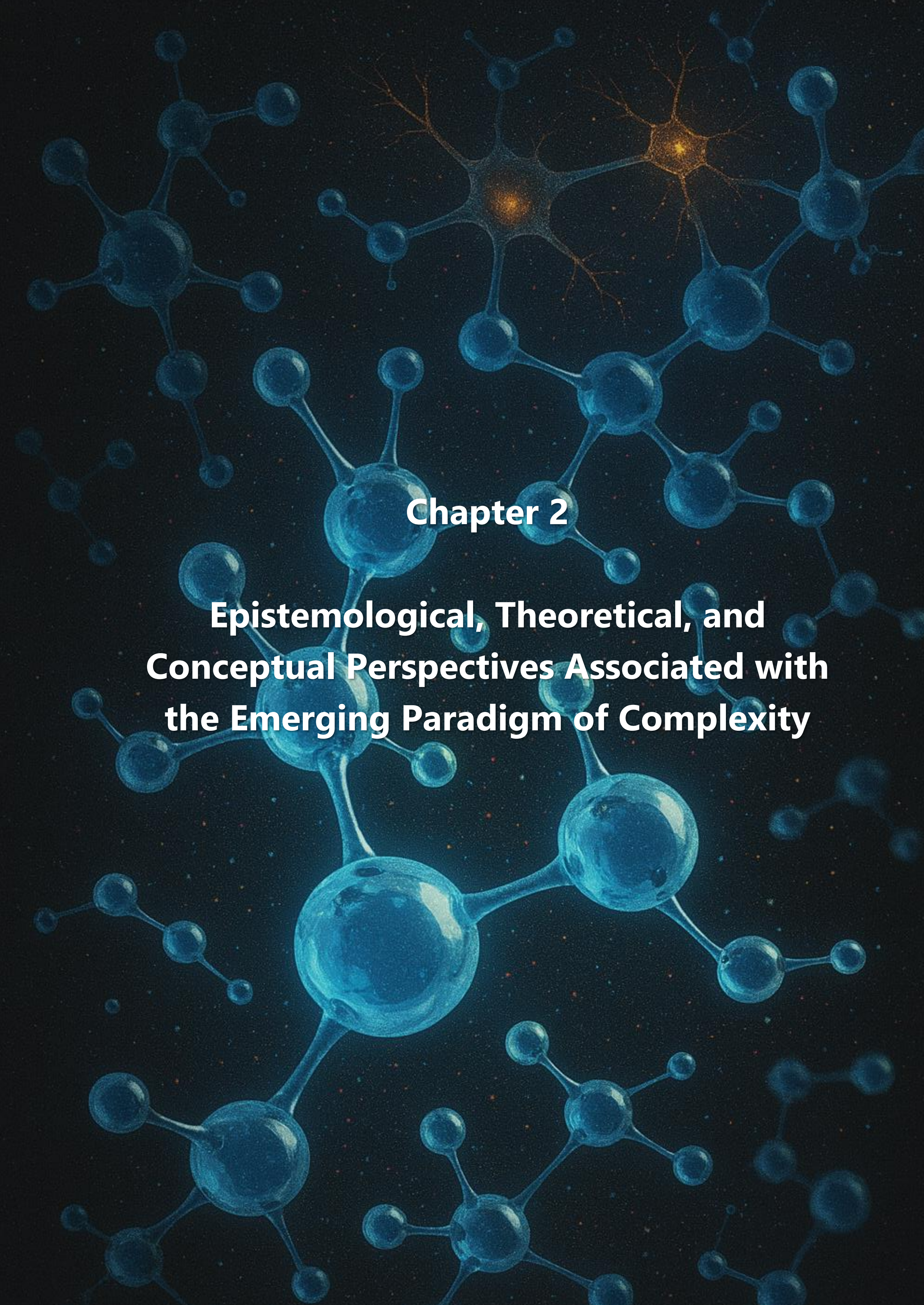
One of Morin's central teachings lies in understanding that all complexity demands a thinking, committed, sensitive, and ethical subject. To know means to become involved, to care, and to transform. Thinking transcends mere passive description to actively integrate into the world and participate in its transformation. This way of thinking proposes a cognitive sensitivity that coexists with contradiction, recognizes limits, and dialogues with diversity.

This approach also transforms existing structures of education, science, and politics. It proposes a reform of thought that impacts the organization of knowledge, validation mechanisms, relationships between disciplines, and training models. Such reform demands a cultural and structural mutation, oriented toward revising ways of teaching, researching, evaluating, and intervening.

Far from representing a definitive overcoming of previous thought, complexity presents itself as a critical and evolutionary instance. It seeks to integrate the contributions of classical rationality within a broader framework that intertwines clarity and formal analysis with ambiguity, relationality, and dialogical logic. The challenge lies in discerning when simplification facilitates understanding and when complexification becomes essential to preserve meaning.

Complex Thinking emerges as one of the most fertile and necessary proposals in contemporary thought. Rather than a closed model, it embodies an evolving project. Rather than a guarantee of truth, it points to a way of seeking understanding. Rather than a technique, it represents a disposition toward the world. Its greatest value lies in the questions it raises, in the certainties it challenges, and in the possibilities it opens to build lucid, relevant, and humanizing knowledges.

The history of science teaches that no paradigm is eternal, and that every profound change requires time, controversy, practice, and risk. Complex Thinking calls us precisely to that risk: daring to think beyond inherited frameworks, to cross disciplinary boundaries, to sustain ambiguity without falling into relativism, and to turn knowledge into a form of care in a world in transformation.



Chapter 2

Epistemological, Theoretical, and Conceptual Perspectives Associated with the Emerging Paradigm of Complexity

Epistemological, Theoretical, and Conceptual Perspectives Associated with the Emerging Paradigm of Complexity

In the past five decades, various intellectual circles have reignited a crucial debate on the need to reformulate the foundations of thought and knowledge. In this context, Ludwig von Bertalanffy's general systems theory has consolidated itself as a key conceptual tool for generating relevant and contextualized knowledge. This theory proposes a reading of reality as an organized, functional, and multidimensional whole, where elements interact dynamically and recursively, generating emergent properties that are irreducible to the sum of the parts.

This shift implied a significant epistemological rupture. From systems theory, the analytical orientation of classical science began to give way to a systemic approach that originated a new discipline: systemics. This perspective coexisted with the dominant analytical paradigm, although by the last third of the 20th century, systemic thinking began to consolidate itself as a viable alternative to the mechanistic model based on linear causality, reductionism, and determinism. From this process emerged the paradigm of complexity, conceived as a theoretical framework capable of integrating multiple dimensions, levels, and logics of knowledge.

From an epistemological perspective, complexity has been characterized by authors such as Delgado as a novel and still marginal current within contemporary scientific fields. Its originality lies in the rupture it proposes with hegemonic rationality.

Complexity establishes a post-classical rationality that enables the inclusion of phenomena historically excluded by modern science while redefining the criteria of scientific validity.

Among the phenomena marginalized by classical science are disorder, chaos, interrupted linearity, disequilibrium, undecidability, uncertainty, contradiction, chance, emergence, temporality, and self-organization. The paradigm of complexity assigns these phenomena a central epistemological value. In this way, it configures a new way of thinking and doing science that transcends the limits of mechanistic, reductionist, and deterministic frameworks, pillars of the modern paradigm (Delgado, in Rodríguez and Aguirre, 2011, p. 2).

In the field of complex systems, the specialized literature offers diverse approaches. One of them, represented by García (in Rodríguez and Aguirre, 2011, p. 2), conceives complex systems as organized totalities composed of inseparable elements. This idea proposes a deeply anti-reductionist stance: when the components of a system depend on their interactions to generate emergent properties, their analysis must focus on the constitutive relationship they maintain with the whole.

The distinction between separability and inseparability allows for the classification of systems into two types: on the one hand, those whose parts can be examined separately; on the other, those in which the elements mutually define each other. In this context, García introduces the concept of interdefinability, which goes beyond mere interaction. This implies that each component only acquires meaning through its relationship with the totality, making isolated analysis impossible. Therefore, complex systems are essentially interdefined: their identity emerges from the whole that constitutes them.

Alongside these formulations, the contributions of Edgar Morin are essential, widely recognized as the founder of complex thought. For him, his proposal goes beyond the philosophical realm and presents itself as a general theory of knowledge that transcends the Cartesian structure. Morin proposes a radical reformulation of knowing, based on multidimensionality, uncertainty, contradiction, and self-organization as constitutive dimensions of reality.

From this perspective, Complex Thinking transforms the process of knowledge by integrating regularities and irregularities, order and disorder, stability and instability. In this framework, the coexistence between the logical and the contradictory is recognized as essential for understanding reality. To know means to integrate both the elements of a phenomenon and their relationships, contexts, feedbacks, and loops. In this sense, Complex Thinking proposes an epistemic ethics that assumes uncertainty with responsibility.

This rationality distances itself from the classical ideal of absolute objectivity by introducing a vision that acknowledges the incompleteness, partiality, and provisionality of knowledge. Morin's perspective emphasizes the need for knowledge that articulates instead of fragments, that connects instead of dissociates. In this way, Complex Thinking redefines the foundations of science by proposing an epistemology that embraces uncertainty with rigor and seeks to understand complexity without reducing it.

The paradigm of complexity represents a significant transformation in the way knowledge is understood and generated. With the contributions of Bertalanffy, García, Delgado, and especially Morin, a transdisciplinary, systemic, and critical vision is established that challenges the foundations of classical science. This approach dialectically transcends scientific modernity by integrating its achievements, highlighting its limits, and proposing epistemological horizons where thought reconciles with the complexity of the inhabited world.

Dialogues/Debate on Complexity

Below is the first thematic dialogue, based on a critical analysis of relevant sources in specialized literature. It presents the controversy between Complex Thinking and complexity sciences, considering divergent positions, epistemological foundations, and an argued reflection from the author's perspective.

Dialogue 1: Complex Thinking vs. Complexity Sciences

In the field of complexity, at least three main strands coexist: complexity as a method, linked to Edgar Morin's thought; complexity as a systemic worldview; and complexity as science, understood in its technical-computational sense. This section examines the critique maintained by Carlos Eduardo Maldonado of Morin's work, particularly regarding its epistemological validity compared to formal sciences.

> "Of the three paths of or towards complexity, complexity as a method is the most popular, both because of the accessible language it employs, despite its neologisms and graphic representations, and for its direct character. This

> is evident in Edgar Morin's work. In contrast, complexity as science involves frontier research, with mathematical, physical, and biological languages, which are difficult for the general public to access."
> (Maldonado, 1999, pp. 37–53)

Maldonado argues that Morin formulates a partial critique of the classical method, focusing solely on its technical dimension (organon) and omitting a questioning of the method as the normative canon of modern thought. This omission, according to him, weakens the consistency of his epistemological proposal.

In response, Morin, through Osorio (2012), clarifies that his approach extends beyond a methodological alternative. He proposes an emerging paradigm of complexity aimed at replacing the reductionist model of modern science. His approach is based on four pillars:

1. A philosophical tradition that embraces contradiction as a constitutive principle of thought (Heraclitus, Nicholas of Cusa, Pascal, Hegel, Marx, Adorno, Jung, Lupasco).

2. Theories of information, cybernetics, systems, self-organization, and self-production (Von Foerster, Maturana, Atlan).

3. The phenomenological and hermeneutic critique of modern science (Husserl, Heidegger).

4. A critical epistemology influenced by the emergence of uncertainty during the scientific revolutions of the 20th century (Bachelard, Popper, Kuhn, Feyerabend).

From this perspective, Morin vindicates an epistemology that articulates science and philosophy in a recursive, contextual, and non-linear process. Complex Thinking is conceived as a metacognitive act, an ethical and intellectual commitment to understanding uncertainty, contradiction, and the multidimensionality of reality.

> "Sacrilege! How many borders crossed without a passport! How many sanctuaries profaned! What an impossibility to understand that relevance is achieved by overcoming specialization and that to enclose oneself within it is to renounce it!"
> (Morin, 2001, in Osorio, 2012, pp. 271–272)

From our perspective, Maldonado's critique seems to delegitimize Complex Thinking by applying a criterion of scientific validity restricted to logical-mathematical formalism. This stance overlooks the fact that Complex Thinking belongs to an epistemological field distinct from the exact sciences and does not seek to replace them. Its proposal broadens the horizon by integrating the quantitative with the qualitative, the formal with the experiential, and the objective with the subjective. Reducing this perspective to mere rhetoric ignores both its theoretical depth and its heuristic value.

The second objection, related to the absence of a unified method, deserves reconsideration. Morin proposes abandoning the idea of a single, universal method and instead suggests an "anti-method" in which each investigative process designs its own path. According to this perspective, "the path is made by walking," which requires embracing the singularity and indeterminacy inherent in each act of knowledge. Andrade and Rivera (2019) emphasize that relationality characterizes Complex Thinking and constitutes an essential attribute of complexity sciences.

> "Relationality entails recognizing, integrating, and connecting the constituent elements of the event under investigation, moving from the object of study towards the relational fields of knowledge. Every research endeavor thus possesses a relational character, intention, and praxis that is undeniable and comprehensible." (
> Andrade & Rivera, 2019, p. 12)

Both authors argue that relational-complex thinking emerges directly from the sciences of complexity and responds to a key epistemic need: overcoming the fragmentation of knowledge through the connection of conceptual entities. Critiquing this approach overlooks its structuring role in contemporary research. It requires a reconfiguration of rigor, hypotheses, and theoretical frameworks so that they adapt to the complexity of the studied phenomenon rather than imposing rigid or simplified structures.

From our perspective, the relational thinking questioned by Maldonado is compatible with the sciences of complexity and crucial for understanding natural and social systems. Its value lies in facilitating the identification of relationships, interactions, and interdependencies among system components. Therefore, the alleged methodological incompatibility lacks foundation.

Although Morin, Andrade, and Rivera responded with solid arguments, Maldonado chose to redirect his critique toward the very concept of complexity. He argued that Morin reduces it to a method of approaching the world and noted that this interpretation, which he considers superficial, has been the most widespread in the Hispanic American context (Maldonado, 2009, pp. 42–54).

Morin responded clearly, emphasizing that complexity manifests as a fundamental quality of the empirical world. He argued that this approach requires incorporating uncertainty, dealing with inherent contradictions, recognizing the variability of laws, and addressing the emergence of phenomena that challenge reductionist explanations.

> "The complex reclaims the empirical world, uncertainty, the inability to achieve certainty or formulate a law, and reclaims contradiction as a structuring fact of knowledge." (Morin, 1999, p. 99)

This argument highlights an interpretative fallacy in Maldonado's reading: by presenting Complex Thinking as merely rhetorical, he overlooks its epistemological depth and ontological scope. To date, no systematic rebuttal has addressed these considerations.

In a different critical line, Miguel Ramón Viguri (2019), citing Carlos Reynoso, argues that Complex Thinking lacks the characteristics of a theory in the strict sense. From this perspective, it would be a philosophical discourse based on metaphors, without achieving the capacity to model or intervene empirically. In contrast, complexity sciences, through algorithmic models, offer operational definitions of complexity.

> "Complexity sciences, on the other hand, are theoretical developments with a strong mathematical foundation, born within the natural sciences, such as the thermodynamics of systems far from equilibrium (Prigogine), chaos theory (Poincaré), fractal geometry (Mandelbrot), and catastrophe theory (Thom). These disciplines study nonlinear phenomena and are expressed in algorithmic models of computational simulation." (Viguri, 2019, pp. 88–89)

In response to this critique, Morin defends his approach as an operative conception of action. Every action, he argues, involves uncertainty, strategy, changing scenarios, and epistemological vigilance. The strategic dimension, in his proposal, enriches rationality through adaptive creativity and risk awareness:

> "Every strategy, in any domain, begins with an initial decision, though it must be capable of modifying scenarios according to new data and random elements that may arise." (Morin, 1999, p. 113)

This perspective complicates Viguri's critique by showing that Complex Thinking proposes a situated, open, and recursive operativity that persists beyond mathematical models, though it does not exclude them.

From our perspective, Reynoso's critique reveals a significant methodological bias. His ideal of scientific validity privileges a restricted concept of science, centered exclusively on what is quantifiable and computational, leaving aside transdisciplinary, ethical, and cultural approaches. Complex Thinking values mathematical formalization but does not impose it as the sole criterion of validity. Its main intention is to integrate multiple languages and analytical scales to address deeply heterogeneous phenomena.

Dialogue/Debate 2: Is complexity a paradigm or a theory?

One of the central controversies in the literature on complexity revolves around its epistemological status: is it a new scientific paradigm in the Kuhnian sense, or merely a theoretical field still fragmented and under development? This second dialogue addresses that question by confronting definitions, approaches, and tensions among key authors such as Morin, Kuhn, Sotolongo, Hayles, and Reynoso.

1. What is a paradigm?

First, it is crucial to clarify the concept of "paradigm." The most influential definition comes from Thomas Kuhn (1971), who describes it as a set of beliefs, values, techniques, and exemplars shared by a scientific community. This framework regulates normal science by determining what is considered a problem, a valid solution, and acceptable evidence. According to Kuhn, a paradigm structures scientific practice within a specific historical context.

From another perspective, Ángel Sotolongo (cited in Araújo, 2008) proposes that a paradigm organizes a way of experiencing and thinking about reality, encompassing cognitive, affective, cultural, and political dimensions. It represents comprehensive worldviews that guide both knowledge and praxis. Both perspectives highlight that a paradigm goes beyond theory, as it shapes, legitimizes, and guides knowledge at all levels.

2. Edgar Morin's approach: the paradigm of complexity

Morin offers a different perspective on the paradigm, considering it as a web of fundamental logical relationships: conjunction, distinction, inclusion, exclusion, implication, among others, that connect essential categories of thought. These relationships configure the structures of knowledge and implicitly guide cognitive choices, ways of interpreting the world, and criteria for selecting information.

> "The paradigm of simplification is still alive, and as long as it does not die, the paradigm of complexity cannot be born."
> (Morin, 1999, p. 110)

Modern thought has been governed by a paradigm of simplification, sustained by two main operations: disjunction (separating, isolating) and reduction (explaining the complex through the simple). In contrast, the paradigm of complexity is based on three logical operations: distinction, conjunction, and implication. These integrate contradiction and uncertainty as components of knowledge.

In this sense, complexity constitutes an emerging proposal. Its objective is to replace the simplification matrices of modern thought with a rationality capable of embracing disorder, emergence, interaction, recursion, self-organization, and indeterminacy.

3. Is there a theory of complexity?

This point has generated disagreements among those who affirm the existence of a consolidated theory and those who consider it a still heterogeneous field.

N. Katherine Hayles argues that there is indeed a coherent theory of complexity. In her view, concepts such as emergence, self-organization, nonlinear dynamics, fractals, and adaptive systems constitute a shared theoretical grammar applicable to diverse phenomena, from neural networks to ecosystems and financial markets (Hayles, cited in Cárdenas, 2004, pp. 131–141).

Carlos Reynoso contends that what is commonly identified as the "theory of complexity" actually represents a collection of diverse, sometimes incompatible, models and approaches, including chaos theory, fractal geometry, computational simulation, and network analysis.

From his perspective, a shared theoretical core is still lacking, which would allow this diversity to be considered as a unified theory or a strict paradigm in the full sense (Reynoso, in Rodríguez & Aguirre, 2011, p. 3).

4. Table 2: ***Comparison: Morin vs. Complexity Sciences***

Dimension	**Complexity Paradigm (Morin)**	**Complexity Theories (Hayles, Reynoso)**
Epistemological scope	Metamodel guiding all human knowledge	Models applied to specific systems
Internal logic	Dialogical, recursive, open	Mathematical formalization, nonlinearity, simulation
Foundational axes	Ethics, politics, philosophy of science	Physics, biology, mathematics, computation
Current status	In development, lacking full institutional validation	Consolidated subfields, lacking an integrative framework
Main function	Integral understanding of ontological complexity	Prediction and modeling of complex systems

Source: Author's own elaboration

5. Critical appraisal

From an integrative perspective, the opposition between paradigm and theory appears artificial. Below, three key arguments are presented to overcome this dichotomy:

a) **Functional coexistence.** An emerging paradigm generally relies on multiple theories that provide partial evidence, heuristic models, or proof-of-concept frameworks. These, in turn, require a metatheoretical framework to articulate them. Complex Thinking and complexity sciences should be understood as complementary dimensions.

b) **Progressive maturation.** Complexity has advanced beyond its initial programmatic stage. It is still seeking the institutional stability and internal coherence characteristic of a fully consolidated paradigm. Tools such as cellular automata, complex networks, and multi-agent models represent formal expressions of this paradigm in formation.

c) **Structural challenge.** As noted by authors such as Sotolongo and Badii, consolidating a new paradigm implies transformations that go beyond the theoretical plane: it demands changes in education, funding systems, academic evaluation, and disciplinary organization. Without these supports, epistemic transition will continue to face resistance.

6. Our position

Based on the preceding analysis, we consider that Complex Thinking should be understood as an emerging paradigm that nurtures and guides the various theories of complexity. Its strength lies in opening epistemic possibilities: replacing linearity with circularity, certainty with uncertainty, disjunction with integration, and specialization with transdisciplinarity.

Morin proposes a perspective that articulates formal sciences with social and human sciences while also responding to contemporary ethical-political challenges. His work transcends the conventional concept of "method" and is configured as a flexible cognitive strategy grounded in the understanding of the inherent complexity of both the world and knowledge.

When faced with the question “Is complexity a paradigm or a theory?”, the answer is dialogical: it acts as both, at different levels of abstraction. Theory provides tools. Paradigm provides orientation. Complexity sciences analyze. Complex Thinking integrates. In their convergence, an epistemological path aligned with the challenges of the 21st century can be traced.

Dialogue/Debate 3: Paradigm of Simplicity vs. Emerging Paradigm of Complexity

The history of modern scientific knowledge has been predominantly shaped by the paradigm of simplicity: an epistemological conception centered on certainty, control, linearity, and reduction.

Alongside this hegemonic model, an increasingly powerful alternative paradigm has emerged: that of complexity, which challenges the fundamental principles of classical science and proposes new ways of understanding the world.

1. Foundations of the paradigm of simplicity

Delgado (2011) clearly describes the assumptions underlying the paradigm of simplicity. According to this approach, knowledge is legitimized by its ability to accurately represent reality, dominate its laws, and apply this mastery for human well-being. Science thus becomes a technical tool for intervening in nature, which is conceived as a passive entity, stripped of agency, ready to be deciphered and exploited. This vision is articulated in a cultural equation: to know in order to control, and to control in order to guarantee well-being. Such a formula granted modern science symbolic centrality within the Western Enlightenment project.

Added to this model was an ontology of the separate object: the experimental method, at the heart of the Galilean-Cartesian project, separates the phenomenon from its context, extracts it from the natural world, and analyzes it under controlled, artificial conditions. This decontextualization, although effective for certain purposes, imposes a fragmentary logic that tends to distort the inherent complexity of real systems (Delgado, 2011, p. 9).

2. Kant and the limits of reason

In Delgado's reconstruction, Kant appears as a key figure in the institutionalization of the modern paradigm. His Critique of Pure Reason sought to overcome naïve empiricism and dogmatic rationalism through a critical delimitation of the possibilities of human knowledge. Kant posits that reason, while autonomous, is both the foundation and the limit of knowledge: it is the only instance capable of self-regulation, though also of recognizing its own finitude.

This Kantian gesture, though emancipatory, consecrates the primacy of reason as the supreme criterion of epistemic validation, displacing other forms of experience (intuitive, everyday, relational) to the margins of legitimate knowledge. In this framework, objectivity is consolidated as the core of valid knowledge, relegating the subjective, the experiential, and the contextual to the anecdotal or secondary (Delgado, 2011, pp. 8–9).

3. The experimental method and its distancing from reality

The consolidation of the experimental method marked an unprecedented technical advancement. By creating artificial conditions, the scientist could control variables, repeat experiments, and isolate causes.

This operation introduced an epistemologically significant side effect: the separation between object and context, between phenomenon and world. What is gained in precision is lost in relevance. The isolated object ceases to be representative of the system to which it belongs.

Morin warns that this process generates a form of knowledge that is decontextualized and mutilated. By excluding everyday experience as a legitimate source of knowledge, modern science becomes increasingly self-referential, detached from concrete life. Epistemic legitimacy becomes internalized, self-contained, and loses sensitivity to lived reality (Morin, as cited in Delgado, 2011, pp. 9–10).

4. Popper's critique: falsification and the limits of inductivism

Against the logical optimism of classical inductivism, Karl Popper offers a forceful critique: no amount of observations can justify a universal law. Induction, he argues, is logically invalid. He therefore proposes falsification as the criterion of scientificity: a theory must be formulated in such a way that it can, in principle, be refuted by experience.

Popper dismantles the myth of objectivity: every observation is mediated by a theoretical framework, and "pure" access to data is dismissed. In this sense, science ceases to be an accumulation of truths and becomes a process of trial and error, where theories are presented as conjectures subject to revision and eventual rejection. According to Popper, science progresses through the continuous correction of its proposals (Popper, as cited in Cuesta, 2020, pp. 9–10).

5. Morin's response: from method to anti-method

Edgar Morin proposes a radical transcendence of both inductivism and the logic of falsification. According to him, the problem lies in the validation criteria and in the very conception of method. Complex Thinking defines itself as an openness to learning, distanced from any closed protocol. For Morin, method emerges from experience and is built upon it. Knowledge is conceived as a journey, a transformative process where uncertainty, contradiction, and ambivalence constitute essential dimensions of knowing. He expresses this metaphorically:

> "Traveler, there is no path. The path is made by walking." (Morin, as cited in López, 1998, p. 102).

Morin's anti-method is defined as a reflective, adaptive, and situated meta-method. Its function is not to prescribe steps but rather to foster co-evolution between subject and object, between researcher and phenomenon. In this way, it replaces the illusion of control with an epistemic navigation strategy, where each decision is justified within a complex, relational, and evolving framework.

6. Critical evaluation: paradigm replacement or coexistence?

From this confrontation between the paradigm of simplicity and the paradigm of complexity, the Cartesian model continues to dominate current scientific practice. This methodological hegemony prevents science from responding effectively to contemporary challenges, including:

- The global environmental crisis.
- The fragmentation of knowledge.
- The loss of meaning within scientific culture.
- The disconnection between knowledge and social problems.

These symptoms configure what Morin describes as a "civilizational crisis," understood as an exhaustion of the guiding principles of modern thought. In light of this situation, it becomes urgent to reformulate the epistemic foundations of science. This reform requires a dialogue with the Cartesian tradition, integrating it with new logics that expand and enrich the understanding of the world.

- Incorporating uncertainty as an epistemological category.
- Recognizing the value of situated and transdisciplinary knowledge.
- Overcoming the disjunction between subject/object, theory/practice, reason/emotion.
- Integrating scientific, philosophical, cultural, and popular knowledges.

In this sense, Complex Thinking represents a dialectical overcoming of the modern paradigm, without adopting an iconoclastic rupture. It advocates for an enriched rationality: open to contradiction, sensitive to emergence, and capable of self-reflection. It maintains rigor, although redefined as reflective, contextual, and ethical rigor.

The dispute between the paradigm of simplicity and the paradigm of complexity should be understood as a transformation. The first offered powerful tools for scientific analysis but now faces evident limitations. The second, still under construction, traces a path toward recomposing knowledge, making it more integral, more relevant, and more human.

In an increasingly interdependent, uncertain, and conflictive reality, science requires more than technical precision: it demands epistemological awareness. This is the decisive contribution of complex thought, conceived as a critical and creative attitude toward knowledge, far from any closed system.

Dialogue/Debate 4: Creative Chaos and Organization

This exchange between Ilya Prigogine and Edgar Morin represents one of the most fertile conceptual cores in the articulation between science and philosophy: the recognition of chaos as a generator of order and as an essential factor. Far from conceiving it as a threat, both authors understand it as an indispensable condition for the emergence of new organizational forms, whether in physical systems or in social, biological, and cognitive structures.

Ilya Prigogine opens the debate with a provocative yet scientifically grounded statement:

> "The irreversibility of time is a fundamental condition for the emergence of order. In far-from-equilibrium systems, chaos is not destruction, but a possibility for innovation."

With this assertion, Prigogine breaks away from the deterministic and reversible vision of classical physics, indicating that it is precisely the distancing from equilibrium that creates space for creativity within systems. Through his theory of dissipative structures, he demonstrates that under conditions of thermal instability, far from thermodynamic equilibrium, new forms of spontaneous and complex organization can arise. Disorder thus becomes a platform for the emergence of new configurations of order, moving away from the idea of regression towards entropy.

Edgar Morin embraces and amplifies this idea, shifting it to a broader epistemological plane:

> "Indeed, chaos is part of the organizational process. To understand this process, physics alone is insufficient; it is necessary to integrate biology, sociology, and philosophy. It is an epistemological and ethical problem."

Morin emphasizes that understanding chaos transcends the domain of physics. In his vision, chaos manifests in physicochemical processes, historical events, social crises, cultural ruptures, and processes of subjectivation. Therefore, he proposes a transdisciplinary reading of chaos as a generative phenomenon. Merely describing its dynamics is insufficient; it is essential to understand its cognitive, ethical, and political implications. Chaos challenges both the knowing subject and the known object.

Prigogine, in consonance with this broadening, responds:

> "I agree on the need for transdisciplinarity. Dissipative structures show that order can arise from disorder. This also occurs in societies."

He acknowledges that his model of emergent order, originally formulated within the framework of the thermodynamics of irreversible processes, holds resonances beyond physics. The notion of the dissipative structure transcends the description of molecular systems and becomes a scientific metaphor with great heuristic power for understanding the dynamics of social organizations, cultural transformations, and evolutionary processes.

This dialogue condenses, in just a few lines, a radical turn in contemporary epistemology: the overcoming of the simplifying dualism between order and chaos, and its replacement by a dialogical vision in which both are co-implicated. Far from excluding one another, chaos and organization are part of the same vital dynamic: that of change, emergence, and transformation. The idea that disorder can be a source of organization has had a profound impact across various disciplines:

- In biology, mutations and disruptions can give rise to new species or evolutionary adaptations.
- In sociology, disruptive social movements generate new institutions, norms, and forms of collective life.
- In psychology, personal crises enable identity reorganizations and more complex processes of self-understanding.
- In pedagogy, breaking with rigid schemes fosters meaningful, creative, and situated learning.

From the perspective of complex thought, chaos is understood as a bearer of virtualities. It represents the bifurcation point where alternative possibilities emerge, where the system ceases to reproduce itself through its habitual mechanisms and is forced to reorganize. For this reason, Morin emphasizes that self-organization processes are both adaptive and generative of novelty.

This view avoids glorifying chaos, highlighting its ambivalence: it represents both threat and opportunity, collapse and genesis, crisis and potential. Hence, Morin insists that any approach to chaos must be both scientific and ethical. What do we do with chaos? How do we inhabit it? What meaning do we assign to uncertainty?

This debate invites a rethinking of our conceptions of knowledge, evolution, and change. What Prigogine and Morin teach is that order arises from chaos, feeds on it, and requires it for renewal. In times of planetary, political, and civilizational crisis, this lesson becomes particularly urgent. Recognizing complexity and chaos as sources of reorganization allows for the construction of more integrative, sensitive, and contextually relevant forms of knowledge.

Dialogue/Debate 5: Emergence and Autopoiesis

In this crucial dialogue for contemporary epistemology and the life sciences, Stuart Kauffman and Francisco Varela converge on a revolutionary idea: life and knowledge arise as emergent, self-organized, and embodied phenomena, not as externally produced or pre-defined products.

Stuart Kauffman opens the debate with a statement that challenges the mechanistic paradigm:

> "Life emerges at the boundary between order and chaos. Autocatalytic biological systems show that organization does not require centralized design."

With this phrase, Kauffman synthesizes his key contribution to complex thought: the notion of emergence. According to his research in theoretical biology, complex biological systems, such as primitive metabolic networks, can organize themselves spontaneously through autocatalytic processes, without the need for an external directing agent. This implies that life does not depend on an architect; it emerges as an emergent property in sufficiently complex and dynamic systems. His work demonstrates that biological order originates in molecular chaos, within a critical zone characterized by unstable yet fertile equilibrium.

Francisco Varela responds, expanding the scope of the discussion:

> "I agree, although the organization of living systems is more than autocatalytic it is autopoietic. That is, they self-construct and continuously self-reference."

Varela introduces a fundamental concept of the biology of cognition, which he developed together with Humberto Maturana: autopoiesis. While autocatalysis explains the generation of self-reinforcing dynamics at a chemical level, autopoiesis describes a deeper form of organization. It defines how a living system produces and maintains itself within a closed network of processes that continuously regenerate its own identity. A living organism transcends mere function execution since these functions enable the constitution of its own structure. It presents itself as an operationally closed unit that interacts with the environment without being exclusively determined by it.

Kauffman resumes the thread and transfers these ideas to the cognitive field: "This implies that knowledge is also emergent and situated. The brain, for example, does not merely represent the world it co-constructs it."

This shift marks a decisive step toward an evolutionary epistemology. Kauffman suggests that the mind acts as an active system that co-creates its world, far from behaving as a passive mirror that merely reflects reality. This view aligns with the enactive perspective, which conceives knowledge as an act of intervention in a meaningful environment, mediated by the body and action.

Varela closes the dialogue with a synthesis that reformulates the foundations of cognitive science: "Exactly. Hence the importance of enaction and embodied cognition. Science must return to the body, the subject, the context."

Varela insists that the mind can never be understood separate from the body, from situated action, and from its intertwinement with the environment. His proposal of embodied cognition breaks with decades of Cartesian dualism that split mind and body, subject and object. From this perspective, cognition presents itself as a lived phenomenon: it occurs in a concrete body, in a dynamic environment, and through a relational history. This conception imposes on science the demand to contextualize its models and rethink the relationship between observer and observed phenomenon.

This exchange between Kauffman and Varela enriches our understanding of living systems and radically transforms the way we conceive knowledge and epistemology itself. The dialogue between emergence and autopoiesis makes it possible to envision a science that transcends classical reductionism and opens the field to new forms of rationality:

- Emergence allows the new to arise without being derived from the preceding, representing the realm of structural creativity

- Autopoiesis reveals how living systems self-produce through a reflexive dynamic, going beyond mere reactive behavior
- Enaction integrates these ideas into a theory of knowledge that understands knowing as situated action, far from passive representation

These three notions form an articulating axis of contemporary complex thought. They are more than new terms; they represent a shift from science as control and prediction to science as understanding, openness, and transformation. These epistemological proposals carry deep ethical and political implications. In a world marked by fragmentation, technocracy, and ecological crisis, recognizing the autopoiesis of social and ecological systems entails acknowledging their agency, vulnerability, and capacity for self-organization. The thought of Varela and Kauffman invites us to abandon the logic of vertical intervention in favor of an ethic of co-creation and co-emergence.

Toward a Complex and Situated Intelligence

Dialogues between proponents of Complex Thinking and complexity sciences reveal significant epistemological affinities and contrasts. These exchanges allow for the articulation of an intellectual horizon of transformation that transcends the limits of the modern paradigm, incorporating both the formal rigor of modeling and the reflective openness of a critical, ethical, and transdisciplinary epistemology.

While complexity sciences have consolidated since the mid-twentieth century in centers such as the Santa Fe Institute developing mathematical, computational, and simulation-based tools complex thought, driven by Edgar Morin, has established itself as a critique of the linear, fragmented, and reductionist thinking that dominated modernity.

Both approaches, emerging in different contexts and with distinct aims, respond to the collapse of the classical paradigm and the exhaustion of its epistemological premises.

Epistemological Convergences
Among the most notable commonalities are the following:

- **Rejection of reductionism:** Both perspectives challenge the fragmentation of knowledge and uphold the importance of understanding phenomena in their multidimensionality and interrelation. Emergence, the unexpected, and qualitatively novel outcomes are seen as constitutive dimensions of complex systems rather than secondary or marginal aspects.

- **Recognition of nonlinearity:** The ideal of total predictability is abandoned. Causality becomes multiple, recursive, and retroactive. Small initial variations can trigger significant transformations, as evidenced by chaotic systems sensitive to initial conditions.
- **Importance of feedback:** Complex systems exhibit feedback loops that constantly reshape their behavior. This logic, present both in Prigogine's thermodynamics and in second-order cybernetics, reshapes our understanding of stability and change.
- **Radical interdisciplinarity:** Understanding complexity requires an epistemological openness that crosses disciplinary boundaries. In the case of complex thought, this takes the form of a transdisciplinarity that integrates scientific, humanistic, and popular knowledge. In complexity sciences, it manifests through models that bring together physics, biology, sociology, economics, and ecology.
- **Rehabilitation of the subject:** There is a growing recognition that the observer is part of the system being observed. Both second-order cybernetics and enactive cognition propose a reflexive science in which knowledge is conceived as a co-construction between subject and environment.

Productive Tensions and Divergences

These intellectual currents also reveal epistemological tensions. As Cilliers (2005) points out, complexity sciences tend to seek regularities within a technical-formal framework, whereas Complex Thinking introduces the ethical, political, and existential dimensions of knowledge. The former operates with powerful computational tools, though it risks falling into a form of "cold cybernetics" if it neglects the involvement of the subject. The latter, by emphasizing uncertainty and paradox, sometimes leans toward conceptual vagueness, which may hinder methodological operability.

A key difference lies in the vocation of knowledge. Complexity sciences are generally oriented toward modeling and simulation, that is, the formalization of patterns in dynamic systems. Complex thought, by contrast, seeks a living knowledge capable of integrating contradictions, embracing disorder, and understanding incompleteness as a source of learning and transformation.

Paths of Convergence

Despite these tensions, various authors have explored integrative avenues. Transdisciplinarity, in Nicolescu's (2020) formulation, offers a fertile framework in which the technical meets the philosophical, and the quantitative intersects with the qualitative. Along similar lines, Enrique Leff's (2018) environmental epistemology of complexity brings together scientific knowledge with cultural and ecological critiques, promoting a situated intelligence attentive to territories, bodies, and collective memory.

These paths of convergence aim not for a totalizing synthesis, but rather an articulated plurality. Complex intelligence emerges as a mode of thinking that treats uncertainty as a driving force for knowledge and links understanding the world with the way we inhabit it.

A Civilizational Challenge

In a world marked by systemic ecological, social, epistemic, and political crises, the dialogue between Complex Thinking and complexity sciences becomes a civilizational necessity. Knowing more is not enough. It is imperative to know in an integrated, ethical, and contextualized manner.

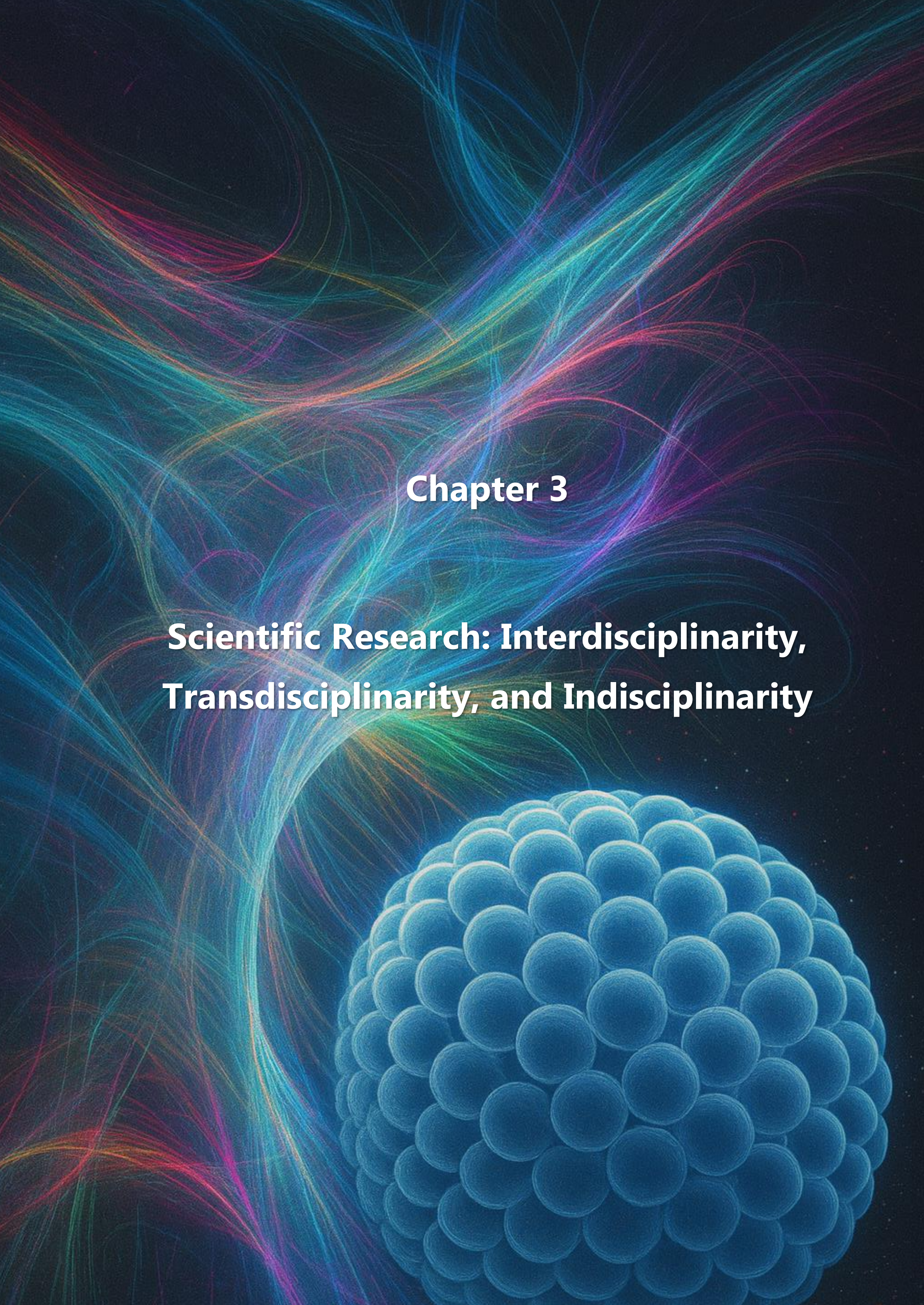
Complex Thinking offers an epistemology grounded in connection, uncertainty, and responsibility. Complexity sciences provide tools to map nonlinear dynamics and emergent behaviors. Their convergence holds the potential to cultivate an applied complex intelligence capable of addressing today's polycrisis with clarity, humility, and creativity.

As Morin (2008, p. 33) affirms, "complexity is more than an object of study; it is a way of living thought." From this perspective, the articulation between both approaches aims not only to transform our theories, but also our ways of inhabiting, thinking, and caring for life.

Edgar Morin and Katherine Hayles
Image generated with AI

Chapter 3

Scientific Research: Interdisciplinarity, Transdisciplinarity, and Indisciplinarity



Scientific Research

Interdisciplinarity, Transdisciplinarity, and Indisciplinarity

The history of science transcends the mere constitution and proliferation of disciplines. It also encompasses the rupture of their boundaries. This rupture is expressed in the appropriation of problems across fields, the circulation of concepts, and the emergence of hybrid disciplines that eventually fragment or reconfigure. Within this process, the disciplinary narrative coexists with another thread: that of transdisciplinarity (Morin, 2015). While the former recounts the consolidation of specializations, the latter reflects the increasing complexity of knowledge and its continual recomposition.

This reflection advocates for an epistemology of science that enables human beings to recognize themselves in their bio-spiritual condition and, from there, to establish a relationship with others through a deep ethics, free from distorting ideologies. A more integral understanding of the human being opens the way for the design of new conceptual frameworks always provisional that guide knowledge production as a plural, unfinished process tied to the harmonic development of individuals situated within both local and planetary communities. This epistemic perspective transforms the scientific act: rather than fragmenting knowledge, it conceives of it as a discovery of an interrelated world, where the subject participates fully from their human dimension and in relation to their natural and cultural environment.

Scientific knowledge has oscillated between the consolidation of specializations and their questioning. This dynamic reveals tensions between the logic of specialization and the need to recompose what has been fragmented. Forms of disciplinary interaction such as multidisciplinarity, pluridisciplinarity, interdisciplinarity, transdisciplinarity, and indisciplinarity must be understood as historical configurations that respond to specific epistemic, methodological, and political demands.

Modern disciplines, consolidated between the eighteenth and nineteenth centuries, were built upon principles of methodological autonomy, thematic delimitation, and specialized accumulation. This structure enabled vast technical and conceptual advances. It also generated knowledge fragmentation, discursive isolation, and difficulties in addressing complex problems that transcend any closed disciplinary framework. In response to this crisis, new forms of articulating knowledge have emerged that reconfigure relationships, objects, and modes of collaboration among disciplines. Each modality proposes a specific logic with distinct implications.

Multidisciplinarity juxtaposes disciplines that address the same problem from their respective frameworks without real interaction. It is common in institutional projects where each specialist contributes from their own field without altering their fundamental categories. Although it offers a variety of perspectives, it lacks conceptual integration and maintains compartmentalized knowledge structures.

Pluridisciplinarity introduces greater articulation by identifying thematic intersections and promoting closer collaborations. It is often organized around a dominant discipline, reproducing epistemic hierarchies. The risk is a superficial integration that conceals asymmetries in knowledge production.

Interdisciplinarity involves a deeper level of interaction. It transforms theoretical frameworks, hypotheses, and validation methods through a process of mutual re-signification that requires openness, dialogue, and epistemological negotiation. It proves effective in areas such as public health, education, sustainability, or territorial development, where natural, social, and human sciences converge. Its implementation demands complex epistemological competencies that often exceed the capacities of researchers or institutional structures.

Some problems demand a radical openness that incorporates extra-academic knowledge, local understandings, ancestral practices, and diverse worldviews. Within this horizon, transdisciplinarity emerges as an epistemological alternative that transcends the classical disciplinary framework. It represents a shift that redefines the relationship between knowledge, subject, and world.

According to Nicolescu (2008), transdisciplinarity is grounded in three pillars: the existence of multiple levels of reality, the logic of the included third, and a vision of complexity as an organizing principle. This approach seeks to articulate diverse forms of knowledge while respecting epistemic and methodological pluralism, avoiding totalizing impositions. It posits that no single domain holds exclusive access to truth, and that contemporary challenges such as ecological collapse, social exclusion, and institutional disintegration require alliances among scientific, technical, popular, and spiritual knowledge systems.

This framework demands a new ethics of knowledge, grounded in shared responsibility, recognition of the other, and a commitment to transforming the world. As Morin (2005) warns, knowledge is a situated action, imbued with subjective, political, and existential implication. Transdisciplinarity embraces this implication and advances an epistemology committed to the complexity of reality, including its ambiguities and contradictions.

The transdisciplinary ideal faces significant operational challenges. Critics such as Mittelstraß (2003) and Buch (2016) point to the lack of clear methodological protocols, the risk of diluted scientific standards, and the danger of empty rhetoric. Without solid training in epistemic dialogue, transdisciplinarity can degenerate into a mere slogan.

Hence, the development of specific methodologies becomes essential: setting collective goals, fostering shared languages, stimulating co-creation of knowledge, and agreeing on validation mechanisms tailored to the specificity of the issues addressed. Successful cases in watershed management, participatory policy design, and community health demonstrate the viability of this approach when implemented with rigor and an open mindset.

The shift toward transdisciplinarity also requires institutional transformation. Universities, funding agencies, and evaluation criteria remain governed by disciplinary logics that hinder the recognition and sustainability of transdisciplinary trajectories. Epistemic transformation must be accompanied by structural reform to ensure adequate conditions for its advancement.

Within this framework, indisciplinarity conceptualized by Enrique Leff and Edgar Morin emerges as a disruptive alternative that transcends disciplinary integration. Rather than rejecting disciplines outright, it promotes a critical and creative stance toward the institutional frameworks of knowledge, opening spaces to reflect from the margins and fissures of the dominant cognitive system. This approach converges with the epistemologies of the South proposed by Boaventura de Sousa Santos (2009), which value knowledge systems marginalized by modern, colonial, and capitalist rationality.

In the educational domain, indisciplinarity goes beyond thematic transversality. It calls for a deep transformation of pedagogical devices, classroom hierarchies, and criteria for legitimizing knowledge. It entails a critical pedagogy that denaturalizes traditional forms of knowledge transmission and fosters emancipatory learning processes.

At the same time, it faces significant tensions. Its critical potential may be constrained by the lack of well-structured theoretical frameworks, insufficient documentation of successful experiences, and difficulties in establishing operational consensus. These limitations highlight the importance of strengthening it through dialogue with other perspectives, careful systematization of innovative practices, and collaboration with social movements that already embody indisciplinary logics in their actions.

Epistemic Tensions in Transdisciplinary Research

Although the transdisciplinary paradigm has emerged as a comprehensive response to the complexity of contemporary problems, its practical implementation faces methodological, ontological, epistemological, and political challenges. One of the main obstacles is the conceptual ambiguity surrounding the term transdisciplinarity. The multiplicity of definitions ranging from disciplinary collaborations to frameworks that include extra-academic knowledge has led to semantic confusion, complicating its effective application. Max-Neef (2005) notes that transdisciplinarity oscillates between an elevated epistemological aspiration and a poorly defined practice.

This ambiguity extends beyond semantics and technique. It stems from a historical conception of science inherited from Enlightenment rationalism, in which knowledge is presented as objective, neutral, and decontextualized. Within this model, the researcher appears as an abstract figure who observes an equally abstract object, detached from social, cultural, or political contexts. Transdisciplinarity operates from a radically different principle: knowledge is always situated, embodied, and shaped by values, interests, and power relations.

This shift transforms the role of the researcher, now conceived as a mediator among diverse knowledges, heterogeneous languages, and divergent epistemic cultures, moving away from the limited vision of merely applying pre-established methods. This approach demands the development of transversal competencies such as intercultural communication and the creation of shared languages skills still absent in most current academic programs. Hence, one of the major challenges in consolidating transdisciplinarity lies in the radical reform of higher education, as proposed by Morin (1999), through a complex pedagogy aimed at forming individuals capable of thinking within uncertainty, engaging in dialogue across difference, and co-constructing shared knowledge.

A paradigmatic experience that illustrates both the potential and the challenges of transdisciplinarity is the ecological restoration project of Lake Atitlán in Guatemala. Led by Universidad del Valle de Guatemala in collaboration with local Maya communities and international organizations, the project integrated scientific knowledge such as limnology, sociology, and ecological economics with ancestral knowledge regarding water management, traditional agricultural practices, and spiritual worldviews associated with the lake. Despite linguistic, epistemic, and political tensions, the project achieved contextualized, legitimate, and sustainable solutions. This case demonstrates that transdisciplinarity is consolidated through practice through conflict, dialogue, and negotiation.

It is essential to avoid an uncritical celebration of transdisciplinarity. One of the most serious risks is the erosion of conceptual rigor. Integrating diverse knowledges requires avoiding ungrounded eclecticism, ensuring that each perspective undergoes reflective debate. As Mittelstraß (2003) warns, transdisciplinarity retains its validity by maintaining internal epistemic coherence, remaining open to critical scrutiny, and sustaining an analytical rigor proportional to the complexity of the problems it seeks to address.

One danger lies in the romanticization of extra-academic knowledge. Acknowledging its legitimacy and potential requires avoiding its idealization as a pure or conflict-free form of knowing. All knowledge production, whether scientific or traditional, is shaped by power relations, cultural biases, and internal disputes. Therefore, transdisciplinarity promotes ethical, horizontal, and transformative relationships in which knowledges encounter one another without subsuming each other.

It is necessary to revisit public policies on science, technology, and innovation that still prevail across Latin America. In many countries, an instrumental model persists, oriented toward productivity and subordinated to economic interests. This approach, promoted by international agencies and reinforced by ministerial structures, prioritizes strategic areas such as energy, mining, and information technologies, while excluding transdisciplinary approaches for being perceived as inefficient, uncertain, or difficult to measure. Overcoming this inertia demands academic will and a political shift that recognizes the relevance of Complex Thinking and embraces alternative models of scientific development.

A crucial question thus arises: is it possible to institutionalize transdisciplinarity without neutralizing its critical potential? Can it remain a transformative paradigm without being absorbed by the bureaucratic and standardizing logic that characterized traditional disciplines? This tension between institutionalization and dissidence runs through every epistemological innovation. The history of paradigms such as cybernetics, general systems theory, and constructivism demonstrates how initially subversive proposals were progressively domesticated by the academic system. Transdisciplinarity faces the same risk if it ceases to unsettle, interrogate, and reinvent itself.

At this juncture, indisciplinarity emerges as a necessary critical stance to prevent the crystallization of transdisciplinarity into a new canon. Rather than opposing it, indisciplinarity radicalizes it. While transdisciplinarity articulates knowledges, indisciplinarity interrogates the very notion of knowledge itself: what counts as knowledge? Who has the authority to define it? What criteria legitimize it?

These questions connect with ongoing debates around epistemologies of the South, decolonial feminisms, and critical pedagogies. All these currents share a central thesis: modern science is configured as a situated cultural construction, embedded within colonial, patriarchal, and capitalist structures. From this perspective, indisciplinarity seeks to deconstruct the foundations of hegemonic knowledge and to create space for plural, insurgent, and embodied ways of knowing.

An exemplary model of indisciplinary praxis is the People's Health Movement in Latin America. This network, composed of healthcare professionals, community collectives, popular universities, and social organizations, questions the assumptions of hegemonic medicine and promotes a holistic vision of health. In this context, research ceases to be a merely technical act and becomes a situated, collective, and transformative practice. The boundaries between theory and praxis, subject and object, knowledge and action become blurred.

This type of experience demonstrates that indisciplinarity reconfigures the very foundations of rigor. It centers on an ethical, political, and epistemic rigor that responds to the real challenges of communities, acknowledging the epistemic dignity of historically marginalized actors. In times of systemic crises such as health, climate, food, and migration this mode of thought offers a powerful critique of dominant knowledge and opens pathways for a cognitive reconstruction centered on life.

For this reconstruction to be sustainable, it is crucial to consolidate indisciplinary epistemic communities capable of sustaining this attitude as a form of intellectual life. This entails networks of collaboration among critical universities, cultural collectives, social movements, and alternative educational spaces. It also requires its own methodologies, innovative pedagogical materials, specialized publications, conferences, gatherings, and festivals that celebrate epistemic diversity. This endeavor goes beyond an academic strategy: it constitutes a political stance toward knowledge, life, and the world. Indisciplinarity demands courage, creativity, and commitment. And in contexts where thought is increasingly threatened by technocratic, bureaucratic, or authoritarian logics, this attitude may mark the difference between knowledge that reproduces the world and knowledge that transforms it.

Towards an Ecology of Knowledge and Complex Research

A critical review of contemporary research modalities such as multidisciplinarity, pluridisciplinarity, interdisciplinarity, transdisciplinarity, and indisciplinarity demands more than a terminological classification or a linear succession of approaches. Beneath this debate lies a deeper issue: the capacity to generate meaningful knowledge in a world marked by uncertainty, systemic interdependence, and the urgent need for civilizational transformation.

The paradigm of complex thought, developed by Edgar Morin, provides an epistemic and ethical framework for radically rethinking research practices. Morin moves beyond the mere denunciation of fragmented knowledge, proposing an open, dialogical, and recursive rationality capable of recognizing uncertainty, feedback loops, emergence, and contradictions as constitutive features of reality.

His critique of scientific hyperspecialization encourages articulation, contextualization, and epistemological self-critique.

From this perspective, every research practice begins with the ontological and epistemological recognition of complexity. This involves conceiving phenomena as relational processes organized across multiple levels of reality and traversed by dynamics of self-organization, emergence, and uncertainty. At the same time, it requires acknowledging that the knower cannot be separated from what is known: they are implicated, situated, and affected by values, emotions, power structures, and histories.

An ecology of knowledge transcends the combination of approaches or a mere plural methodological repertoire. It requires a profound transformation of the scientific ethos: abandoning the logic of control in favor of openness to risk. Replacing the illusion of absolute objectivity with critical reflexivity. Shifting from a productivist obsession to a commitment to vital problems relevant to communities. This metamorphosis spans institutional, pedagogical, and existential dimensions.

At the institutional level, it is urgent to reform the systems of scientific evaluation, currently dominated by quantitative logics that reward productivity measured by indexed publications, bibliometric citations, and extreme specialization. Such criteria exclude slow, collaborative, dialogical, or situated projects, which cannot fit into the timelines and formats of standardized science. An ecology of knowledge entails revaluing quality over quantity, social impact over formal prestige, and methodological coherence over standardization.

On the pedagogical level, researchers are needed who can inhabit the borders between knowledges, think with others, and engage in dialogue with epistemic otherness. This means shifting from vertical and specialized training models to transversal experiences: social laboratories, action-research, co-creation workshops, intercultural exchanges, and horizontal mentoring. It implies, in short, a living, situated pedagogy aimed not only at explaining the world but transforming it.

At the existential level, an ecology of knowledge challenges the researcher as an ethical and political subject. Research goes beyond the mechanical application of a method and demands engagement with the worlds being studied. It entails assuming responsibility for the narratives produced, the silences reproduced, and the effects of cognitive intervention. It requires replacing the figure of the neutral scientist with that of an epistemic actor who is aware of their involvement in the social, ecological, and symbolic fabric.

This proposal aligns with contemporary movements that converge in their critique of modern epistemic hegemony: decolonial feminisms, epistemologies of the South, popular education, citizen science, and participatory action research. All of them propose alternative horizons in which knowledges are mutually recognized in their incompleteness, are constructed horizontally, and are oriented toward cognitive justice. This convergence allows for conflicts between approaches while offering a shared ethical foundation for building a renewed epistemological pact.

A powerful example of this transformation is the project Health, Territory, and Culture, promoted in Colombia by the National Institute of Health in collaboration with universities, Indigenous communities, and campesino organizations. The team addressed issues such as malaria, child malnutrition, and socio-environmental conflicts through a logic of knowledge co-production. Rather than imposing uniform models, they translated concepts, adapted methodologies, and articulated biomedical knowledge with traditional wisdom and community practices. This experience demonstrates that a complex, situated, and plural science ceases to be a theoretical utopia and becomes a real possibility when appropriate ethical, methodological, and institutional conditions converge.

Even as such practices advance, they remain marginal in relation to the dominant apparatus of science and technology. Calls for research proposals, funding systems, evaluation criteria, and university policies remain anchored in a productivist disciplinary rationality. In this context, the pursuit of an ecology of knowledge demands a political dimension: contesting the meaning of knowledge, transforming its institutional rules, and building collective platforms of epistemic resistance. As Sousa Santos (2009) warns, modern science lacks neutrality and innocence: interests, power relations, and exclusionary mechanisms permeate its structures. Acknowledging this fact is the starting point for its transformation.

The work of Edgar Morin offers fundamental insights for this shift. His insistence on reforming thought, his critique of the mutilating logic of hyperspecialization, his call to rebind knowledges, and his recognition of subjectivity and ethics in knowledge production are crucial contributions for imagining another way of conducting research. It is important to avoid turning his thought into dogma. It is better held as a dynamic horizon of inquiry, a critical and creative compass in the face of today's challenges.

In this regard, it is essential to subject Complex Thinking to internal critique. Various authors, such as Osorio (2014), Escobar (2015), and Kusch (2007), have pointed out methodological limitations, conceptual ambiguities, and operational deficits in some formulations of the Morinian paradigm. These observations, far from weakening it, strengthen it by preventing canonization and encouraging its critical reappropriation from contextualized, plural perspectives rooted in the lived experiences of communities.

A substantial contribution to this critical expansion is Boaventura de Sousa Santos's (2009) ecology of knowledges. This proposal advocates for epistemic interculturality based on mutual recognition, affirmation of incompleteness, and the creation of dialogues without ontological hierarchies. While it converges with Morin in its rejection of fragmentation, it more explicitly incorporates the political, decolonial, and situated components, thereby enriching the discussion on complexity.

The current challenge goes beyond formulating new categories or accumulating approaches. It requires building institutional, pedagogical, political, and existential conditions that enable the production of relevant, ethical, and transformative knowledge.

The categories explored such as interdisciplinarity, transdisciplinarity, and indisciplinarity should be understood as articulated stages in a larger struggle: the pursuit of a different rationality capable of addressing the complexity of contemporary problems without reproducing colonial, patriarchal, and productivist forms of hegemonic knowledge.

In a world marked by sanitary, ecological, political, and epistemic crises, producing information without transforming modes of knowing is insufficient. It is essential to reclaim the ethical and political dimension of research, build alliances among knowledges, and value those forms of knowledge born from life, experience, and resistance. Only then can a science emerge that is sensitive to suffering, an intelligence attuned to complexity, and a form of knowing deeply committed to life.

Building New Knowledge

The challenges of the twenty-first century share a structural characteristic: their complexity. It is unfeasible to address them from a single discipline or from isolated academic knowledge. Global crises such as climate change, structural inequalities, food insecurity, and democratic destabilization possess a systemic, multicausal, and trans-scalar nature. In this context, effective responses require a transdisciplinary approach that reconnects diverse forms of knowledge and articulates multiple levels of analysis. This epistemological imperative stands in sharp contrast to university education still anchored in sectorized structures and fragmented specialization logics.

As Nicolescu (1994) warns, major contemporary challenges particularly those of an ethical nature demand multiple and articulated competencies. The mere aggregation of specialists without proper integration never results in effective collective competence. The accumulation of knowledge without articulation can lead to a state of "generalized incompetence" due to the absence of a synthetic and situated vision.

Historically, knowledge construction relied on disciplinarity, understood as the mastery of a specific field with its own theoretical frameworks, methods, and language. This mono-disciplinarity, linked to the mechanistic, reductionist, and objectivist paradigm, proved effective for certain technical developments, but proves insufficient when addressing phenomena that exceed the limits of a single perspective (Max-Neef, 2005).

By the mid-twentieth century, more open forms of disciplinary interaction began to emerge. Pluridisciplinarity gathers several disciplines to study an object from different perspectives, respecting their respective methods and conceptual autonomy. For instance, a work by Giotto can be analyzed through art history, physics, chemistry, the history of religions, or geometry, enriching its comprehension without altering disciplinary boundaries (Nicolescu, 1994).

> Multidisciplinarity, which is less integrative, involves different disciplines approaching the same problem in parallel, resulting in an accumulation of diagnoses lacking conceptual integration and epistemic articulation. According to Carvajal (2010), this modality can be useful as an initial stage, although it limits the transformation of the disciplinary frameworks involved.
>
> Interdisciplinarity implies a deeper level of interaction. It encourages mutual transformations through the transfer of concepts, methodological exchange, and epistemological reconfiguration. According to Nicolescu (1994), it may operate on three levels:

- Application: the use of methods in another field
- Epistemological: problematization of shared foundations
- Generation: creation of new disciplines

This approach holds strong innovative potential, though it requires competencies in epistemic dialogue, conceptual translation, and critical thinking.

Given the limitations of these modalities, transdisciplinarity proposes a more radical orientation. The prefix trans signifies that which traverses, articulates, and transcends established frameworks. Its purpose is never limited to addressing complex problems it seeks to understand reality in a holistic manner. It drives a paradigm shift that connects scientific knowledge with traditional wisdom, community experiences, artistic expressions, and spiritual or symbolic dimensions (Nicolescu, 1994). The three methodological pillars of transdisciplinarity, according to Nicolescu, are:

- **Levels of reality:** acknowledges ontological plurality from the physical to the symbolic articulated without resorting to reduction.
- **Logic of the included third:** replaces binary logic (A / anti-A) with an integrative term that incorporates contradictions.
- **Complexity:** conceives phenomena as dynamic networks involving feedback loops, emergence, and uncertainty.

From this perspective, transdisciplinarity advances a relational form of knowledge that connects diverse intelligences without striving for a totalizing synthesis. Its commitment is both epistemological and ethical: it seeks a more comprehensive understanding of the world to intervene in it with responsibility, relevance, and a transformative purpose. Knowledge construction demands collaborative methodologies that integrate languages, practices, and diverse horizons. It calls for a pedagogy of teamwork grounded in negotiated meaning, epistemic respect, and openness to heterogeneity. Universities must create learning spaces that foster cross-disciplinary dialogue, intercultural sensitivity, and social responsibility in research. The mere coexistence of experts proves insufficient without tools that enable the co-production of knowledge.

This is why transdisciplinary teams are needed to develop comprehensive responses to challenges such as poverty, violence, or environmental collapse. Each discipline offers valuable contributions. A lack of articulation hampers the attainment of complex understanding. Advancing toward transdisciplinarity requires intensive training, flexible institutional structures, shared methodological tools, and an ethical horizon focused on socially relevant goals.

The contemporary historical context presents challenges distinct from those of the past. Globalization, the interconnection of natural and social systems, technological acceleration, ecological crisis, and the complexity of human relationships create an epistemic landscape marked by profound uncertainty. Within this panorama, scientific research requires deep reinvention. Refining old models is insufficient. They must be transformed from their foundations. A renewed imperative emerges: to construct ecologies of knowledge that weave together the local and the global, the technical and the ethical, the empirical and the symbolic into a plural, situated, and recursive fabric. This approach reconfigures disciplines around real, collective, and multidimensional problems. It proposes, as Morin states, to relink what has been separated, to transcend the fragmentary logic of compartmentalization, and to forge an integrative intelligence capable of confronting uncertainty and embracing it as a constitutive element of knowledge (Morin, 2005).

Transdisciplinarity transcends academic trends and terminal goals. It constitutes both an epistemic and civilizational necessity. In response to the exhaustion of the disciplinary paradigm, it opens pathways to regenerate thought, reconfigure research practices, and reconnect knowledge with life. It represents a commitment to a conscious science, a knowledge imbued with meaning, and a form of rationality deeply rooted in the complexity of the world and in the dignity of those who inhabit it.

Historical Origins of Interdisciplinarity, Transdisciplinarity, and Indisciplinarity

The fragmentation of modern scientific knowledge has deep roots in the historical formation of disciplines. This division was consolidated through the positivist model and structured around the classical opposition between subject and object, which established a dualistic, reductionist, and disjunctive rationality. In France, at the end of the nineteenth century, the concept of the discipline was institutionalized as an organizational form of knowledge (Mankeliunas, 1989), marking the beginning of an era of extreme specialization that transformed the structure of the modern university.

The Emergence of Interdisciplinarity

The concept of interdisciplinarity emerged between the First World War and the 1930s, though it did not achieve significant institutional resonance in its early expressions (Torres, 1996). The Second World War marked a turning point, as the need to address complex problems technological, economic, and social fueled cooperation across different fields of knowledge. Engineers, physicists, economists, sociologists, and planners joined forces to confront systemic challenges. This pragmatic experience gave rise to an epistemological impetus that would consolidate in the following decades.

Beginning in the 1960s, and more intensely during the 1970s, UNESCO promoted a political vision of interdisciplinarity aimed at generating shared solutions to contemporary problems. This effort crystallized in key publications such as Research Trends in the Social and Human Sciences (1970), Research Currents in the Social Sciences (1977), and Interdisciplinarity in the Social and Human Sciences (1982). In parallel, institutions such as the OECD and the French Ministry of Education organized events like the International Seminar on Pluridisciplinarity and Interdisciplinarity in Universities (Nice, 1970), which academically legitimized this approach (Palmade, 1979).

Interdisciplinarity emerged both as a response to the complexity of social problems and as an internal critique of the traditional scientific model. The work of Thomas Kuhn (1962) marked a decisive shift by showing that science operates under historical paradigms subject to rupture, discontinuity, and sociocultural constraints. This critique of the supposed neutrality and linearity of scientific knowledge opened the door to new forms of knowledge organization grounded in reflexivity, historicity, and epistemic plurality.

Interdisciplinarity sought to recompose the unity of knowledge while preserving disciplinary specificity. Integrated study programs such as gender studies or environmental studies emerged, alongside flexible curricular structures and collaborative projects. Nevertheless, it faced persistent obstacles including institutional rigidity, epistemic resistance, difficulties in constructing shared languages, and challenges in evaluation criteria. These limitations motivated the search for a more radical alternative.

The Emergence of Transdisciplinarity

Transdisciplinarity emerges as a critical evolution of interdisciplinarity and as a response to its inability to integrate knowledge beyond the academic realm. The term was introduced by Jean Piaget in 1970 during the International Congress on Interdisciplinarity in Nice. Piaget proposed a form of knowledge without fixed boundaries, capable of establishing reciprocal relationships among disciplines and opening a totalizing system of knowledge without lapsing into totalitarianism. He based this aspiration on successful hybridizations such as those between logic and mathematics and on the overcoming of phenomenalist reductionisms.

A more systematic development of this proposal was promoted by Basarab Nicolescu, who in 1994 spearheaded the adoption of the Charter of Transdisciplinarity during the First World Congress held in Portugal. There, transdisciplinarity was defined as an orientation that crosses, connects, and transcends disciplines, proposing a new way of understanding the world through the unity of knowledge. Nicolescu formulated three foundational pillars:

- Multiple levels of reality, which acknowledge the coexistence of irreducible planes of the world (physical, biological, social, symbolic)
- The logic of the included third, which reconciles contradictions and transcends classical binary logic
- Complexity, understood as a web of interactions and uncertainties that are constitutive of reality

From this perspective, transdisciplinarity represents both a cognitive and ethical attitude that fosters radical dialogue among scientific, philosophical, spiritual, artistic, and community-based knowledge systems through openness, epistemological humility, and social responsibility. As Nicolescu affirms, transdisciplinary knowledge is grounded in absolute respect for otherness, the rejection of dogmatism, and the collaborative construction of knowledge oriented toward common life on Earth.

Although transdisciplinarity has gained recognition, it faces resistance due to its difficult institutionalization. Its philosophical orientation, open-ended character, and incompatibility with the technocratic logic of scientific evaluation hinder its operational viability in academic contexts dominated by rigid disciplinary structures. Nonetheless, it has left a significant mark in fields such as agroecology, collective health, transformative education, and sustainability studies.

Alongside these developments, indisciplinarity seeks a critical rupture with the very notion of the discipline as a device of epistemic power. Systematized by Carlos Eduardo Maldonado in 2016, it is presented as an epistemological and political attitude linked to complex education oriented toward freedom, autonomy, and cognitive disobedience.

Indisciplinarity challenges the neutrality of the disciplinary structure. It argues that this structure defines what can be said, thought, and published within margins functional to a hegemonic, instrumental, and Eurocentric rationality. Its goal is to dismantle disciplinary boundaries and to deconstruct the normative frameworks that determine what counts as science, who can produce knowledge, and for what purposes. It represents a creative, radical, and collective insurgency toward alternative ways of knowing, inhabiting the university, and practicing research.

It shares roots with the epistemologies of the South (Santos, 2010), decolonial feminisms, critical pedagogies (Freire, 1970), and postcolonial studies (Mignolo, 2007). It is connected to militant research practices, popular universities, citizen laboratories, artistic practices as modes of thought, and insurgent methodologies that challenge the academic monopoly on knowledge. It seeks to provoke an attitude: thinking without permission, researching without molds, and constructing embodied, collective, and transformative knowledge.

Historically, indisciplinarity has flourished in contexts of institutional crisis and social urgency. In Latin America, it has taken root in communities resisting extractivism, in Indigenous and peasant pedagogies, in popular science collectives, in feminist networks, and in open knowledge platforms. In these spaces, knowledge emerges from shared experience, wounded lives, and organized rage. Although all three modalities arise in response to the exhaustion of the disciplinary paradigm, they operate from distinct logics:

- Interdisciplinarity articulates: it builds bridges between disciplines to address common objects without dissolving their specificities
- Transdisciplinarity transcends: it integrates diverse academic and extra-academic knowledge systems through a complex, relational, and open rationality
- Indisciplinarity subverts: it disobeys the canon, dismantles epistemic hierarchies, and challenges hegemonic validation criteria

These differences represent complementary expressions of a shared historical necessity: to reinvent knowledge so that it becomes relevant, plural, and committed. Understanding their origins allows us to delineate their scope, identify their limitations, and articulate their transformative potential in response to contemporary challenges.

Recoverable Elements from the Reviewed Authors

Manfred Max-Neef

Max-Neef identifies that contemporary global ills such as water degradation, migration, poverty, environmental collapse, violence, and the breakdown of social fabric require transdisciplinary approaches. He criticizes traditional universities for producing specialists unable to articulate knowledge across disciplines. Assembling experts merely accumulates partial perspectives; integration must occur within the mind of each researcher. He proposes postgraduate programs organized around themes such as water, energy, or food, where diverse disciplines converge to address integral phenomena.

Key Contributions

- Recognizing the systemic nature of global problems
- Moving beyond the mere sum of perspectives toward thematic approaches
- Transforming postgraduate education into a space for epistemological articulation

Edgar Morin

Morin affirms that the human being is biological, psychic, and cultural. Sciences must be understood as interdependent: the physical sciences are rooted in the biological and the social. He notes that hyperspecialization helps clarify complex objects but also reifies them by disconnecting them from their contexts. He proposes an academic culture that combines depth with openness and a scientific practice based on rigor, tolerance, and dialogue.

Key Contributions

- Reintroducing the subject and context into scientific explanation
- Balancing specialization with complex thinking
- Avoiding the reification of the object through self-critique

Laura Frade

Frade introduces the concept of the "observing system," which unites the observer and the observed. The researcher is part of the ecosystem being studied and co-produces reality. This idea strengthens the notion of a situated, committed, and reflective researcher.

Key Contributions

- Breaking the subject/object dichotomy
- Recognizing the cultural embeddedness of the researcher
- Applying the observing system in methodological design

Basarab Nicolescu

Nicolescu argues that despite the quantum and information revolutions, a fragmented view of the world persists. He presents transdisciplinarity as a path to integrate multiple levels of reality, overcome binary logic, and embrace complexity as a condition of knowledge. He advocates for an ethic of openness, humility, and transformation.

Key Contributions

- Replacing binary logic with the logic of the included third
- Integrating physical, biological, social, and symbolic levels of reality
- Humanizing knowledge through transdisciplinary ethics

Rigoberto Pupo Pupo

Pupo critiques scientism for reducing truth to empirical-logical adequacy. He contends that authentic knowledge includes intersubjective relationships, imagination, and values. Education must be creative, critical, and connected to life.

Key Contributions

- Expanding the notion of truth beyond empiricism
- Valuing imagination as a path to knowledge
- Promoting a sensitive and transformative education

Strategic Convergences

From the reviewed authors emerge five principles for meaningful research:

a) Complexity as a Principle (Morin, Nicolescu):

Approaching phenomena from their multidimensional nature.

b) Epistemic Plurality (Max-Neef, Leff):

Articulating scientific, traditional, and community-based knowledge.

c) Situated Researcher (Frade, Pupo):

Embracing the ethical, political, and affective dimensions of the researching subject.

d) Transdisciplinary Ethics (Nicolescu):

Practicing openness, radical respect, and rejection of dogmatism.

e) Institutional Transformation (Max-Neef):
Reforming curricula, evaluation systems, and research teams to address real-world problems.

Operational Implications
These principles enable a redefinition of methodology:

- Shared Problematization: Building the research core around a common problem (e.g., water security).
- Bridge Language: Developing shared glossaries to facilitate translation between disciplines and local knowledges.
- Recursive Design: Integrating action-reflection cycles with community feedback.
- Plural Evaluation: Combining academic criteria with cultural relevance and social impact.

The authors converge on a central diagnosis: the current crisis demands a new rationality. Rather than offering closed formulas, they propose complementary pathways in which complexity, transdisciplinarity, and indisciplinarity are interwoven. Integrating their insights requires institutional courage, curricular flexibility, and personal commitment to critical dialogue. In doing so, research may cease to reproduce the fragmentation it critiques and become an ethical, situated, and emancipatory practice.

Table 3: ***Comparative Synthesis of Transdisciplinarity in Four Authors***

Author	**Core Definition**	**Main Characteristics**	**Differences with Others**	**Shared Coincidences**
Basarab Nicolescu	Relationship “between, across, and beyond” disciplines with the purpose of understanding the present world and reconstructing	• Dynamic guided by levels of reality, the logic of the included third, and complexity. • Disciplinary and transdisciplinary research nourish each other. • Ethical	Offers the most developed methodology: explicitly states epistemological pillars and ethical criteria that the others only suggest.	All conceive transdisciplinarity as a bridge that does not eliminate disciplinary specialization, even as it transcends it.

Author	Core Definition	Main Characteristics	Differences with Others	Shared Coincidences
	the unity of knowledge.	emphasis on openness, dialogue, and tolerance.		
Edgar Morin	Cognitive framework capable of traversing disciplines and articulating them around a shared object and project.	• Cooperation, articulation, and shared project. • Embeds transdisciplinarity within his theory of complexity (dialogics, recursivity, self-eco-organization).	Explicitly links transdisciplinarity to complexity theory and the reform of thought. Others do not emphasize this as strongly.	Accepts complementarity with disciplines: proposes integration without annulling disciplinary identity.
Carlos Delgado	Investigative effort that integrates analogous fragments of knowledge on diverse objects to weave a supra-disciplinary corpus.	• End of isolated disciplinary dominance. • Gradual dialogue between knowledges expands and deepens the transdisciplinary mesh. • Advocates for the social relevance of the resulting knowledge.	Less concerned with logical foundations and more with the social function of transdisciplinary knowledge.	Recognizes the same principle of dialogue and cooperation as Nicolescu and Morin.

Author	Core Definition	Main Characteristics	Differences with Others	Shared Coincidences
Julie Thompson Klein	Common system of axioms or principles that serves as a "trunk" to articulate various disciplines (inspired by Piaget).	• Sees transdisciplinarity as an epistemological stage superior to interdisciplinarity. • Emphasizes structural patterns shared across fields.	Focuses on epistemological architecture (axioms, structures) rather than ethical or political dimensions.	Agrees with the others in positing a stage that goes beyond mere multidisciplinary collaboration.

Source: Author's own elaboration

Points of Convergence

• Transcending Boundaries
All four authors understand transdisciplinarity as a movement that blurs disciplinary boundaries while recognizing the value of specialization.

• Need for Dialogue
They emphasize cooperation, the articulation of languages, and the construction of a shared problem or project.

Centrality of Complexity

- With varying emphasis, they all identify complexity as the underlying condition that compels thinking "in-between" and "beyond."

Transformative Purpose

- Transdisciplinarity is never merely a method. It seeks to renew science and render it socially meaningful.

Table 4: ***Tensions and Nuances***

Axis	Nicolescu	Morin	Delgado	Klein
Logical Foundation	Included Third	Dialogic		Structural Axioms
Ethical-Political Emphasis	High	Medium	High	Low
Methodological Detail	Very High	Medium	Medium	Medium-High
Practical Orientation	Understanding & Global Ethical Action	Reform of Thought	Social Impact of Knowledge	Design of Epistemological Frameworks

Source: Author's own elaboration

1. Transdisciplinarity emerges, across all four frameworks analyzed, as a response to the epistemological and methodological challenge posed by complexity.
2. Nicolescu offers the most systematic architecture.
3. Morin situates it within a broader program of reforming thought.
4. Delgado highlights its potential for social and political impact.
5. Klein focuses on its function as an organizer of shared axioms.

Together, these perspectives outline a plural yet convergent field that encourages the articulation of disciplines without dissolving them, placing at the center the unity-in-diversity of knowledge and its responsibility in addressing global challenges.

A Critical Reading of the Sokal Affair

Errors and Failings in Transdisciplinary Processes and Concepts

The case of physicist Alan Sokal, who in 1996 managed to publish a deliberately nonsensical article in the journal Social Text, exposes the dangers of irresponsibly using complex concepts, lacking epistemological rigor, and abusing academic language. His experiment revealed that certain sectors of the humanities accept meaningless content as long as it aligns with familiar theoretical or ideological frameworks.

Far from mocking the social sciences, Sokal denounced intellectual imposture and the erosion of theoretical standards in discourses that claim epistemic openness without conceptual grounding or methodological responsibility. His warning is crucial for transdisciplinarity: without rigor or an ethics of knowledge, this approach risks becoming empty rhetoric.

1. Pseudo-Transdisciplinarity: Form Without Substance
A common mistake is assuming that juxtaposing concepts or disciplines equates to integrating them. Many initiatives label themselves transdisciplinary without building shared languages or collaborative mechanisms.

Sokal cautions that invoking terms such as levels of reality or complexity without grasping their theoretical depth renders them meaningless. The concept of complexity, for example, is often used as a synonym for difficulty, disregarding essential principles in Morin's framework: recursivity, contextualization, uncertainty, self-eco-organization, and hologrammaticity.

2. The "Sokal Effect": Misuse of Scientific Language
Sokal (1998, 2008) and Bricmont (1998) identify recurrent errors:

• Making assertions without understanding
• Using obscure language that hinders communication
• Abusing technical metaphors like chaos, non-linearity, or entropy without comprehending their scientific foundation

These concepts have meaning within mathematical and experimental models. When employed as rhetorical embellishments, they distort ideas and discredit complex approaches.

3. Ambiguity and Misappropriations
Another problem lies in articulating banalities with convoluted language or making false statements with a veneer of depth. There's also the mistake of indiscriminately borrowing concepts from the natural sciences, ignoring that the social sciences operate with distinct epistemic frameworks. Applying quantum metaphors to social relations or using entropy to describe education may seem appealing, yet without technical foundation, these become conceptual parodies.

4. Metaphor as Tool, Not Facade
Sokal and Bricmont acknowledge the value of metaphor in science communication. Authors like Morin employ them with philosophical depth: thought that reflects upon itself, the re-linking of knowledge, the ecology of action. The problem arises when metaphors replace substance. Without theoretical anchoring, they become masks concealing conceptual voids.

5. Present-Day Risks and Lessons to Learn
Sokal's critique calls for a reconfiguration of rigor open, contextual, and ethical. This entails:

- Epistemological vigilance understanding concepts, their origins, and limitations
- Critical openness valuing both conventional and alternative knowledge systems without lapsing into relativism

6. Complexity as a Formative Challenge
Authors such as Andrade (2005) argue that contemporary individuals need tools to relearn, unlearn, and self-regulate. Within this context, transdisciplinarity positions itself as a pedagogy of complex thinking. The migration of concepts, strategic use of metaphor, and the construction of new categories can enrich research when grounded in a knowledge ethic and a semiotics oriented toward meaning.

Sokal's lesson is clear: a conscious, rigorous, and transformative transdisciplinarity is urgently needed. In an era of epistemic, ecological, and social crises, knowledge must resist superficiality. Navigating complexity requires clarity, depth, responsibility, and critique. Only then can transdisciplinarity evolve from an academic trend into a fertile epistemic commitment.

Tensions Between Approaches and Practical Experience

The implementation of inter-, trans-, and undisciplinary approaches in research is marked by contradictions, methodological tensions, and epistemic disputes. Although critical literature emphasizes the urgency of overcoming the fragmentary paradigm, the transition to complex models faces structural and cultural obstacles. The academic field, grounded in a disciplinary logic, continues to operate with criteria that restrict cross-sector collaboration, marginalize alternative knowledge systems, and hinder effective transdisciplinarity.

A persistent tension lies in the epistemic asymmetry between forms of knowledge with different trajectories, languages, and levels of legitimacy. In interdisciplinary teams, hierarchies often privilege the "hard" sciences over social, cultural, or ethical-political perspectives. This hegemony obstructs horizontal dialogue and perpetuates a coloniality of knowledge in which certain discourses are deemed more valid, while others are relegated to the illustrative or anecdotal (Santos, 2009).

Many research initiatives that self-identify as transdisciplinary operate under multidisciplinary schemas: they juxtapose knowledge without integration or epistemological critique. Genuine transdisciplinarity transforms actors, forms of knowledge, and methodologies. This process demands time, resources, openness to conflict, and a radical openness to the other.

Methodologically, the challenge is to design research frameworks aligned with the principles of complexity. Traditional methods, focused on regularities and linear causality, prove insufficient. Complexity requires the incorporation of singularity, feedback, emergence, and uncertainty. This methodological transformation remains nascent and presents a pending challenge.

An illustrative case arises in studies of socio-environmental issues such as climate change or biodiversity loss. These phenomena demand the articulation of scientific knowledge, traditional knowledge, public policy, and community participation. Many investigations address them from sectorial perspectives, yielding fragmented outcomes. Projects that establish intercultural dialogue, horizontal collaboration, and co-construction of knowledge generate transformative impacts (Leff, 2004).

In this context, undisciplinarity as proposed by Maldonado introduces a deeper rupture. His critique targets the epistemic structure of modernity. It overflows the logic of institutional disciplining, curricular frameworks, evaluation criteria, indexed journals, and funding policies. Many undisciplinary proposals fail, not due to theoretical weakness, but because of a lack of institutional conditions. Adopting a critical stance entails risks such as marginalization, difficulties in publication, and exclusion from legitimizing networks. For this reason, the transition to new paradigms requires an institutional transformation to accompany the cognitive shift. This restructuring confronts entrenched interests and cultural habits that separate knowledge, ethics, and life.

In educational contexts, tensions are also evident. Many programs claiming to be inter- or transdisciplinary maintain rigid structures focused on technical competencies. Flexible trajectories that are socially sensitive and open to transversality remain marginal. Faculty, often trained in disciplinary traditions, sometimes lack pedagogical tools to facilitate dialogic, creative, and ethical learning. Complex education demands educators who can inhabit uncertainty, sustain paradoxes, foster autonomous thinking, and legitimize situated knowledge. It calls for an epistemic ethic that combines coherence with openness and depth with humility.

The research experience is a contested terrain. Disciplinary practices coexist with efforts to transcend them. This tension holds transformative potential. The transition to new modes of knowledge is built collectively through persistent critique, the creation of viable alternatives, and institutional and cultural commitment.

A Science with Conscience

Faced with the limits of fragmented knowledge, Edgar Morin's notion of a “science with conscience” proposes an ethical, epistemological, and political reconfiguration of knowledge. This idea extends beyond a moral commitment; it embodies a profound transformation of science’s role in contexts marked by ecological, sanitary, economic, and civilizational crises.

It entails acknowledging the limits of the modern paradigm. Absolute objectivity, value neutrality, and universal predictability have been critically examined by multiple traditions. Thinkers such as Popper, Kuhn, Feyerabend, Habermas, and the epistemologies of the South have shown that science is a historical and situated construction shaped by interests, ideologies, and power structures.

A science with conscience embraces its own historicity. It acknowledges the risk of error and sustains a vigilant epistemology. This vigilance fosters reflection and responsibility. It reintegrates knowledge and life, ethics and inquiry, action and understanding. The notion of *pertinent knowledge*, central to this approach, shifts away from the mere accumulation of isolated data toward responses to vital challenges. It weaves together fragmented insights, lived experience, values, and emotions. It also affirms the ontological legitimacy of historically marginalized knowledges such as Indigenous cosmovisions, campesino wisdom, feminist epistemologies, and philosophies outside the Western canon. These forms of knowing must be recognized in their epistemic autonomy, not co-opted or subordinated by academic discourse.

Complex Thinking provides the conceptual scaffolding for this transformation. Through principles such as relationality, multidimensionality, retroactivity, emergence, and uncertainty, it promotes a decentralized science that renounces control, invites the unexpected, and interrogates itself. This science accepts its limitations and reorients its purpose toward meaning rather than accumulation.

This vision demands a new kind of scientific formation. Beyond transmitting content, it calls for cultivating epistemic sensitivity, ethical disposition, and critical attitude. The twenty-first-century researcher must also be a global citizen reflective, prudent, empathetic, and committed.

A science with conscience is ultimately measured by its contribution to the common good: social justice, ecological sustainability, democratization of knowledge, and epistemic inclusion. Innovation must be interrogated for its purpose. Understanding the world requires caring for it.

Contemporary Applications: Complexity and Transversality in Practice

To transcend theory, it is essential to examine how interdisciplinarity, transdisciplinarity, and indisciplinarity manifest in situated scientific practices. Today's global crises climate disruption, public health, food security, biodiversity loss, and mental health overwhelm any isolated discipline. One illustrative example is the One Health approach, promoted by the World Health Organization. It acknowledges the interdependence between human, animal, and environmental health. This integrated vision calls for coordinated health policies that bring together medical professionals, veterinarians, ecologists, economists, and communities. The COVID-19 pandemic underscored the urgency of such integration, as zoonotic transmission, epidemic dynamics, and institutional responses demanded convergence of technical, ethical, and cultural knowledge systems.

From an indisciplinary lens, initiatives led by Indigenous communities and social movements stand out. In the Amazon, participatory mapping projects combine ancestral wisdom with geospatial technologies to defend territories. These knowledges cease to be mere objects of academic study; they emerge as legitimate epistemic systems that challenge colonial modes of knowledge production (Escobar, 2016). Urban studies conducted in Bogotá, São Paulo, and Mexico City have addressed issues such as mobility, water access, and food security by forging alliances among architects, epidemiologists, engineers, artists, and local communities. Though not always labeled as transdisciplinary, these initiatives embody its principles: situated interpretation, lived experience, openness to extra-academic knowledge, and intercultural dialogue.

In the educational domain, programs like those of Universidad Veracruzana integrate science, art, and community to address regional problems. These models dismantle fragmented curricula and foster knowledge co-creation and learning oriented toward social transformation (González-Gaudiano & Meira-Cartea, 2020).

In mental health, interdisciplinary teams in rural Colombia and Peru have partnered with traditional healers and community leaders to develop culturally resonant strategies addressing youth suicide and collective depression. Rather than imposing biomedical protocols, these initiatives recognize the multiplicity of meanings attached to suffering and healing across cultural contexts.

Across all these examples, practices that integrate, traverse, or dismantle disciplinary knowledge respond to urgent and complex realities. To ensure they do not collapse into unstructured eclecticism, a sustained attitude of critical inquiry and vigilant epistemological reflection remains imperative.

Indisciplinarity and Epistemic Rupture

Beyond inter- and transdisciplinary approaches, indisciplinarity proposed by Carlos Eduardo Maldonado emerges as a critical stance that overflows the traditional organization of knowledge and thinks from the margins of the scientific-institutional system (Maldonado, 2014).

Indisciplinarity challenges the foundations of disciplinary order. It represents a political, ontological, and epistemological gesture that resists the normalizing logics of modern science such as efficiency, predictability, and standardization and instead promotes openness, creativity, and multiplicity.

This cognitive insubordination demands the abandonment of the comfort offered by consolidated theoretical frameworks and calls for an openness to emergent thinking, uncertainty, and the unforeseen. It implies inhabiting paradoxes, sustaining tensions, and formulating questions from the edges. Rather than following well-trodden paths, it forges routes in unexplored epistemic territories.

The critical attitude projected by indisciplinarity translates into an educational orientation aimed at forming subjects capable of thinking from within uncertainty, contradiction, and ontological openness. It entails unlearning academic taxonomies, dismantling devices that fragment knowledge, and enabling intellectual experiences that transcend the repetition of the instituted.

In practice, indisciplinarity faces structural academic obstacles such as curricula, evaluation committees, calls for research proposals, and journals designed to validate stable disciplinary trajectories. For this reason, it is often marginalized or neutralized. This tension requires understanding indisciplinarity as a transversal attitude capable of energizing inter- and transdisciplinary approaches. It breaks in, destabilizes zones of comfort, and expands horizons of possibility.

Its role lies in challenging closed and self-congratulatory thinking. It exposes blind spots in science, opens new questions, and keeps the act of thinking alive from within the unforeseen. It creates conditions for the emergence of new inquiries and demands greater coherence, openness, and commitment to the real contexts in which knowledge is produced.

Implications of Transdisciplinarity in Scientific Research

The positivist scientific method fragments objects of study under the assumption that the sum of the parts equals the whole. While effective in laboratory settings, it presents limitations when confronting contemporary challenges, as it excludes alternative forms of knowledge and hinders the understanding of complex, interrelated, and dynamic phenomena.

Scientific observation is often regarded as neutral, though the observer participates in constructing what is being described. From a constructivist perspective, a theory explains the observer's codified experiences, and the properties of the cognitive system determine what can be observed and which explanations are possible. Description is often mistaken for explanation, as laws articulate regularities without uncovering underlying causes.

The paradigm of complexity calls for a reformulation of epistemological foundations. It integrates the analytical vocation of the natural sciences with the critical and transdisciplinary perspective of the humanities. It warns that hyper-fragmentation obstructs the comprehension of phenomena involving multiple biological, social, cultural, and ecological levels in interaction.

Interdisciplinarity softens specialization, although it proves insufficient to grasp the deep entanglement of reality. Complexity, therefore, proposes a reorganization of knowledge through transdisciplinarity, oriented toward complex systems conceived as organized totalities. Such an approach comprehends interactions, feedback loops, and emergent properties that configure real-world phenomena (Núñez & Pérez, 2003).

This paradigm redefines problem formulation, transforms methodological architecture, and expands the repertoire of valid forms of knowledge. Research becomes a situated, dialogical, and ethical practice a recursive process marked by openness, uncertainty, negotiation, and constant re-signification. It demands epistemic sensitivity, a disposition toward uncertainty, and flexible institutional frameworks.

It acknowledges the legitimacy of extra-academic knowledge such as lived experiences, popular knowledge, ancestral worldviews, and artistic practices, transforming science into a co-production of meaning. This recognition democratizes knowledge and fosters more just and relevant inquiries, positioning research as a potential tool for emancipation in the face of structural inequalities.

However, the paradigm also faces risks, such as vagueness when methodological rigor is diluted, eclecticism due to lack of internal coherence, or discursive adoption without real impact. It therefore requires epistemological vigilance, an ethics of incompleteness, and a willingness to learn through conflict. Advancing this orientation entails profound changes: alternative frameworks for education, evaluation, and funding, hybrid spaces, critical pedagogical practices, and indicators that value qualitative and transformative processes rather than quantitative metrics. Transdisciplinarity redefines researchers, problems, methods, and purposes, guiding the construction of a responsible, creative, complex science committed to life.

Final Reflections

The journey traced throughout this chapter demonstrates that the various forms of disciplinary interaction from the minimal cooperation of multidisciplinarity, the structured collaboration of interdisciplinarity, the transformative integration of transdisciplinarity, to the radical critique of indisciplinarity must be understood as situated, tension-filled, and complementary modalities for addressing the complexity of contemporary phenomena.

Each modality responds to specific problems, contexts, and institutional frameworks. Their value lies in offering epistemic, methodological, and ethical tools adapted to the characteristics of the objects of study and the social conditions of knowledge production. The challenge is to discern with rigor which approach is most appropriate, depending on the research problem, the actors involved, and the intended objectives.

Transdisciplinarity, conceived as a paradigm that articulates knowledge, values, and practices, emerges as a response to the crisis of meaning that afflicts modern science. Its aim to re-link what has been separated, to reintroduce the subject into knowledge production, and to situate knowledge within the living fabric of reality implies a profound reconfiguration of contemporary scientific thought. For this promise to materialize beyond celebratory rhetoric, it requires robust operational mechanisms, clear methodological protocols, and institutional structures capable of sustaining its transformative praxis.

Indisciplinarity plays a key role in epistemic critique. Its strength lies less in a consolidated methodology and more in its capacity to disrupt established orders, denaturalize the boundaries of knowledge, and enable the emergence of new questions. As an attitude of rupture, it keeps alive the possibility of thinking from uncertainty, from the margins, and from the as-yet-unnamed. Its greatest contribution is to energize other approaches by forcing them to reconsider their limits, exclusions, and claims to completeness.

Interdisciplinarity remains a legitimate avenue for reconfiguring objects of study, formulating questions, and articulating diverse methodologies. Strengthening it prevents its reduction to exercises of juxtaposition. Its potential lies in generating creative syntheses among differentiated forms of knowledge, provided there is an explicit willingness for dialogue, mutual translation, and shared construction of meaning.

Complex Thinking functions as a unifying thread that grants coherence to these modalities. It manifests less as a unified theory or methodological recipe and more as a critical and creative epistemological attitude that recognizes multidimensionality, uncertainty, retroactivity, emergence, and self-organization as constitutive properties of the world. Thinking through complexity redefines rigor, understood as sensitivity to paradox, contradiction, and becoming.

This plural, dynamic, and situated conception of knowledge demands abandoning totalizing illusions and embracing an open, relational, and committed rationality. In a world marked by eco-social crises, political polarization, cultural dislocations, and accelerated technological transformations, science can no longer operate from a position of neutrality, autonomy, or self-sufficiency. It must be rethought, reconnected, and reoriented to understand the world and actively contribute to its transformation.

The emerging epistemic horizon points toward an ecology of knowledges, as proposed by Boaventura de Sousa Santos, where diverse forms of knowledge engage in dialogue, tension, and mutual empowerment. This ecology is built on difference, reciprocity, and critical openness.

The call is to transform not only the conceptual frameworks of science but also its material and institutional conditions: systems of evaluation, curricular structures, pedagogical devices, and funding criteria. Without such transformations, any epistemic proposal risks remaining marginal or ineffective.

Complex Thinking and alternative forms of knowledge organization offer more than ready-made solutions or closed formulas. They constitute invitations to an unfinished task one that demands epistemic humility, a willingness to engage in dialogue, ethical sensitivity, and political commitment. In this way, knowledge becomes truly relevant: capable of inhabiting, caring for, and transforming the world.

Table 5: Definitions, Characteristics, Differences, and Similarities Among Authors

Elements / Authors	**Basarab Nicolescu**	**Edgar Morin**	**Carlos Delgado Díaz**	**Julie Thompson Klein**
Definition	Transdisciplinarity concerns, as suggested by the prefix *trans*, what is between, across, and beyond all disciplines. Its goal is to understand contemporary	Transdisciplinarity involves cognitive frameworks that traverse disciplines, often with such intensity that they destabilize them. It is associated with	Transdisciplinarity is a research effort oriented toward articulating knowledge derived from various disciplinary, multidisciplinary, or	It refers to a shared system of axioms across a set of disciplines. Klein builds upon Piaget, who conceived of transdisciplinarity as an advanced phase of epistemological

Elements / Authors	Basarab Nicolescu	Edgar Morin	Carlos Delgado Díaz	Julie Thompson Klein
	reality through the unity of knowledge.	cooperation, articulation, and the construction of a shared project, and has been a fruitful element in the history of the sciences.	interdisciplinary objects of study, thereby generating a theoretical corpus that transcends conventional disciplinary frameworks.	integration in which common structures and patterns of thought emerge, potentially leading to a general theory.
Characteristics	It focuses on the dynamics generated by the interaction between different levels of reality. Its methodology is based on three pillars: levels of reality, the logic of the included third, and complexity. Transdisciplinarity does not replace disciplines; it is nourished by them and feeds back into them.	It emphasizes cooperation, the articulation of knowledge, the construction of a common object, and the development of a shared project. It is a key methodological pillar in the architecture of complex thought.	It does not eliminate disciplines, although it ends their claim to self-sufficiency. It fosters a progressive dialogue between bodies of knowledge that, through conceptual and methodological bridges, build articulated and transformative understanding.	It presents transdisciplinarity as a “common trunk” that connects disciplines within scientific research processes, enabling the emergence of new epistemic configurations.
Differences Among Authors	Its conception is the most methodologically structured. It introduces key elements such as levels of reality, the logic of the included third,	Unlike Klein, Morin’s approach is closely tied to the paradigm of complexity and to a deep critique of knowledge fragmentation.	His proposal aligns with those of Morin and Nicolescu, though it focuses more on the progressive articulation of knowledge than	Klein focuses more on the organizational and historical aspects of interdisciplinary relationships, and less on the ontological or

Elements / Authors	Basarab Nicolescu	Edgar Morin	Carlos Delgado Díaz	Julie Thompson Klein
	and the principle of complexity, setting it apart from more pragmatic or descriptive proposals.		on a formalized epistemological structure.	epistemological dimensions emphasized by Nicolescu or Morin.
Similarities and Common Ground	All four authors agree that transdisciplinarity transcends disciplines, promotes cooperation between knowledge systems, and dissolves rigid boundaries between fields of knowledge. They recognize that it does not replace disciplinary perspectives but rather complements them. They all incorporate complexity as a necessary condition for addressing contemporary phenomena.			

Source: Author's own elaboration

Basarab Nicolescu, Edgar Morin,
Carlos Delgado Díaz, Julie Thompson Klein
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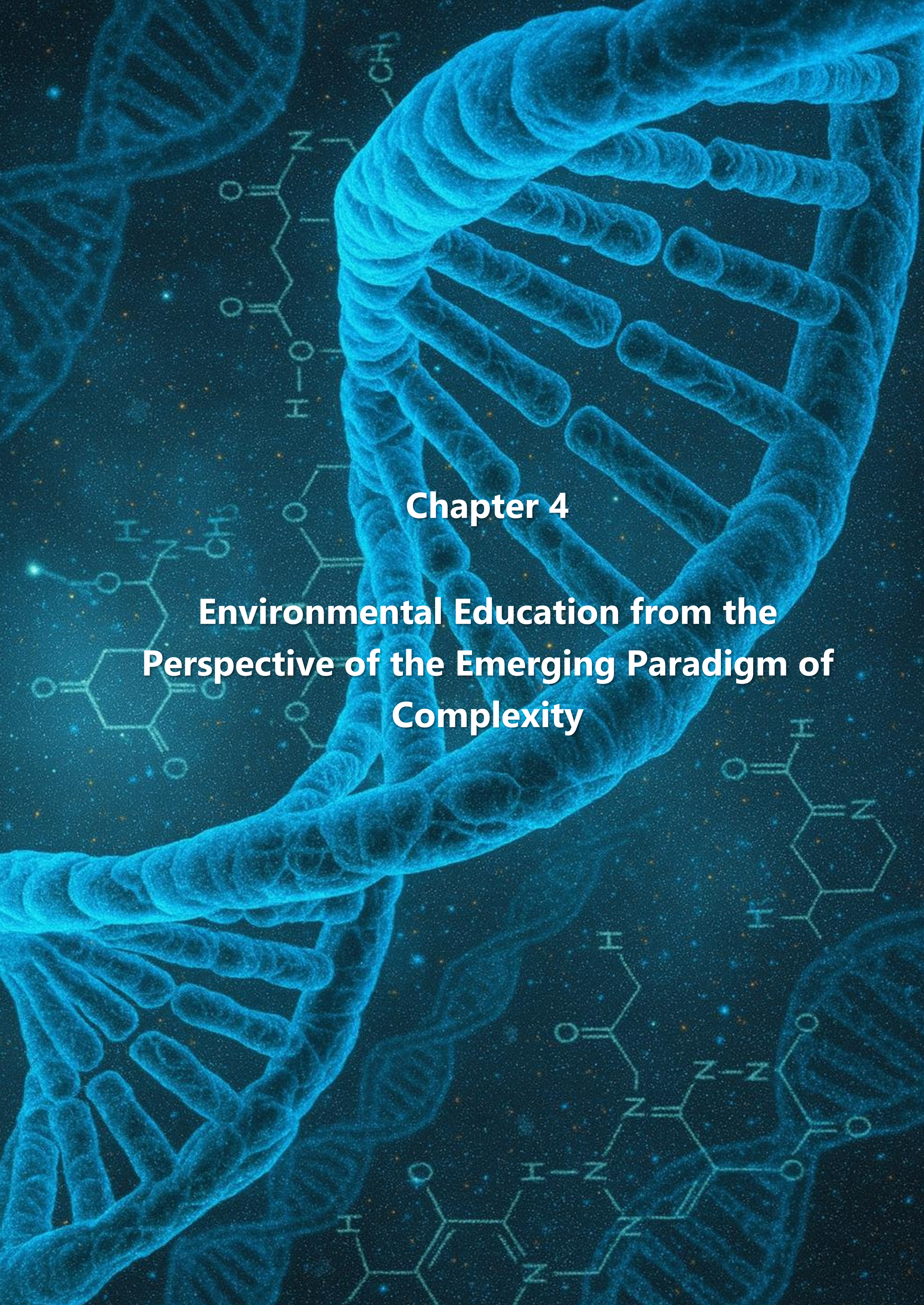


Chapter 4

Environmental Education from the Perspective of the Emerging Paradigm of Complexity

Environmental Education from the Perspective of the Emerging Paradigm of Complexity

The contemporary environmental crisis goes beyond the ecological; it constitutes a civilizational crisis. Epistemological, cultural, and ethical ruptures converge within it, transforming our ways of knowing, inhabiting, and acting in the world. In this context, Environmental Education (EE) requires more than the transmission of information about natural resources or the promotion of environmentally friendly behaviors. It demands a profound revision of the cognitive and cultural foundations of the modern model that has led to this situation. Complex thought, particularly that developed by Edgar Morin, offers an alternative epistemological and pedagogical horizon capable of reshaping EE as a project of social and cultural transformation.

The paradigm of complexity challenges disciplinary fragmentation, techno-instrumental rationality, and the value neutrality that have prevailed in modern education. In contrast to the mere accumulation of isolated data, Morin (1999) advocates for a "well-made head" that is, an intelligence capable of contextualizing, relating, and integrating diverse forms of knowledge. Within this framework, EE transcends technical specialization and is configured as a formative process oriented toward critical understanding, shared responsibility, and transformative action in an interdependent world.

For decades, EE operated under a reductionist, functionalist, and technocratic logic. Its implementation focused on modifying individual behaviors and managing natural resources, without challenging the cultural, political, and economic structures that sustain the ecological crisis. This vision proved insufficient to grasp socio-environmental phenomena that are simultaneously ecological, social, economic, cultural, and ethical. As Morin (2000) warns, fragmented, specialized, and decontextualized knowledge limits our understanding of the world's complexity and, therefore, our ability to respond to its challenges. This limitation extended to EE, which became trapped in linear and instrumental pedagogical approaches. In response, Complex Thinking proposes an epistemological and pedagogical shift: a transition from content-based teaching to the formation of a critical, situated, and ecological rationality.

Principles of Complexity Applied to Environmental Education

Reconfiguring Environmental Education (EE) through the lens of complexity entails transforming its objectives, epistemological foundations, and methodologies. Key principles include:

- **Contextualization of Knowledge:** All knowledge is situated. No form of knowledge is neutral or universal. Morin (2000, p. 60) emphasizes that "all knowledge must be contextualized to be relevant." In EE, this means beginning with the territories, their specific problems, ecological memories, and cultural practices. Globalization loses legitimacy when it renders local contexts invisible.

- **Inter- and Transdisciplinarity:** Environmental issues surpass disciplinary boundaries. As Nicolescu (2008, p. 4) states, transdisciplinarity addresses what lies between, across, and beyond disciplines. EE articulates scientific, technical, philosophical, and popular knowledge in a fertile dialogue that challenges epistemic hierarchies and generates new ways of understanding.

- **Dialogical Thinking:** Reality is permeated by tensions and contradictions that resist simplistic synthesis. Morin's concept of dialogics allows the coexistence of opposites such as order and disorder, individual and community, reason and emotion as dimensions that coexist within reality. This perspective enriches EE by conceiving sustainability as a dynamic, situated, and contested construction.

- **Ethics of Planetary Responsibility:** Educating for the environment involves forming ethical subjects who are aware of the interdependence between humanity and the biosphere. Leff (2006, p. 139) argues that EE contributes to the reconfiguration of rationalities and life meanings in accordance with sustainability. This ethic emerges from shared experience, dialogue, and the recognition of common vulnerability.

- **Ecology of Action:** Every action generates effects that escape linear sequences and are often unforeseen. EE requires educating for action with an awareness of uncertainty, cultivating the capacity to anticipate, reflect, and adapt. The ecology of action (Morin, 2001) fosters a careful, flexible, and situated praxis oriented toward transformation without reproducing the very logics it seeks to critique.

Transforming EE involves a profound renewal of its pedagogical practices. Complex eco-pedagogy presents itself as a critical, dialogical, and emancipatory alternative, inspired by the Freirean tradition of education as liberating praxis. As Freire (1997, p. 34) asserts, "education does not change the world; it changes the people who will change the world." From this standpoint, complex EE fosters inquiry, collective reflection, and transformative action.

This approach redefines the teacher's role: no longer a transmitter of knowledge but rather a mediator, facilitator, and co-learner. The classroom becomes a space for problematization, where knowledge emerges from dialogue between lived experiences, prior knowledge, and contextual challenges. The classroom opens to the territory, and the school connects with community networks, social movements, and ecological resistance processes.

Evaluation is also redefined: beyond assessing technical competencies, it values critical analysis, ethical commitment, cooperation, and creativity. Complex eco-pedagogy represents an ontological and political commitment to forming subjects capable of inhabiting the world with awareness, solidarity, and responsibility.

Historical Origins of Environmental Education: From Ecologism to Complexity

Environmental Education (EE) emerged in the mid-20th century as a response to increasing environmental degradation denounced by both the scientific community and social movements. Key documents such as the Stockholm Declaration (1972) and the Brundtland Report (1987) promoted its integration into formal education systems. This initial impulse adopted an ecologist approach rooted in biologicism, focused on nature conservation and the modification of individual behaviors.

Although appropriate at the time, this model soon revealed its limitations. It failed to address the structural roots of the ecological crisis and lacked a systemic vision of the relationship between society and nature. Over time, more integrative approaches emerged, linking EE to environmental justice, citizen participation, and territorial sustainability.

In Latin America, critical thought and liberation pedagogy expanded the horizons of EE by incorporating a political, historical, and cultural reading of socio-environmental conflicts. The scale of today's crisis, which is less ecological than civilizational, demands a profound epistemological redefinition. EE loses relevance if it remains grounded in a deterministic, simplistic, and linear paradigm. It requires openness to emergence, uncertainty, self-organization, and relationality.

From this perspective, the paradigm of complexity is neither an academic trend nor a superficial conceptual update. It becomes a condition of possibility for reconfiguring EE as a civilizational project. A complex rationality provides tools to educate subjects capable of thinking and acting in an interdependent, uncertain, and deeply damaged world yet one still open to transformation.

Environmental Problems

Contemporary environmental problems are symptomatic manifestations of a civilizational crisis that intertwines ecological, social, economic, cultural, technological, and ethical dimensions. Reducing them to economic externalities or individual "bad practices" perpetuates a simplistic and ineffective perspective. From the standpoint of complexity thinking, these issues emerge from nonlinear causal networks, feedback loops, and critical thresholds that overflow the classical cause-effect logic. They demand interpretive frameworks capable of integrating uncertainty, contingency, and relationality (Morin, 2000).

Historically, anthropogenic pressures on the biosphere such as raw material extraction, industrial production, mass consumption, and waste disposal have surpassed the planet's carrying capacity (Wagner, 2016). The so-called Great Acceleration, initiated after World War II, triggered sharp increases in energy consumption, urbanization, and biodiversity loss, closing the Holocene's period of stability and inaugurating the Anthropocene, an era in which humanity has become a dominant geological force (Steffen et al., 2015).

Climate change stands as the emblem of this transition. It reflects a mode of energy-intensive production and consumption, fueled by faith in unlimited technological progress (Latour, 2017). Its impacts such as extreme weather events, population displacement, and food crises expose the systemic vulnerability of the modern civilizational model. The technocratic logic that proposes purely engineering-based solutions, such as geoengineering or carbon offsetting, reproduces the very paradigm that created the problem and displaces the ethical and political debate.

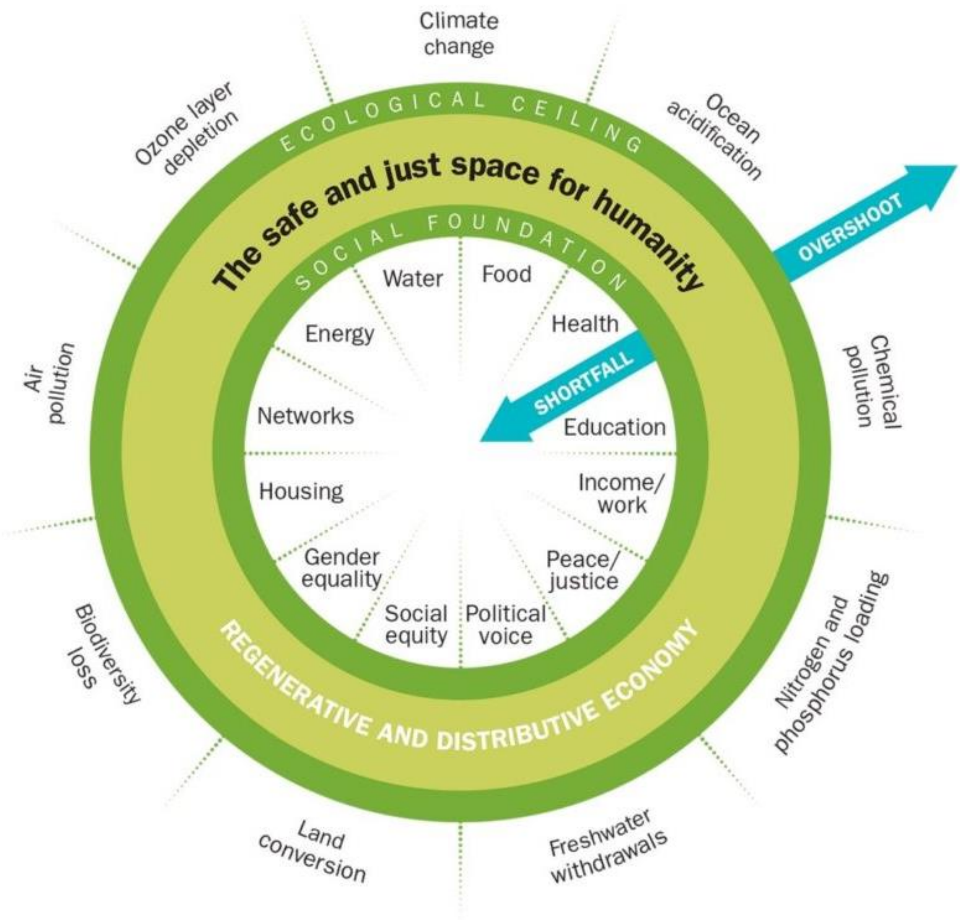
The accelerated loss of biodiversity represents another critical symptom. Deforestation, agribusiness expansion, and large-scale mining erode ecosystems and eliminate biocultural knowledge systems that have co-evolved with them. Extinction entails not only the disappearance of species but also the homogenization of languages, worldviews, and cultural practices that sustain socioecological resilience (Toledo, 2013). It constitutes a form of epistemic violence that imposes a utilitarian and colonial relationship with nature.

In parallel, the waste crisis especially the surge in plastic use reveals the limits of the linear economy based on extraction, production, and disposal. Each year, millions of tons of waste end up in oceans, fragmenting into microplastics that infiltrate food chains and human bodies. Addressing this challenge demands going beyond technological frontiers such as advanced recycling, toward a cultural transformation of production and consumption patterns, and a redefinition of value and obsolescence itself (Gregson et al., 2015).

Freshwater scarcity further confirms the interdependence between ecological degradation and social justice. Overexploitation of aquifers, agrochemical contamination, and the privatization of public services turn water access into a political battlefield (Acosta, 2013). What is known as water stress underscores that environmental conflicts are also distributive and democratic, raising fundamental questions about who decides over common goods and for what purposes.

In urban contexts, the problem intensifies. Expanding metropolises built on impermeable surfaces concentrate air pollution, lack of green spaces, socio-spatial segregation, and heightened vulnerability to disasters. Latin American peripheries, marked by informality and exclusion, embody the intersection of social inequality and environmental risk. These configurations reveal that sustainability requires environmental justice and a redistribution of power in territorial planning (Harvey, 2012).

To guide transformative alternatives, economist Kate Raworth (2018) proposes the Doughnut Economics model, which integrates twelve minimum social thresholds such as access to water, food, health, education, energy, decent housing, and fair employment with nine planetary boundaries that must not be crossed, including climate change, biodiversity loss, ocean acidification, and chemical pollution. The safe and just space for humanity lies within the doughnut, a zone situated beyond social deprivation yet below the ecological ceiling. This framework shifts the debate from abstract economic growth to human well-being within finite biophysical limits, re-signifying development as a dynamic balance between material sufficiency, distributive justice, and ecosystem resilience.



https://doughnuteconomics.org/

Incorporating Doughnut Economics into public policy without an epistemological shift risks reducing it to rhetoric. To avoid this, it is essential to operationalize its indicators in territorial plans, participatory budgets, and evaluation instruments that integrate science, local knowledge, and democratic deliberation. Otherwise, the doughnut may be co-opted by weak sustainability discourses that conceal extractivism.

Education plays a strategic role in this transition. Various authors highlight that educational systems shape imaginaries, values, and skills whose effects unfold over the long term (Gómez, 2019). An Environmental Education (EE) grounded in the paradigm of complexity moves beyond catastrophe-centered fear narratives and fosters learning processes that combine critical analysis, ethical sensitivity, and collective action. This implies:

- Integrated curricula that link natural, social, and human sciences
- Participatory methodologies such as service learning, action research, and citizen labs that connect schools, territories, and communities while fostering transformative agency
- Qualitative assessments oriented toward reflection and cooperation
- Critical ecological literacy that weaves together scientific, local, and ancestral knowledge, counteracting technocratic hegemony and recognizing the ontological plurality of nature

Such educational transformations challenge the classical, reductionist, mechanistic, and linear paradigm still dominant in Latin America. Fragmented environmental policies, overloaded school programs, and standardized evaluation mechanisms hinder the emergence of a complex Environmental Education. Developmentalist visions persist, equating progress with GDP growth and technological intensification, disregarding Leff’s (2018) warning about the limits of an economistic imaginary grounded in the illusion of infinite growth.

Reversing this inertia requires the articulation of permanent spaces for reflection and action, bringing together universities, social movements, local governments, and the productive sector. These spaces must cultivate a social ethic rooted in interdependence and co-responsibility, capable of reorienting economic and political praxis toward strong sustainability. Maldonado (2020) argues that Western modernity emerged with a congenital ailment: its promise of domination over nature and absolute certainty led to a crisis of meaning and loss of future. Hence the urgency of decentering the dominant epistemology through openness to emerging paradigms such as complexity, ecofeminism, Buen Vivir, and decoloniality, which restore the plurality of possible worlds.

In this direction, the concept of sustainable development understood as meeting present needs without compromising future generations' ability to meet theirs (UN, 1987) requires critical revision. It is essential to distinguish between economic growth, understood as quantitative accumulation, and development, conceived as a qualitative process of social justice and ecological balance (Zarta, 2018). Critics such as Girault and Sauvé (2008) warn against the appropriation of the sustainability discourse by agendas that perpetuate exploitation. A complex Environmental Education must illuminate the tensions between sustainability and global capitalism, energy transition and neo-extractivism, green innovation and the coloniality of nature.

An integral change strategy transcends the school setting and engages families, neighborhoods, media, businesses, and the state. Shaping ecosocial citizenships entails reimagining the roles of parents, teachers, students, workers, and public officials as co-producers of environmentally relevant practices. This demands continuous learning platforms, solidarity economy networks, ecological budgets, and collaborative governance mechanisms that strengthen shared responsibility in managing common goods.

In Latin America, regulatory and academic advances in Environmental Education are recognized. However, disarticulation between policies, curricula, and territorial practices persists. Frequently, programs stem from incomplete diagnoses and aim to modify individual behavior without transforming the structures that perpetuate degradation. In this context, complexity thinking and complexity sciences offer tools to reframe Environmental Education as a transversal subsystem that fosters new cultural patterns. The goal is to promote environmentally protective behaviors as intentional, directed, and effective actions that respond to real problems and co-construct future alternatives.

Contemporary environmental problems crystallize the drift of a civilizational project that ignored the planet’s biophysical limits and cultural diversity. Addressing them demands dismantling hegemonic narratives of domination and replacing them with an ecological rationality centered on life, justice, and interdependence. Complex Environmental Education emerges as a catalyst for this shift by articulating critical thinking, ethical sensitivity, and transformative praxis. Its horizon is the reinvention of ways of inhabiting the Earth that restore the co-evolution of society and nature within the safe and just space proposed by Doughnut Economics.

Against this backdrop, the immediate challenge is to move from diagnostic critique to democratic action, weaving multiscale and multicultural alliances that consolidate fair ecosocial transitions. Historical time is short. The possibility of re-enchanting the future depends on the collective capacity to imagine, deliberate, and materialize other worlds worlds in which progress is measured by ecosystem health and the dignity of peoples.

Critical Reconstruction of the Concept of Environmental Education

Environmental Education (EE), as traditionally conceived, requires a critical revision that transcends its conceptual, methodological, and historical limitations. Although it has gained visibility on the international educational agenda since the 1970s, its evolution carries ambiguities, reductionisms, and a weak articulation between discourse and practice, which has hindered its effectiveness in addressing the complexity of today’s socio-environmental crisis.

One of the main problems of conventional EE lies in its instrumental focus, centered on the transmission of ecological content and the modification of individual behaviors, without a deeper understanding of the structural causes of environmental degradation. Education is thereby reduced to a means of adaptation to the dominant model, without questioning the underlying logics of production, consumption, exclusion, and domination that sustain the crisis (Sauvé, 2005). Within this framework, EE functions as a pedagogy of adaptation, when what is required is a pedagogy of transformation.

EE has frequently been formulated from a technocratic logic, oriented toward resource management, energy efficiency, and recycling, without challenging the epistemological foundations of the relationship between humanity and nature. This technical-managerial rationality, influenced by a weak version of “sustainable development,” reinforces the notion of nature as an object of intervention, denying its relational nature, its constitutive role in human existence, and its status as a subject bearing rights (Leff, 2004). This reproduces an anthropocentric and extractivist imaginary.

In many contexts, EE has been incorporated into curricula in a marginal fashion, as a transversal topic without institutional strength, dedicated time, or relevant teacher training. This formal yet fragile integration has turned EE into a "bodiless subject," with little impact on pedagogical practices. The absence of an integrated educational policy that connects EE with other knowledge areas, territories, and social actors limits its transformative potential.

Given this panorama, a critical reconstruction of the concept of Environmental Education becomes indispensable. This task begins by recognizing EE as a contested field, where diverse approaches, conflicting rationalities, and divergent societal projects converge. As Lucie Sauvé (2002) asserts, there are multiple currents of EE naturalist, conservationist, humanist, critical, ecofeminist, socioconstructivist each with its own conception of nature, education, and subjectivity. This diversity reflects the complexity of contemporary challenges and must be embraced as epistemic richness.

From a critical and complex perspective, EE entails a political and ethical praxis oriented toward social transformation. This implies redefining goals, content, methods, and subjects. The objective cannot be limited to educating for the environment; it must also form individuals capable of reconfiguring their relationships with nature, with others, and with themselves, guided by ecological justice, social equity, and strong sustainability. EE must integrate ecological knowledge, aesthetic sensitivity, ethical imagination, agency, and critical thinking.

Methodologically, EE must open itself to learning modalities that incorporate experience, emotion, embodiment, spirituality, and community action. A situated learning approach is needed, grounded in real environmental problems, involving local actors and action-research processes. The school becomes a space for the dialogue of knowledges, where scientific knowledge is interwoven with ancestral, popular, and territorial forms of knowing. This articulation demands a pluralist epistemology that acknowledges the legitimacy of multiple ways of knowing.

EE must also be conceived through the notion of ecosophic formation, proposed by Félix Guattari (1996), which integrates environmental ecology, social ecology, and mental ecology. This triadic framework makes it clear that the environmental crisis is not limited to ecosystem degradation; it also involves the breakdown of social ties and the pathology of subjectivities. EE must help heal these fractures by strengthening community bonds, promoting mutual care, and cultivating deep ecological sensitivity.

A complex EE must imagine and construct alternative futures. In the face of civilizational collapse, education becomes a laboratory of concrete utopias, where transitional practices toward new ways of inhabiting the world are born. This requires educating for uncertainty, conflict, creativity, and collective action.

Critically reconstructing EE means embracing it as a long-term cultural project, rooted in territories, social struggles, climate justice movements, and community-based experiences of re-existence. Inspired by complexity thinking, this form of education does not seek to domesticate the crisis it seeks to inhabit it with dignity, lucidity, and active hope.

Evaluation of Environmental Education Processes

One of the most critical yet least developed aspects of Environmental Education (EE) programs is evaluation. Traditionally, evaluation processes have replicated quantitative, standardized, and cognitive logics rooted in the technocratic paradigm.

These practices, focused on content memorization and the verification of individual learning through objective tests, are inadequate for assessing the personal, social, and ecosystemic transformations that critical and complex EE seeks to promote.

From the perspective of complexity thinking, evaluation involves accompanying transformative processes. What is at stake is not only knowledge, but also being, feeling, acting, and coexisting. Evaluation is understood as a reflective, dialogical, situated, and ethical practice aimed at strengthening autonomy, co-construction of knowledge, and critical engagement with one's environment.

It constitutes an integral part of the educational process, rather than merely a control or grading mechanism.

1. Evaluation of systemic understanding. Complex EE promotes the comprehension of interrelations among natural, social, cultural, and economic elements shaping environmental issues. Evaluating this dimension

entails assessing the capacity to make connections, recognize interdependencies, identify contradictions, and formulate relevant questions.

Instruments such as concept maps, case studies, multi-perspective analyses, participatory simulations, and systems modeling are suitable. The focus lies on reasoning processes, articulation of relationships, and the disposition to think through ambiguity.

2. Evaluation of ethical and political commitment. EE forms individuals capable of adopting ethical stances toward socio-environmental injustices and acting with planetary responsibility. This dimension requires evaluating attitudes, values, and dispositions emerging throughout the formative process. Rather than moralizing, it is about enabling reflective spaces where students develop their positions regarding the care of life, equity, and ecological justice.

Reflective portfolios, ethical journals, debates, personal narratives, community projects, and peer co-evaluations serve to assess meaning-making and coherence between discourse and action.

3. Evaluation of transformative practices. EE transcends the classroom to engage with territories, communities, and ecosystems. Therefore, evaluation considers the capacity to generate transformative proposals in specific contexts. The goal is to imagine and implement sustainable and participatory solutions.

Methodologies such as project-based learning, socio-environmental campaigns, school gardens, or participatory action research allow for the assessment of planning processes, decision-making, conflict management, collaboration, stakeholder engagement, and adaptability.

4. Evaluation as a dialogue of knowledges. To evaluate is to recognize and validate both academic and extra-academic forms of knowledge. Complex EE promotes an ecology of knowledges (Santos, 2009) where scientific knowledge engages in dialogue with ancestral, popular, territorial, and spiritual wisdoms. This perspective demands tools that acknowledge epistemic diversity without imposing a single criterion of validity.

It requires active listening, epistemic humility, and co-evaluation with community actors, parents, social leaders, and other participants. Evaluation becomes an intercultural, horizontal, and context-sensitive exercise.

5. Institutional and political evaluation. Every educational process is embedded within an institutional framework. Evaluating EE entails a critical examination of public policies, regulations, school practices, and organizational cultures that affect its implementation. This includes resource allocation, teacher training, curricular flexibility, and democratic participation.

A complex evaluation provides inputs for institutional improvement, pedagogical innovation, and political advocacy through self-assessments, pedagogical audits, and accountability mechanisms involving the community.

Evaluating from the paradigm of complexity shifts the focus from outcome measurement to process understanding, from unilateral judgment to dialogue, from homogenization to diversity. Evaluation becomes a tool for transformative education capable of responding to contemporary ecological and social challenges.

Environmental Education as a Pathway to Planetary Thinking

Environmental Education (EE), in its deepest expression, emerges as a pathway toward the construction of planetary thinking. This notion, central to Edgar Morin's work, calls for a radical reformulation of our relationship with knowledge, the world, and others. It shapes subjects who recognize themselves as part of a living, interdependent, and diverse totality, committed to inhabiting the Earth with lucidity, humility, and care.

Planetary thinking breaks with modern anthropocentrism, Eurocentrism, and utilitarianism. It situates the human being as a node within a complex web of relationships, where all beings share a common home. To think planetarily is to think from unity-in-diversity, from interrelation, from alterity as the foundation of existence.

EE can be a privileged device for cultivating this mode of thought. To achieve this, it must overcome logics based on competition, fragmentation of knowledge, and the dissociation between reason and emotion. Instead, it proposes formative processes that integrate critical reason, aesthetic sensitivity, an ethic of care, secular spirituality, empathy, and affectivity. To educate is to shape lucid minds, attentive hearts, and committed hands.

Four Commitments for Planetary Environmental Education:

- Commitment to life. EE fosters awareness that we are nature, and our actions affect the web of life. It recognizes the rights of nature and ecological limits, adopting a biocentric ethic.

- Commitment to social and ecological justice. The environmental crisis is also a crisis of justice. Those who pollute the least are often those who suffer the most. EE highlights inequalities, epistemic violence, and the resistance of excluded communities as legitimate sources of knowledge and action.

- Commitment to cultural and epistemic diversity. Planetary education embraces multiple knowledges, languages, and worldviews. It promotes dialogue between science and spirituality, technical knowledge and traditional wisdom, logical reasoning and symbolic narratives. Recognizing plurality is essential for collective care.

- Commitment to transforming the world. Planetary thinking drives transformative action. EE forms critical, participatory, and hopeful individuals capable of imagining and constructing alternatives to the prevailing civilizational model. It recovers the utopian dimension of education as the capacity to dream and materialize possible futures.

These commitments translate into coherent pedagogical practices: territorial projects, learning in contact with nature, art as a path to understanding, collaborative work, intercultural dialogue, and critical use of technology to build networks of knowledge and solidarity.

It also entails the self-formation of the environmental educator as a reflective subject, open to learning and ethical accompaniment. As Morin (2000) affirms, to educate is to teach how to live. And to live today requires meaning, connection, responsibility, and love. An EE grounded in the paradigm of complexity becomes a pathway to planetary thinking. This mode of thinking is a vital urgency. Only through such expanded awareness will it be possible to face the global ecological crisis and open paths toward a more just, compassionate, and life-rooted civilization.

The Importance of Addressing This Issue

The urgency of rethinking Environmental Education (EE) from a complexity-based perspective constitutes an inescapable civilizational imperative. The global ecological crisis manifested in climate collapse, accelerated biodiversity loss, ocean acidification, desertification, systemic pollution, and the depletion of vital resources arises as the cumulative result of a predatory development model rooted in extractivist logic, epistemological reductionism, and a profound disconnection between culture and nature. This situation demands a radical transformation in how we know, educate, organize societies, and inhabit the planet.

One of the pillars of this transformation stems from the critique of dominant approaches that have reduced EE to instrumental, technocratic, and functionalist strategies. In contrast, alternative paradigms such as deep ecology, ecocentrism, transdisciplinarity, and complexity thinking propose a reconfiguration of the relationship between humanity and the biosphere on renewed ethical, ontological, and epistemic foundations.

Between Shallow Ecology and Deep Ecology

In the mid-twentieth century, Aldo Leopold and Arne Naess pioneered deep ecology, a school of thought that shifts focus from anthropocentrism to an ecocentric worldview. While shallow ecology views nature as a utilitarian resource and concentrates on human health and sustainable consumption, deep ecology affirms the intrinsic value of all living beings and ecosystems, independent of their instrumental usefulness. This perspective asserts that humanity exists within and depends upon the vital cycles of the planet.

Ecocentrism, a specific post-anthropocentric approach, recognizes the inherent worth of every life form as well as the systemic value of ecosystems as wholes. It challenges the logic of unlimited economic growth and technoscientific domination. In educational terms, this implies a transition from teaching *about* the environment to learning *with* and *from* the environment in reciprocity and co-belonging.

Two epistemological trends coexist within Environmental Education (EE). The first, modernist and aligned with positivism, corresponds with shallow ecology and promotes individual behavior change through biological or technical frameworks. The second, anti-positivist and critically reconstructive in nature, rejects disciplinary fragmentation, fosters transdisciplinarity, and frames EE as a political, ethical, and cultural field.

From this latter view, EE transcends impact mitigation or the instruction of best practices to become a tool for cultural transformation, decolonization of knowledge, and the construction of an environmental rationality grounded in ecosocial justice. It involves a deep critique of the modern paradigm that separates subject and object, culture and nature, reason and emotion.

Redefining EE through complexity thinking and the sciences of complexity constitutes a far-reaching academic, political, and pedagogical commitment. This transformation directs educational processes toward systemic understanding of socio-environmental phenomena, integrates multiple scales, temporalities, perspectives, and forms of knowledge, and acknowledges the knower as an active participant in the process. Education ceases to be a transfer of knowledge and becomes a space for co-construction of meaning.

Concepts drawn from second-order cybernetics such as self-organization, emergence, feedback, and adaptive networks enable the interpretation of environmental dynamics and the transformation of teaching and learning processes. Complexity demands a rethinking of relationships, uncertainties, and contexts, replacing linear transmission models with dialogical, territorial, affective, and cognitive experiences that foster holistic understanding and ethical engagement.

In Latin America and the Global South, EE has largely been dominated by superficial and technocratic perspectives. Fragmented awareness campaigns lacking critical depth have prevented EE from serving as a catalyst for structural transformation. Reversing this trend requires robust research, educational, and community-based processes that reframe EE through critical environmentalist currents such as deep ecology, ecopedagogy, and complexity thinking developing integral visions of socio-environmental reality that welcome inter- and transdisciplinary approaches.

Reconfiguring EE produces impact on three levels: academically, by encouraging context-based pedagogical models; socially, by fostering critical and responsible citizenship; and politically, by strengthening collective capacities for the democratic management of common goods. This complex perspective displaces the trivialization of learners. Students become co-creators of knowledge, capable of interpreting, questioning, and transforming their environment. This demands open, horizontal, and collaborative learning environments that promote ecological subjectivation and transformative action.

A complex approach to EE reinvents the relationship between society and nature based on ethics of responsibility, care, and interdependence. The aim is no longer to produce environmental technicians but to educate ecologically conscious individuals capable of thinking the world through diverse ways of knowing, imagining alternative futures, and acting with commitment to transform their realities.

The Environmental System and Environmental Education as a Subsystem

Redefining the relationships between humanity, nature, and knowledge demands a rethinking of the concepts that underpin educational practices, particularly in the field of Environmental Education (EE). Far from constituting a closed category, EE must be understood as an articulated subsystem within a broader environmental system, whose structure, functioning, and dynamics can only be comprehended through a complex, relational, and contextual perspective.

The concept of system, developed by various currents of thought, refers to sets of interrelated elements that interact with one another and with their environment. In the environmental domain, this system is conceived as a network of interactions among physical, biotic, social, and cultural components that shape the living space. This view transcends mechanistic approaches and redefines the environment as a web of dynamic, feedback-driven, and co-evolving relationships, where culture acts as a mediator between the natural and the social.

From this standpoint, analyzing environmental problems requires a situated vision, one capable of incorporating territorial dynamics, cultural configurations, and power structures that influence the production, use, and transformation of the environment. Any approach to the environmental system must therefore integrate the complexity framework, understood as the capacity to articulate multiple interacting scales, dimensions, and levels (Morin, 2005). Within this relational architecture, EE is understood as a pedagogical and cultural subsystem that operates within the environmental system to reinterpret, reconfigure, and transform social practices regarding the environment.

The term *educare*, in its etymological root, refers both to nurturing and to drawing out what is latent. Education is thus a process that combines cultural transmission and subjective construction. In EE, this dual dimension is expressed in the re-signification of collective knowledge, aimed at constructing new forms of relating to the environment.

Education, understood as a cultural practice, is inscribed in the symbolic production of meaning, beliefs, ways of life, and social structures. From this perspective, EE acquires a strategic function: displacing fragmented, anthropocentric, and technocratic conceptions of the environment by generating new values, understandings, and practices.

The environment is thus conceived as a complex system of heterogeneous and interdependent elements, where ecological, historical, economic, and symbolic factors converge. EE is embedded in this web to reorganize the relationships between knowledge, practice, and nature through an integrative logic.

Transformative Functions of Environmental Education

As a cultural subsystem, Environmental Education (EE) fulfills essential functions:

1. **Fostering Critical Reflection**

It opens spaces to examine how societies relate to ecosystems. This reflection is oriented toward transformative practices capable of challenging the prevailing development model and designing alternative forms of production, consumption, and social organization grounded in strong sustainability.

2. **Empowering Social Subjects**

It moves beyond the figure of the passive student to strengthen critical actors capable of interpreting, proposing, and constructing collective knowledge. EE thus becomes a tool for the democratization of knowledge and the enhancement of environmental citizenship.

3. **Redefining Educational Goals and Means**

It reorients education toward lifestyles consistent with sustainability, promoting cultures of sufficiency, rational use of resources, and a reconfiguration of well-being understood as harmony with nature. In the words of Ortagaz (2018), it involves fostering an ethic of consuming the planet's resources at a slower pace, based on a paradigm of abundance rooted in quality of life. This ethic is linked to environmental justice, eco-social resilience, and intergenerational equity.

EE Through the Lens of Complexity

One of the persistent challenges is dismantling the reductionist frameworks that have historically constrained EE, treating it as a complementary subject or a set of isolated actions disconnected from institutional or territorial educational projects. Overcoming these limitations involves integrating the principles of complex thinking into the planning, implementation, and evaluation of EE programs. This includes:

- **Contextualizing Knowledge:** Acknowledging its grounding in territories, historical moments, and social configurations
- **Fostering Interdisciplinarity and Transdisciplinarity:** Avoiding compartmentalization and encouraging dialogue among sciences, local knowledge systems, and diverse worldviews
- **Embracing Uncertainty:** As an inherent condition of living systems, cultivating the ability to make decisions in ambiguous contexts
- **Stimulating Critical Autonomy:** Enabling reflective, ethical, and creative interpretations of environmental reality
- **Recognizing the Complexity of Subjects:** Rejecting homogenizing pedagogical models and valuing diverse experiences and identities

Complex EE moves away from the mere improvement of environmental indicators. It is a meaning-making practice that reweaves the bonds between knowledge, affect, and existence. This demands a reconfiguration of the teacher's role as mediator and co-learner, capable of activating problematizations, dialogue, and co-construction.

Territory becomes central. The environment emerges as a living pedagogical text where ancestral knowledge, collective memory, conflicts, and transformative potentials converge. This territorialization of knowledge breaks with universalist logics and fosters an education that is situated, affective, and committed. EE must therefore shed its peripheral status and assume a structuring role within the educational system. Its horizon is civilizational. It entails reimagining education as a tool for transitioning toward just, resilient, and sustainable societies.

Articulating the environmental system with EE as a subsystem demands a rereading from the perspective of complexity. This framework dismantles fragmented, functionalist, and instrumental views, proposing instead a relational, critical, and transformative paradigm. EE becomes a pathway to rethinking how we inhabit the world, how we organize socially, and how we construct meaningful knowledge. The challenge is to reconstruct EE as a pedagogical, ethical, and political space capable of projecting a new civilizational imaginary one that faces the crisis without evasion, mobilizes memory and hope, reason and emotion, science and wisdom. In this way, it rises to meet the demands of our historical moment.

Epistemological Foundations of Environmental Education from a Complex Perspective

In the context of the current civilizational, environmental, epistemic, ethical, and cultural crisis, Environmental Education (EE) must break free from reductionist approaches and outdated epistemological paradigms. Forming subjects capable of understanding and transforming their socio-ecological reality demands a critical revision of EE's conceptual and philosophical foundations. This revision does not reiterate previously addressed topics, such as the distinctions among ecologies or the critique of the modern fragmentary paradigm. Instead, it focuses on the tension between paradigms, the hermeneutic turn in environmental thought, and the role of EE as an epistemic, ethical, and political subsystem.

1. **A New Rationality for a New Era.** In the planetary era a historical phase defined by global interdependence and the collapse of biophysical boundaries it is essential to reconfigure the epistemic framework of the human mind. Overcoming both the hedonistic anthropocentrism that instrumentalizes nature and exclusionary biocentrisms calls for a polycentric horizon that acknowledges multiple centers of value, human and more-than-human. This orientation nourishes EE with the world's ontological and epistemic plurality.

Such an orientation breaks with Enlightenment rationality based on the disjunction between subject and object, enabling a relational, situated, and transdisciplinary vision in which knowledge is understood as a historical, symbolic, and political construction. From this standpoint, EE operates as a hermeneutic practice that interrogates the meanings, values, and ways of life implicated in the socio-environmental crisis.

2. **Hermeneutic Turn and Paradigmatic Transition.** Environmental thought integrates a hermeneutic turn that moves away from deterministic and functionalist frameworks, proposing a relationship between human beings and nature mediated by interpretation, dialogue among knowledge systems, and ethical reflection. Rather than behaviorist approaches focused on external stimuli, this perspective promotes education oriented toward the subject's critical self-understanding in relation to the world.

This transition conceptualizes environmental problems as conflicts of meaning, territorial disputes, and crises of values. EE, in this regard, contributes to reshaping collective consciousness through processes that integrate scientific knowledge, ethics of care, and political responsibility. In this framework, shifting from strong anthropocentrism to relational biocentrism requires avoiding both human absolutization and the negation of humanity's transformative capacity.

3. **Humanist Environmentalism as a Critique of the Hegemonic Model.** From the Global South, humanist environmentalism emerges as a response to the technocratic and market-oriented discourses of sustainable development. In contrast to moderate environmentalism, which subordinates conservation to economic growth, and to exclusionary conservationism, which naturalizes the separation between society and nature, this current integrates ancestral knowledge, local practices, and appropriate technologies under the principle of sustainability grounded in community needs and values.

EE, from this perspective, becomes rooted in territories as a process of co-constructing meaning, strategies, and ecological relationships. It acknowledges the partial and situated nature of education and its role in reproducing or transforming worldviews.

4. **Posthumanism as an Ontological Critique.** Posthumanism, by rejecting the ontology of the modern sovereign subject, asserts that all living beings are part of biological, technological, and symbolic networks of interdependence. EE, in alignment with this vision, promotes a transformation of subjectivity toward multispecies modes of dwelling.

This transformation incorporates aesthetic, affective, and spiritual dimensions that transcend utilitarian rationalism. As Nadales affirms, deep ecology resonant with posthumanism manifests as an ethical and existential practice that unifies thought, feeling, and action. Consequently, EE cultivates new sensibilities, fostering a reappropriation of the lifeworld through an ecosocial lens.

5. **Epistemological Implications of Complex Environmental Education.** An EE grounded in complexity surpasses the dichotomies that have structured modern education: nature and culture, subject and object, science and values, theory and practice. Its transdisciplinary character requires the

articulation of scientific, ethical, artistic, political, and spiritual knowledge in the service of socio-ecological understanding and transformation.

From this perspective, Environmental Education (EE) guides processes of regeneration rather than superficial sustainability. It invites a rethinking of content, methods, purposes, and educational standpoints, shifting the focus toward the collective construction of meaning, practices, and subjectivities. It introduces critical self-reflection by interrogating the educator, the institution, and knowledge itself in relation to the dominant development model. As proposed by Alvarado and García, cited by López and others, a socio-critical EE fosters participatory reflective action aimed at transforming social and environmental relationships.

6. **EE as a Transversal Matrix for Change.** EE holistically orients educational action from curriculum to community engagement, from pedagogical methods to evaluation practices, from school infrastructure to territorial rootedness. Its triple relevance social, environmental, and educational positions it as a strategic axis for the present.

It functions as a convergence space for thought systems, pedagogies, and social struggles, weaving together tradition and innovation, resistance and creation, utopia and praxis. The plurality of positions that have historically shaped EE constitutes its greatest strength. This is reflected in its capacity to adapt, engage in dialogue, and reinvent itself in response to contemporary challenges (Sauvé, Orellana, and Sato, 2002).

Reviewing and expanding the epistemological foundations of EE in light of complexity enables a move beyond binary visions, projecting a critical, relational, and transdisciplinary form of education capable of responding to the magnitude of the civilizational crisis. This form of EE opens horizons where sustainability becomes embodied as a situated and diverse practice. The challenge lies in forging an education that cultivates awareness, sensitivity, and collective commitment an education courageous enough to question everything, including its own foundations, in the name of life, justice, and a still-possible future.

Environmental Education for Sustainable Development and Second-Order Cybernetics

In today's global context marked by an ecosocial crisis that transcends environmental issues and impacts epistemic, cultural, and political structures Environmental Education for Sustainable Development (EESD) demands a rigorous critical assessment. This analysis goes beyond pedagogical practices and curricular policies to interrogate its theoretical foundations, epistemological frameworks, and transformative horizons. The discussion presented here avoids redundancies addressed in previous chapters, such as the debate between shallow and deep ecology or the critique of disciplinary fragmentation, and focuses instead on methodological implications, articulation with planetary citizenship, and the connection with second-order cybernetics and complex systems theory.

1. **EESD: Between Multiple Approaches and the Urgency of Theoretical Renewal**

EESD has evolved as a heterogeneous field, shaped by initiatives from multilateral organizations, academic institutions, governments, and social movements. While this diversity is generative, it has hindered the consolidation of a systematic theoretical corpus. As Gutiérrez and Pozo note, drawing on Sauvé, Tilbury, and Cooke, EESD is experiencing conceptual saturation without a robust body of research capable of moving beyond declarative discourse and constructing a solid critical foundation. It is essential to avoid the trivialization of sustainability as a keyword or green add-on to traditional educational models. Rather than serving as an instrumental goal, sustainability must be embraced as a structuring category of contemporary educational rationality one that redefines the meaning, aims, and means of educational practice.

2. **Planetary Citizenship: Interdependence, Transnationality, and Biomimicry**

One of the most significant projections of EESD has been its articulation with Global Citizenship Education (GCE), developed as a continuation of the United Nations Decade of Education for Sustainable Development. According to Collado, this framework integrates three key components: transdisciplinarity, an understanding of the human condition as a multidimensional totality, and biomimicry as a learning model grounded in the interdependence between ecosystems and anthroposystems.

GCE proposes a transcultural and transnational vision that enables the comprehension of global challenges through interconnected local perspectives. The Sustainable Development Goals (SDGs) are understood as nodes within a network of interdependent issues, including poverty, climate change, gender inequality, biodiversity loss, and unequal access to education. EESD, through its linkage with GCE, fosters planetary thinking understood as an ethical and cognitive awareness of interexistence and universal co-responsibility.

This approach requires overcoming disciplinary reductionism. In this context, biomimicry is interpreted as both an epistemological and ontological metaphor, revealing that the logic of living systems radically differs from the capitalist logic that governs social systems. This distinction is crucial to prevent the technocratic co-optation of sustainability.

3. Nature, Culture, and Epigenetics: Toward an Emerging Relational Ontology

Along these lines, Maldonado proposes epigenetics as a metaphor for the co-construction between nature and culture. This perspective rejects reducing culture to a mere environmental product and distances itself from genetic determinism. It understands biological and social processes as complex interactions with non-linear effects on the configuration of subjects, ecosystems, and institutions.

From this standpoint, Environmental Education for Sustainable Development (EESD) demands situated pedagogical approaches that acknowledge the complexity of socio-biological trajectories and enable processes of coevolution among education, environment, and society. Sustainability is thus presented not as a fixed goal or universal normative standard but as an open, dynamic, and contextualized process.

4. Second-Order Cybernetics as a Methodological Foundation for EESD

A decisive contribution to the epistemological renewal of EESD comes from second-order cybernetics, developed by Heinz von Foerster and further elaborated by Gregory Bateson and Jesús Ibáñez. Unlike first-order cybernetics, which focuses on observed systems, this perspective centers on observing systems that is, how subjects actively construct the realities they seek to understand. Applied to education, this conception transforms the roles of teacher, student, and knowledge. The educational task is no longer to transmit content but to create conditions that allow subjects to recognize themselves as meaning-makers in dialogue with others and their environment. EESD designs pedagogical experiences oriented toward shared reflection, the de-trivialization of knowledge, and the co-construction of meaningful learning. Key principles include:

- Questioning objectivity: All knowledge is situated and mediated by the observer

- De-trivialization of the student: Subjectivity, creativity, and reflective capacity are acknowledged

- Active construction of reality: Learning is symbolic, situated, and dynamic reconstruction

- Dialogue as a cognitive process: Knowledge emerges from interaction through interpretive reciprocity

These principles allow for the reconfiguration of pedagogical, didactic, and evaluative models in a relational, open, and complexity-aligned logic.

5. Complexity and Educational Systems: From Trivialization to Transformation

Incorporating complex thinking and second-order cybernetics into educational systems implies a structural transformation that affects assessment, teaching, curriculum, and institutional organization. This involves:

- Designing integrated pedagogical systems based on projects, local research, collaborative learning, and real-world problem-solving
- Implementing formative and dialogical assessments focused on understanding, cooperation, creativity, and ethical commitment
- Employing methodologies such as participatory action research, knowledge dialogues, social cartography, mapping of socio-environmental conflicts, and place-based pedagogies
- Encouraging continuous epistemological reflection on the knowledge frameworks used to address environmental issues

Within this framework, EESD is configured as an alternative educational system oriented toward the formation of subjects capable of critically reading their reality, imagining possible futures, and acting transformatively. In order to meet contemporary challenges, EESD transcends normative, functionalist, and behaviorist approaches. Its transformation integrates second-order cybernetics, epigenetics, complex systems theory, and transdisciplinary thinking into an educational praxis that is situated, dialogical, and reflective. This transformation constitutes a political and ethical decision. It entails redefining education as a space for inventing the commons, regenerating the eco-social bond, and opening toward a convivial rationality. In doing so, EESD becomes a structural axis for the civilizational shift demanded by the twenty-first century.

EESD as a Structural Axis of Civilizational Transformation and the Contributions of Complex Thinking to Environmental Education

Within this framework, Environmental Education for Sustainable Development (EESD) takes shape as an alternative educational system oriented toward forming individuals capable of critically reading their reality, envisioning possible futures, and acting transformatively. To address contemporary challenges, EESD moves beyond normative, functionalist, and behaviorist approaches. Its transformation integrates second-order cybernetics, epigenetics, complex systems theory, and transdisciplinary thinking into an educational praxis that is situated, dialogical, and reflective. This transformation is both a political and ethical decision. It entails redefining education as a space for the invention of the commons, the regeneration of eco-social bonds, and the opening toward a convivial rationality. In this way, EESD becomes a structural axis for the civilizational transformation demanded by the twenty-first century.

Key Contributions of Complex Thinking to Environmental Education

Five structuring principles reorient educational practice:

Radical Interdisciplinarity: Integration of scientific, ancestral, popular, and philosophical knowledge to address socio-ecological complexity

- Ecology of Action: Training to anticipate, adapt to, and rectify the multiple and unpredictable consequences of all actions
- Ethics of Care: Sustainability grounded in a relational ethic that fosters shared responsibility
- Emergent Thinking: Education as a spiral process marked by uncertainty, error, and unexpected learning
- Systemic Relationality: Understanding environmental issues in articulation with social, economic, cultural, and symbolic dimensions

These principles shape a pedagogy of complexity, where learning entails developing critical awareness, constructing shared meanings, and inhabiting the world differently.

Three Foundational Ruptures

Complex Environmental Education demands three fundamental ruptures:

- Epistemological: Replacement of instrumental rationality with collective, situated, and dialogical knowledge construction

- Pedagogical: Overcoming vertical paradigms by creating horizontal spaces where the voices of students, communities, and territories are central
- Political: Rejection of neutrality. Environmental education entails taking a stand on development models, ecological inequality, and territorial conflicts

Environmental Education constitutes a field of symbolic and material struggle over the meaning of the future, the organization of collective life, and possible worlds. In the face of climate collapse, resource depletion, cultural uprooting, and the trivialization of knowledge, Environmental Education becomes an act of resistance and hope. It forms planetary citizens individuals aware of their interdependence, committed to ecological and social regeneration, capable of challenging the destructive logics of the present. Individuals who understand that change begins in how we see, think, feel, and act. Complex Environmental Education no longer offers predetermined answers. It opens up essential questions:

- What does it mean to live well in a finite world?
- What are we willing to leave behind so that life may continue?
- How do we build a “we” that includes the Earth?

Answering these questions constitutes a pedagogical, cultural, and civilizational challenge. To materialize this vision within educational systems, a profound reform of public policy is required. It is essential to:

- Transform curricular frameworks by integrating complexity, sustainability, and ecosocial justice
- Promote continuous teacher training in complex thinking, critical pedagogies, and participatory methodologies
- Create quality indicators centered on ethical, ecological, and community-based impacts
- Strengthen the school-territory-community bond as the foundation of a situated and transformative education

Educating from the standpoint of complexity is a vital necessity. It means re-enchanting the relationship between humanity and nature. It means remembering that we are part of the same web of life, where every decision matters and every gesture counts. In times of bifurcation between collapse and regeneration, between barbarism and care complex Environmental Education represents the necessary path to recognize ourselves as inhabitants of the Earth, responsible for the present and co-authors of the future.

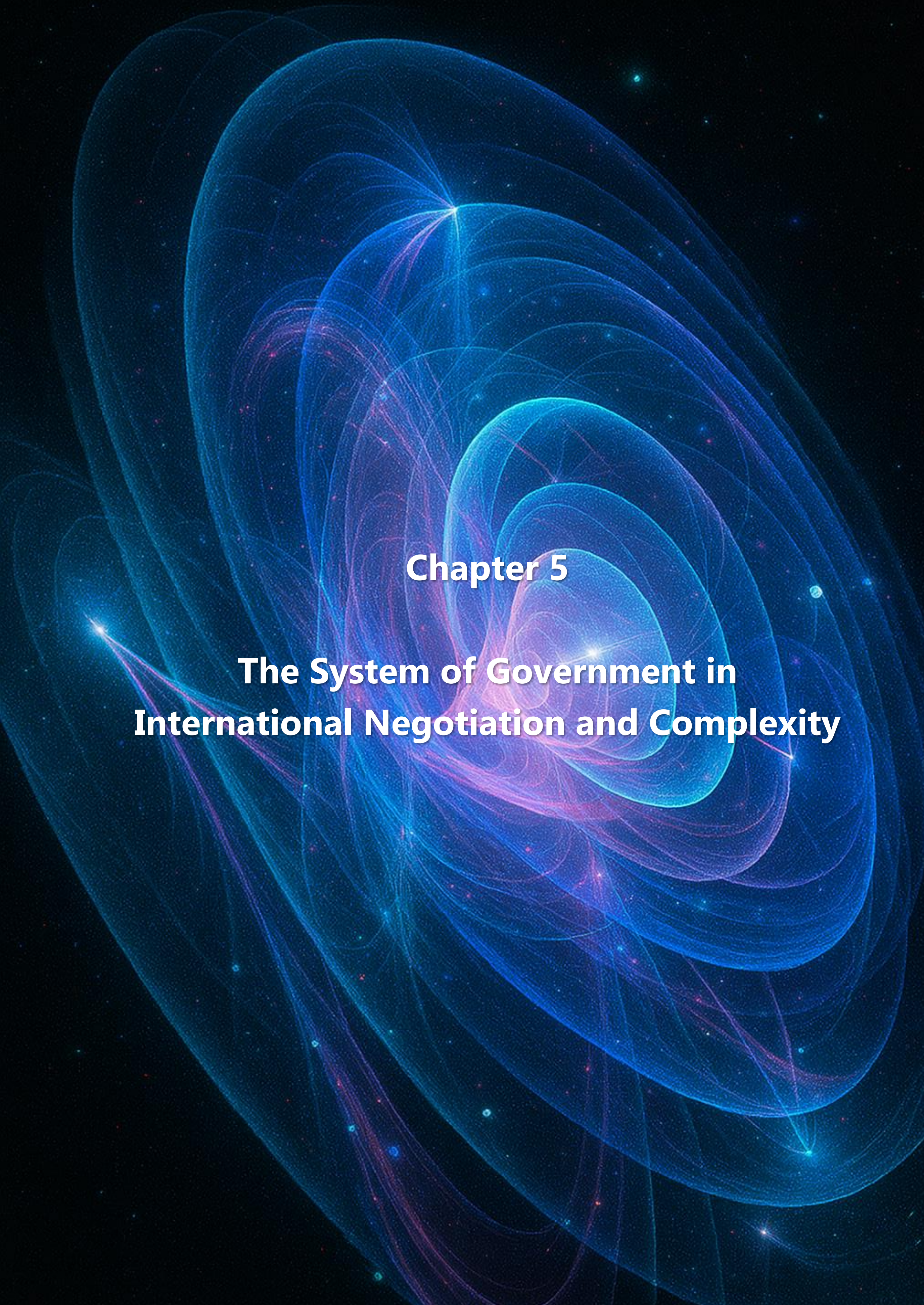
Environmental Education and Complexity as a Civilizational Horizon

The reflective journey undertaken in this chapter affirms that Environmental Education, conceived from the paradigm of complexity and nourished by the sciences of complexity, transcends its role as a didactic tool or marginal component of the school curriculum. It represents an epistemic, ethical, and political project that challenges the core of modern civilization and offers alternatives for profoundly transforming the ways we know, educate, and inhabit the world.

Unlike traditional approaches that reduce environmental issues to data on recycling or biodiversity, complex thinking following Edgar Morin places Environmental Education at the center of a civilizational process of planetary re-learning. This process acknowledges the interdependence of all living systems, the multidimensional nature of the ecological crisis, and the urgency of a cultural reconfiguration centered on the care for life. For centuries, education has served a reductionist epistemology that fragmented knowledge, objectified the world, and severed humanity from nature. This vision fueled a model of development grounded in domination, extractivism, and accumulation. Complex Environmental Education breaks with that tradition. It transforms, interrogates, and connects.

Complexity ceases to be an ancillary topic and becomes an epistemic framework that enables the understanding of environmental problems in their systemic, historical, and political dimensions. It teaches that simple solutions are unviable for complex problems, and that to educate is to imagine and construct different worlds.

Environmental Education exceeds technocratic approaches and the mere transmission of content. Its power lies in cultivating relational, ethical, and situated forms of thought, recognizing that every decision is inscribed within networks of ecological, social, and cultural consequences. To educate environmentally is to enable awareness of interdependence, sensitivity to otherness, and commitment to the commons. It forms individuals capable of perceiving the world as a living system and acting from care, responsibility, and justice. This vision demands a transformation of pedagogical practices. Complex Environmental Education moves beyond the closed classroom, the textbook, and the standardized test. It draws nourishment from experience, territory, knowledge dialogue, and real conflict. Its methodologies are active, dialogical, community-oriented, and emancipatory. Evaluation accompanies processes, acknowledges trajectories, and values transformation.



Chapter 5

The System of Government in International Negotiation and Complexity

The System of Government in International Negotiation and Complexity

Understanding twenty-first-century international negotiation requires moving beyond linear and reductionist analytical models. Contemporary geopolitical dynamics involve economic and military power struggles, along with complex institutional structures, diverse cultural matrices, adaptive processes, and singular political histories. Globalization has dissolved rigid borders, profoundly transforming the rules of the diplomatic game.

In this context, complex thought, as developed by Edgar Morin (2007), provides an epistemic framework suitable for integrating multiple levels of analysis. This perspective weaves together structural, symbolic, and cultural elements without reducing them to simplistic logic. Simultaneously, the sciences of complexity through the study of phenomena such as self-organization, emergence, feedback, and coevolution offer an operational framework that allows for the understanding of political systems as living, adaptive, and dynamic organisms (Holland, 1995).

This dual epistemological and systemic approach unfolds as dialogical thinking. Conceiving international negotiation from the standpoint of complexity entails embracing the coexistence of diverse rationalities, constitutive tensions, and contingent trajectories. Diplomacy, in this sense, expresses how political systems process uncertainty, organize conflict, and project their identity within the international system.

From this perspective, the chapter analyzes how the internal architecture of the systems of government in the European Union, the United States, and China shaped by their institutions, political cultures, and strategic rationalities conditions their international behavior. The hypothesis posits that negotiating capacity depends less on the availability of material resources than on how each system interprets the world, organizes its decision-making, and exercises international agency.

According to Holland (1995), Complex Adaptive Systems (CAS) are networks of interdependent agents that interact, learn, provide feedback, and evolve. These networks generate emergent behaviors that cannot be reduced to the sum of their parts, and whose adaptation to the environment depends on factors such as internal diversity, openness, learning, and self-organization.

Applied to political systems, this approach conceives them as institutional ecologies in constant interaction with their environment. Foreign policy becomes an emergent function of how a system organizes its internal governance and responds to external signals. Governments act internationally guided not only by strategic interests but also by their cognitive and organizational capacities.

Within this framework, international negotiation constitutes a space of coevolution in which decisions emerge from dynamic flows of information, perception, and power. Diplomatic effectiveness is defined by internal coherence, the ability to interpret shifting contexts, anticipate ruptures, generate legitimizing narratives, and sustain strategic resilience.

European Union: Multilevel Negotiation and Emerging Meta-Agency

The European Union (EU) represents a singular case of a politically decentralized system that operates as a relevant international actor. Its multilevel institutional architecture composed of the Commission, the Parliament, the Council, and the member states produces a complex form of governance based on the articulation between supranational and national levels. This organization gives rise to what Jachtenfuchs and Kohler-Koch (2004) call emerging meta-agency, wherein the EU becomes a collective actor through concerted processes that construct common agency.

From the perspective of complexity, this form of collective action is adaptive, as it enables the negotiation of shared positions among diverse actors, fosters democratic legitimacy, and supports the construction of sustainable consensus. The same structure, however, introduces institutional rigidity, decision-making delays, and difficulties in responding to highly volatile contexts. The requirement to reconcile heterogeneous national interests restricts the EU's ability to act swiftly, as evidenced during the war in Ukraine and in trade negotiations with China.

The EU privileges normative power as a tool of international influence, understood as the capacity to shape outcomes through the projection of norms, values, and standards rather than through coercion (Manners, 2002). This strategy reinforces its image as a civilizational actor, particularly in areas such as human rights, climate change, and international cooperation. Its effectiveness depends on internal cohesion, which is often undermined by economic asymmetries, ideological tensions, and Eurosceptic currents.

United States: Institutional Adaptability and Systemic Polarization

The U.S. political system combines executive centralization with institutional fragmentation. The president holds broad powers in foreign policy, allowing rapid and decisive action in times of crisis. This capacity coexists with a Congress endowed with veto powers, an independent press, and a highly mobilized civil society. The result is often an improvised diplomacy lacking strategic continuity.

From the standpoint of complex adaptive systems, the U.S. system exhibits high short-term reactivity but is vulnerable to cycles of polarization (Axelrod & Cohen, 2000). The alternation between administrations with antagonistic worldviews such as the shift from Trump to Biden undermines international credibility and complicates the consolidation of stable alliances. Internal volatility thus becomes a risk factor on the geopolitical stage.

Polarization also operates at a structural level. Media outlets, think tanks, social networks, and lobbying groups constitute a fragmented ecosystem that hinders the construction of strategic consensus. This institutional entropy affects foreign policy, reduces its predictability, and increases reliance on unilateral executive decisions.

Despite these challenges, the United States retains an unparalleled capacity for global projection. Its technological dominance, military power, alliance networks, and cultural influence form a structural platform of power. This hegemony, however, faces challenges both from emerging actors and from the internal erosion of its democratic model, which undermines its legitimacy in the international system.

China: Strategic Centralism and Adaptive Resilience

China's political system is organized around a centralized structure under the Chinese Communist Party (CCP), which integrates strategic planning, ideological cohesion, and political control. This configuration enables rapid and coordinated decision-making as well as the sustained implementation of long-term policies. From a complexity perspective, it is a system that combines internal stability with adaptive capacity, balancing central control with limited openness to markets and innovation (Kissinger, 2011).

Chinese foreign policy follows a strategic pragmatism. Through initiatives such as the Belt and Road Initiative, China has deployed an infrastructural diplomacy that fuses economic investment with geopolitical influence. This strategy, based on bilateral agreements and physical infrastructure, allows China to shape a global power architecture that serves as an alternative to Western multilateralism.

In terms of institutional resilience, China has demonstrated an ability to absorb internal tensions as in the Hong Kong protests resist external pressures such as U.S. sanctions and maintain steady economic growth. This resilience depends on economic performance and social control, which could become vulnerabilities if democratizing demands increase or growth slows.

Regarding soft power, the regime has invested in projecting its cultural narrative through Confucius Institutes, cinema, and digital media. These efforts encounter resistance in contexts where China is perceived as pursuing an expansionist agenda or threatening local autonomy. Thus, China's cultural projection faces the dilemma of legitimizing an authoritarian model in a predominantly liberal-democratic international environment.

Table 6: Effects of the Political and Governmental System on Negotiation Capacity

Category	**European Union**	**United States**	**China**
Political system	Supranational union, multiparty	Federal republic, presidential system	Single-party socialist state
Government	Multilevel, consensus-based	Separation of powers, strong executive	Centralized, authoritarian

Category	European Union	United States	China
Decision-making speed	Slow (consensus among 27 countries)	Medium (agile presidency, congressional constraints)	High (centralized decision-making)
Internal coherence	Low to medium (divergent national interests)	Variable depending on party in power	High (strategic continuity)
Negotiation power	Economic, regulatory	Economic, military, political	Economic, political, strategic
Internal obstacles	Divergences among member states	Congress and political polarization	Limited due to party control
Negotiation style	Rules-based, multilateral agreements	Competitive, strategic leadership	Strategic, long-term interest-oriented
Transparency	High	High (though politically polarized)	Low
Source	Author's own elaboration		

Source: Author's own elaboration

Theories of International Negotiation and Complex Thought

International negotiation has traditionally been approached through theoretical models such as political realism, liberal institutionalism, game theory, and soft power doctrines. These frameworks have provided useful conceptual tools in specific contexts, yet they rely on reductionist assumptions that oversimplify the dynamic, ambiguous, and conflictual nature of global interactions.

From the standpoint of complex thought, these models can be critically revisited to reveal their limitations and incorporate dimensions such as uncertainty, emergence, subjectivity, coevolution, and self-organization.

Realism: The Reductionism of Power as Principle

Classical realism is grounded in a Hobbesian conception of the international system: an anarchic space in which states, viewed as rational and unitary actors, compete to maximize their power. National security becomes the ultimate priority, and alliances are understood as tactical tools in a continuous struggle for survival. According to this logic, powers such as the United States and China act as self-sufficient entities that negotiate from positions of relative strength, based on their military, technological, or economic supremacy.

This perspective proves inadequate in the face of global challenges that demand multilateral cooperation, such as climate change, cybersecurity, pandemics, or artificial intelligence. Realism constructs a deterministic and linear framework incapable of accounting for emergent variables, cultural shifts, internal tensions, or unpredictable dynamics.

States function as open systems traversed by contradictions, multiple interests, and transnational flows. Their decisions emerge from internal negotiations, subjective perceptions, social pressures, and institutional learning. Power is redefined as the capacity to generate meaning, construct legitimacy, and adapt creatively to changing environments beyond the mere accumulation of resources.

Liberal Institutionalism: Between Normative Cooperation and Structural Rigidity

International institutions facilitate cooperation by reducing uncertainty and stabilizing expectations. Through shared rules, arbitration mechanisms, and deliberative forums, multilateral organizations shape a more predictable environment for negotiation processes. Within this framework, the European Union exemplifies a model of normative power by exerting influence through the promotion of values such as human rights, multilateralism, and international law (Manners, 2002). From the perspective of complex thought, however, the assumptions of neutrality, stability, and rationality that underpin this approach become problematic. Institutions operate as fields of power where meanings are contested, interests are reconfigured, and worldviews clash. They function more as interpretive arenas expressing coevolutionary dynamics than as stable consensus platforms.

The idealization of institutional stability overlooks the fact that rigid normative frameworks tend to hinder adaptive capacity. In contexts marked by high uncertainty such as pandemics, hybrid conflicts, or technological disruptions institutions must develop capabilities for learning, operational reconfiguration, and agile response. International cooperation, in this sense, is understood as an evolutionary process sustained by self-regulation, organizational flexibility, and cognitive openness.

Game Theory: Between Strategic Calculation and Chaotic Coevolution

Game theory has been widely employed to model strategic negotiation scenarios. Through frameworks such as the prisoner's dilemma, the game of chicken, and repeated games, it seeks to determine optimal strategies aimed at maximizing benefits in situations of conflictual interdependence. China, with its unified command and long-term planning, is often portrayed as a calculating actor. The European Union, in contrast, faces obstacles linked to its multilevel institutional structure, which requires prior coordination among member states.

This vision rests on assumptions that are difficult to apply empirically, such as the existence of complete information, stable preferences, and perfect rationality. Real-world negotiations unfold amid ambiguities, misinformation, shifting interests, and identity transformations arising from the interaction itself. Rationality adopts situated, historical, and often contradictory forms. Complex Thinking invites us to conceive negotiation as a process of coevolution in which actors learn, transform, and generate new meanings. Dynamics such as feedback, emergence, and recursive loops offer a more accurate depiction of this logic than the static categories of game theory.

The incorporation of the included third, following the transdisciplinary logic proposed by Nicolescu, makes it possible to articulate integrative solutions to paralyzing dichotomies such as sovereignty and cooperation, growth and sustainability, security and freedom.

Soft Power and Legitimacy in Dispute

The concept of soft power, developed by Joseph Nye (2004), has gained relevance as an explanatory category in the analysis of international relations. Unlike coercive power, soft power operates through mechanisms of cultural attraction, normative legitimacy, and symbolic leadership. The European Union has projected itself as a promoter of democratic values, human rights, and environmental governance. The United States has combined expressions of hard and soft power, although its international image has deteriorated due to external inconsistencies and internal dynamics of polarization. China has promoted a cultural diplomacy through Confucius Institutes, cinema, and various digital platforms.

Soft power is constructed as an intersubjective relationship, dependent on external perception, narrative coherence, and the credibility of the source. In contexts marked by misinformation, legitimacy crises, and cultural tensions, its effectiveness is strongly constrained. The European Union faces criticism when its decisions contradict its stated principles, the United States for its ambivalent standards, and China for the distrust generated by institutional opacity and its authoritarian model.

From a complex perspective, soft power forms part of an ecology of symbolic, institutional, and discursive relations. Its effectiveness requires coherence between discourse and practice, intercultural resonance, and openness to mutual recognition. This demands a relational understanding of the link between power and legitimacy, sustained by communicative practices, ethical bonds, and shared learning.

Continuities and Discontinuities: The Institutional Variable

A key aspect of international negotiation is the institutional structure that regulates decision-making. Democratic systems, such as those of the European Union and the United States, undergo cycles of alternation that generate variations in foreign policy.

The arrival of new administrations alters agendas, redefines commitments, and modifies agreements. While this dynamic is valuable for pluralism, it also introduces strategic volatility.

The Chinese model, by contrast, maintains long-term strategies with high consistency, unaffected by electoral cycles. This continuity is sustained by structures with lower democratic legitimacy, limited transparency, and restricted participation. From the perspective of complex thought, this tension is expressed as an unstable equilibrium between structural stability and institutional adaptability.

Each institutional configuration must be assessed based on its capacity to manage uncertainty, process diversity, and construct legitimacy within a deeply interdependent global environment.

Complex Thinking and International Negotiation: An Integrative Perspective

Complex Thinking and the sciences of complexity offer an indispensable epistemic framework for addressing the challenges of global governance. In the face of the limitations of linear and deterministic models, this perspective makes it possible to understand international negotiation as a situated, contingent, and evolutionary process in which structural, symbolic, cultural, and historical factors interact in constant interrelation.

From this vantage point, the international system emerges as a dynamic web of interdependent actors whose decisions produce unpredictable effects through feedback, emergence, and continuous reconfiguration. Complexity is understood as a constitutive condition of the international order, characterized by ambivalence, contradiction, and persistent uncertainty.

Conceiving negotiation from this perspective involves recognizing partial rationalities, shifting identities, and diverse adaptive capacities. Analytical focus moves away from outcomes and toward processes, and from the pursuit of equilibrium to an understanding of transformation.

Complex Thinking introduces a relational notion of power, constructed through interaction. International influence depends less on resources than on the capacity to interpret the environment, generate shared meaning, integrate differences, and sustain legitimacy over time.

The sciences of complexity model these dynamics through concepts such as coevolution, resilience, self-organization, and dissipative structures. Their purpose is to identify transformation patterns, margins of adaptability, and inflection points that make it possible to anticipate geopolitical scenarios marked by discontinuities, accelerations, and partial collapses.

Complex Thinking and the sciences of complexity enrich the analysis of international negotiation and provide conceptual and methodological tools for intervening with responsibility, openness, and strategic vision. The current challenge lies in strengthening analytical capacities that allow us to inhabit ambiguity, recognize creative tensions, and manage uncertainty without attempting to eliminate it.

Complex Thinking and Nonlinear Diplomacy

Complex Thinking does not seek to construct a closed theory of international negotiation, though it does propose guiding principles that enable its critical reconfiguration. The dialogical principle acknowledges the simultaneous presence of complementary and antagonistic elements. In diplomatic contexts, divergent interests can give rise to conflictual collaboration or creative competition, depending on the conditions activated during interaction.

The recursive principle holds that that which is produced transforms the producer. Every decision in international politics generates effects that reconfigure the actor's own position. For example, ratifying an environmental treaty strengthens internal actors such as social movements, which in turn reshape foreign policy from within the system.

The hologrammatic principle affirms that each part contains the whole, albeit in a partial and distorted manner. Applied to diplomacy, this principle requires recognizing that each actor projects its vision of the international system from its own historical, cultural, and symbolic configuration, without full access to the totality. To these foundations is added the imperative of contextualization. Every action, agreement, or narrative acquires meaning from the specific conditions that shape it. International negotiation demands attentiveness to context, openness to local trajectories, and flexibility to adapt responses without imposing uniform schemes. Complex Thinking also introduces the concepts of feedback and emergence to describe how diplomatic dynamics transform through successive interactions. Negotiations involve intentional actions and unforeseen responses that generate learning, adaptations, and unexpected reconfigurations.

These principles allow diplomacy to be conceived as a vital, uncertain, creative process in constant transformation. The goal is to enrich existing approaches, broaden their interpretive frameworks, and connect them with a more relational, situated, and dynamic understanding of international affairs.

Case Studies

The explanatory power of Complex Thinking becomes especially clear when applied to concrete negotiation processes such as the Paris Agreement (2015), the energy sanctions against Russia (2022), or the Conferences of the Parties (COP) on climate change. In each case, multiple actors, heterogeneous rationalities, internal contradictions, and evolving historical trajectories converge, surpassing the boundaries of classical analytical frameworks.

Paris Agreement

The Paris Agreement marks a turning point in climate diplomacy. Unlike the Kyoto Protocol, which relied on binding commitments, this agreement is structured through nationally determined contributions (NDCs) and a periodic review mechanism designed to increase ambition over time.

From a traditional perspective, this approach might seem weak. From the standpoint of complexity, it represents a flexible architecture that acknowledges the diversity of national contexts, political and scientific uncertainty, and the need for adaptive evolution. It promotes collective learning through feedback, peer review, and mutual pressure. Cooperation is sustained through trust, reputation, and shared responsibility.

The agreement incorporates subnational actors, Indigenous peoples, and civil society within a polycentric, multiscalar model of governance. This networked, dynamic, and adaptive structure aligns closely with the principles advanced by complex thought.

Energy Sanctions and Polarized Systems

The sanctions regime imposed on Russia following the invasion of Ukraine in 2022 reveals the tensions inherent in operating within highly polarized systems. The sanctions aim to alter the incentives of the Russian government. They generate collateral effects in sanctioning countries, alter energy prices, stimulate new alliances, and accelerate Europe’s energy transition.

From a simplified viewpoint, this would appear to be a mere act of external pressure. In practice, nonlinear consequences emerge through the interaction of markets, domestic policies, narratives, and geostrategic realignments. The coevolution of actors gives rise to unexpected phenomena: monetization of conflict, new trade routes, and the repositioning of regional powers.

Cultural, symbolic, and affective factors reshape the logic of action and reaction. Narratives of sovereignty, national imaginaries, and historical memory influence state responses beyond rational calculation. The emergence of new forms of agency such as cyberactivism and cryptocurrencies further amplifies systemic complexity.

Climate Summits and Distributed Diplomacy

The Conferences of the Parties (COP) offer privileged arenas for observing global diplomacy in its most complex expression. Rather than mere intergovernmental forums, they function as assemblages in which dissonant discourses, simultaneous agendas, and unstable coalitions converge. COP26, held in Glasgow, exposed numerous fractures: North–South tensions, conflicts between wealthy and poor countries, clashes between fossil-fuel economies and green models, and disputes between technocratic approaches and activist voices.

Instead of linear negotiation, dynamic patterns emerge that elude deterministic forecasts. From the perspective of complex thought, analysis shifts away from a narrow focus on formal agreements toward the observation of agenda-setting processes, the formation of fleeting alliances, the displacement of dominant narratives, and the emergence of distributed power nodes. Climate diplomacy appears as a hybrid, open system in constant transformation, in which uncertainty functions as a structuring condition.

Operational Implications of Complex Thinking in International Negotiation Processes

Applying Complex Thinking to international negotiation entails both an epistemological and methodological shift that challenges conventional analytical frameworks. This approach moves beyond the expectation of resolving conflicts through optimizing algorithms or linear models centered on rational interests. Instead, it acknowledges that every negotiation process is permeated by uncertainty, contradiction, irregular feedback, and the emergence of new collective meanings.

From this perspective, engaging with the world requires embracing complexity as both a strategic input and a constitutive dimension of international reality. Strategies cease to be conceived as unidirectional mechanisms for maximizing benefits and are instead structured around a logic of strategic circularity. Every action generates collateral effects that return in transformed ways, which compels strategic thinking in terms of cycles, feedback loops, dynamic interdependencies, and second-order consequences. Within this framework, rationality is redefined as reflexive and adaptive capacity.

In the multilateral sphere, this approach calls for the construction of flexible structures and the implementation of iterative processes. Agreements are no longer viewed as final resolutions but rather as provisional milestones within a spiral of continuous review. The Global Stocktake mechanism of the Paris Agreement, designed to assess progress every five years and adjust contributions, exemplifies this institutionalized recursive logic as a mechanism for collective learning within complex adaptive systems.

A central implication of this perspective is the incorporation of the dialogical principle as the foundation of diplomatic interaction. Unlike debate, which seeks dominance, or classical negotiation, focused on compromise between fixed positions, complex dialogue entails radical openness to the viewpoint of the other. Every rationality is understood as situated, limited, and partial. Conflict, rather than being suppressed, becomes a source of joint creation.

This principle is articulated with the notion of the included third, developed by Morin and Nicolescu, which enables a logic of integration rather than exclusion. Opposites are inscribed within a higher plane of understanding that allows for the construction of cooperative frameworks capable of articulating sovereignty and interdependence, as well as integrating divergent interests without resorting to homogenization.

Éthique de la Reliance and Planetary Governance

In complex thought, ethics functions as a structural component of knowledge. Edgar Morin proposes an ethics of understanding, which acknowledges the vulnerability of the other, alongside an éthique de la reliance an ethic of reconnection aimed at relinking that which has been dissociated among individuals, cultures, nations, and ecosystems. This form of ethics avoids moralizing tendencies and manifests as a political commitment that demands the creation of institutional structures capable of sustaining mutual care and global co-responsibility.

In international negotiation processes, this ethical orientation invites us to move beyond a logic centered on particular interests toward a vision grounded in common goods. Issues such as climate change, biodiversity, water management, and digital governance require integrative approaches. These challenges defy effective resolution when addressed through fragmented frameworks and instead demand agreements rooted in a planetary ethic, where shared sustainability replaces any ambition of domination.

The concept of complex multilateralism, formulated by Held, points to the need to design systems of international cooperation characterized by networked, flexible, and context-sensitive structures. This form of institutional architecture enables plural and equitable relations, without hegemonic concentrations, fostering the articulation of diversity and interdependence through adaptive and culturally attuned mechanisms.

Methodological Protocol for Complex Negotiation

To operationalize these ideas, a methodological protocol is proposed, aimed at articulating multiple dimensions of analysis. First, it is essential to carry out a mapping of actors and narratives that identifies both visible participants and less apparent ones such as local communities, youth, and Indigenous peoples along with the narratives that drive their actions, including climate justice, intergenerational rights, and energy sovereignty.

Second, a multiscale analysis is required to address the interaction between phenomena at local, national, regional, and global levels, while avoiding simplistic projections that reproduce linear schemes. This is complemented by the mapping of feedback loops, which helps identify complex interactions among decisions, events, and responses, with the goal of anticipating collateral effects and emergent dynamics.

The methodological design must be structured in an iterative and adaptive manner, through open-ended processes that incorporate strategic pauses for evaluation, feedback, and redesign. This logic is enhanced by the integration of plural knowledges, recognizing the epistemic validity of scientific, technical, ancestral, and experiential knowledge on equitable terms thus fostering a genuine ecology of knowledges.

Impact evaluation requires a transdisciplinary approach, employing multiple indicators across social, ecological, economic, and cultural dimensions. These indicators must be aligned with participatory tools that assess the ethical coherence of decisions and their systemic sustainability.

Although Complex Thinking offers a robust alternative to reductionist perspectives, its practical application faces theoretical, methodological, and operational limitations. These challenges demand critical approaches that prevent its principles from becoming a new dogma. One of the most frequent risks lies in the rhetorical use of concepts such as emergence, coevolution, or collective intelligence without rigorous analytical translation. This metaphorical inflation can lead to an empty rhetoric that replaces explanation with suggestion. Morin and other authors have warned of the dangers of transferring concepts from the natural sciences to the social sciences without precise epistemological adaptation.

For this reason, it is essential to distinguish between complexity as an epistemic category which entails a transformation in thinking and an openness to uncertainty and its use as a mere description of chaos or confusion. Addressing the complex requires consistent methodological protocols, rigorous validation criteria, and appropriate tools to confront multicausality without paralyzing analysis.

Modeling complexity empirically in diplomatic contexts presents specific difficulties. Unlike physical systems, international relations involve symbolic, cultural, and historical dimensions characterized by high contingency and low formalization. Attempts to reduce these dynamics to equations or computational models carry the risk of unacceptable simplification.

Validation also faces significant obstacles, as results depend on multiple unexpected factors and effects often unfold over extended time horizons. For this reason, it is crucial to complement models with qualitative methodologies, case studies, counterfactual history exercises, and complex network analysis to better capture the density of contemporary international relations.

Tensions with Structural Realism and Strategic Rationality

From a philosophical standpoint, Complex Thinking enters into friction with the premises of structural realism. While this school conceives the international system as an anarchic, competitive environment governed by the logic of power, the complex perspective proposes a configuration marked by interdependence, instability, and constant transformation.

In contrast to the skepticism of those who reduce diplomacy to strategic calculations and power correlations, Complex Thinking argues that instrumental rationality can have a role provided it is embedded within a broader framework in which ends, means, and values are relationally reconfigured through interaction.

Hierarchical, technical, and rigid diplomatic structures persist, hindering the incorporation of complex approaches. Ministries of foreign affairs, multilateral organizations, and negotiating teams tend to prioritize short-term efficiency over systemic transformations aimed at sustainability and legitimacy.

A complex diplomacy demands the reform of these institutional schemes by enabling transdisciplinary spaces, training negotiators with reflexive capacities, integrating intercultural perspectives, redefining metrics oriented toward structural sustainability, and fostering environments conducive to learning, creativity, and adaptation.

This transformation presents high demands, yet it is unavoidable. As Morin warns, the reform of thought goes beyond theoretical speculation it constitutes a civilizational imperative. Confronting challenges such as climate change, forced displacement, water conflicts, or pandemics requires new ways of thinking, deciding, and acting that are commensurate with the complexity of the contemporary world.

Toward a Complex Diplomacy: Challenges, Principles, and Horizons

Rethinking international negotiation through the lens of complexity entails transforming the foundational premises that guide diplomatic action in today's global arenas. This perspective goes beyond traditional models by consciously integrating tensions and contradictions as constitutive components of the negotiation process. Complexity is never reduced or resolved it is inhabited, interpreted, and transformed.

Complex Thinking transcends mere criticism of the limitations of realism or institutionalism by proposing an epistemology that embraces uncertainty, ambivalence, and coevolution as inherent conditions of both knowledge and action. International negotiations unfold within dynamic systems where heterogeneous rationalities, power asymmetries, divergent values, and historical trajectories converge, all of which resist homogenization.

From this standpoint, diplomacy is no longer conceived as a mere strategic tool of state interest, but rather as a relational political practice. It demands skills for navigating ambiguity, sustaining dissent without paralyzing the process, and building transitional convergences in highly complex scenarios such as climate change, global health crises, technological tensions, and emerging geopolitical reconfigurations. In the face of such conditions, linear schemes prove inadequate.

Adopting the complexity paradigm strengthens rigor without sacrificing critical openness. It requires an understanding that decisions emerge from situated rationalities emotionally marked, cognitively limited, and ethically strained. It calls for a reexamination of categories such as power, success, and effectiveness, and the recognition that the meaning of negotiation lies in the ability to sustain resilient, adaptive, and transformative processes.

The sciences of complexity enrich this perspective by offering key operational tools such as the identification of patterns, the recognition of bifurcation points, and the strategic reading of feedback loops. This approach expands diplomatic capacities by incorporating systems thinking, active listening, ethical management of uncertainty, and intercultural sensitivity.

With these contributions, it becomes essential to avoid distortions. The superficial repetition of terms such as emergence, interdependence, or adaptive systems without a rigorous methodological foundation empties the proposal of its substance. Complexity demands intellectual commitment and political responsibility. This paradigm invites us to reconstruct actors, reframe meaning structures, and reimagine collaborative ways of building agreements. Its adoption requires distance from sterile technocratism as well as from any form of relativist paralysis.

The orientation is clear. What is needed is the construction of an ecology of knowledges and a diplomatic architecture capable of articulating diverse rationalities, multiple scales, and an ethic oriented toward planetary interdependence. Contemporary diplomacy must act without formal guarantees, with strategic lucidity, without absolute certainties, and with historical responsibility. Its task is to transform conflict into an opportunity for political innovation.

What is at stake transcends tactical efficiency. It is about imagining and enabling new forms of planetary coexistence. Complexity ceases to function as a limit and becomes a horizon a horizon that demands the reinvention of diplomatic practice through openness, co-construction, and collective intelligence.

The challenges posed by contemporary international negotiation exceed any analytical framework that fragments reality, operates with binary logics, or assumes homogeneous and fully rational actors. As developed throughout this chapter, negotiation must be understood as a coevolutionary process embedded within diverse, historical, and dynamic systems in which multiple scales, forms of power, and strategic intelligences converge in constant tension.

Complex Thinking and the Sciences of Complexity dismantle reductionist assumptions while offering heuristic and operational principles to understand the logic of adaptive systems, the emergence of novel configurations of power, and the incorporation of uncertainty as a structural condition. This perspective recognizes conflict and contradiction as essential components of any negotiation with transformative intent.

Within this framework, negotiation ceases to be conceived as a technical exercise aimed at maximizing interests and instead unfolds as a practice of contextual intelligence, relational ethics, and shared meaning-making. This praxis articulates four interconnected dimensions: epistemic, institutional, strategic, and ethical.

On the epistemic level, analysis is understood as situated mediated by narratives and interpretations subject to ongoing revision. Complexity is inhabited as a question, never as a closed system of explanation or a simplifiable reality.

Institutionally, it becomes necessary to design governance frameworks capable of sustaining plurality, operating with adaptability, and withstanding systemic fragilities. This entails structures open to learning, equipped with feedback mechanisms, contextual evaluation, and inclusive participation of diverse actors.

From a strategic perspective, effectiveness is measured by the capacity to generate transitional convergences, reframe persistent dilemmas, and create viable solutions under conditions of uncertainty. Relational power becomes central, displacing any accumulative logic oriented toward control.

In the ethical domain, a new ethic of interdependence is proposed grounded in shared vulnerability, mutual responsibility, and a commitment to the sustainability of human and ecological systems. This ethic connects without imposing, articulates without closing, and enables without moralizing.

These dimensions, dynamically interwoven, shape an integrative vision of negotiation as an open system attuned to cultural mutations, technological transformations, and emergent demands for global justice. In contrast to the paradigm of control, governance informed by complexity is oriented toward the care of balances, institutional resilience, and anticipation of critical bifurcations.

As analyzed in the cases of the European Union, the United States, and China, each political system defines its negotiating capacity in accordance with its institutional architecture, political culture, and conception of power. This diversity represents a valuable diplomatic potential when approached through intercultural translation rather than unilateral imposition.

Progress toward planetary diplomacy requires a profound shift in strategic rationality. The preservation of particular interests becomes secondary to the need for enabling sustainable agreements amid a civilizational transition. Complex Thinking provides critical guidance for this process: it acts through lucidity rather than certainty, through cognitive openness rather than identity retreat, through critical readiness to inhabit uncertainty rather than paralysis in the face of it.

Diplomacy in the twenty-first century demands reinvention as the art of mediation. It must emerge as a practice capable of building bridges between dissimilar worlds, conflicting visions, and divergent temporalities. Complexity empowers action and renders it possible. It is the very condition of the common in an era marked by profound transformations.

Table 7: ***Conceptual Synthesis International Negotiation and Complexity***
1. Traditional Approach vs. Complexity-Based Approach

Analytical Element	**Traditional Paradigm**	**Complexity Paradigm**
Epistemology	Linear, causal, reductionist	Nonlinear, recursive, systemic
Central Actor	Rational, unitary nation-state	Multiple, heterogeneous, and adaptive actors
Negotiation Logic	National interest, zero-sum	Coevolution of interests, relational logic
Systemic Condition	Stability, predictability	Uncertainty, ambiguity, emergence
Power	Coercive (hard power)	Relational, symbolic, adaptive (soft & smart power)

Analytical Element	**Traditional Paradigm**	**Complexity Paradigm**
Strategy	Control, calculation	Listening, adaptation, learning
Source	Author's own elaboration	

Source: Author's own elaboration

2. Components of the Complexity-Based Approach

Complex Thinking (Morin)
• Multicausality
• Multiple rationalities
• Ethic of interdependence
• Logic of the included third
• Recursivity and feedback

Sciences of Complexity (Holland, Nicolis, Prigogine)
• Complex adaptive systems
• Emergence and bifurcation
• Self-organization
• Nonlinearity
• Multi-agent dynamics

3. Table 8: *Analytical Dimensions of Complex Diplomacy*

Dimension	**Analytical Key**	**Strategic Function**
Epistemic	Acknowledgment of uncertainty	Problematize hegemonic analytical models
Institutional	Open and adaptive structures	Sustain recursive and multiscalar processes

Dimension	Analytical Key	Strategic Function
Strategic	Collective intelligence, narrative resilience	Articulate temporary convergences and contextual responses
Ethical	Interdependence, care, shared responsibility	Ground legitimacy in plurality

Source: Author's own elaboration

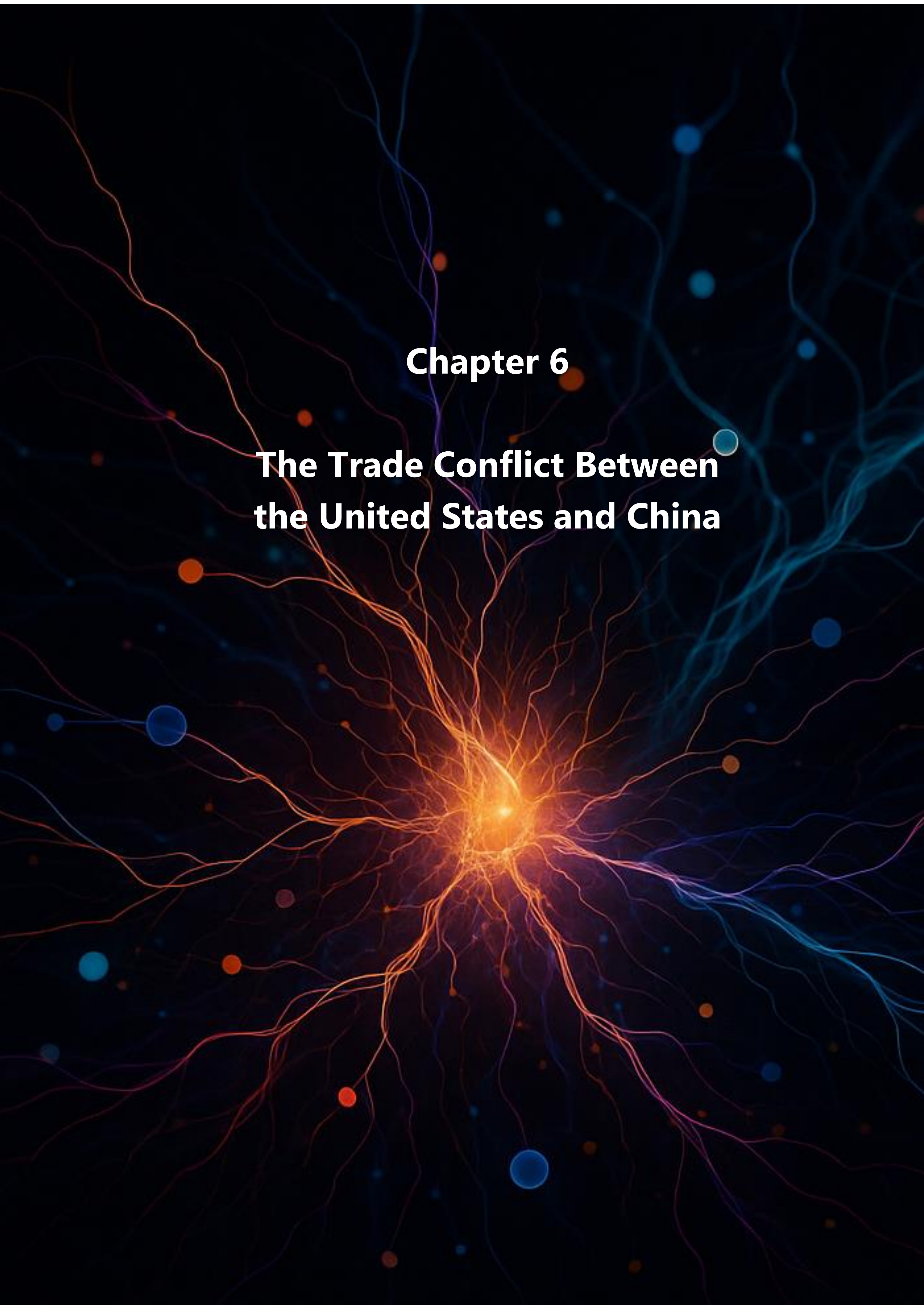
4. Table 9: *Systemic Comparison*

Actor	Type of Political System	Adaptive Capacity	Strategic Coherence	Main Limitation
European Union	Multilevel governance	Medium	Fragmented	High internal rigidity and slow decision-making
United States	Presidential democracy	High (short term)	Volatile	Systemic polarization
China	Strategic centralism	High (long term)	High	Low democratic legitimacy

Source: Author's own elaboration

5. Principles for a Complex Diplomacy

- Inhabit uncertainty without collapsing
- Build agreements through diversity
- Process conflict without suppressing it
- Manage tensions without resolving them artificially
- Design negotiation systems that are resilient, open, and recursive



Chapter 6

The Trade Conflict Between the United States and China

The Trade Conflict Between the United States and China

The trade conflict between the United States and China, formally initiated in 2018, stands as one of the most significant geoeconomic events of the twenty-first century. Although it was publicly framed as a tariff dispute between the world's two largest economies, its underlying dynamics reveal a structural struggle for global hegemony, a clash between development models, and a profound reconfiguration of international power relations. Understanding this phenomenon requires moving beyond fragmented approaches and adopting an epistemically complex perspective that integrates strategic, institutional, discursive, and cognitive dimensions.

From the standpoint of political realism, as formulated by Hans Morgenthau in 1948 and developed structurally by Kenneth Waltz in 1979, the international system is characterized by its anarchic structure, in which states act to ensure their survival and expand their influence. Within that interpretive framework, the Trump administration's trade offensive can be read as a deliberate containment effort in response to China's systemic rise as a technological, industrial, and military power.

The measures adopted by the United States such as tariffs on goods exceeding $250 billion, sanctions targeting Huawei, and pressure on allies to limit Chinese participation in the global deployment of 5G networks follow a logic of offensive realism, as proposed by Mearsheimer in 2001. Under this view, a dominant power deploys containment strategies to avoid losing its hegemonic position. The trade war served as a prolonged instrument of resistance against the challenge posed by China's state-led, technonationalist form of capitalism.

The rivalry between these two powers extends far beyond the economic sphere. It constitutes a contest to define the rules that shape the international order during a phase of systemic transition, in which a multipolar balance is still in formation. Realism helps to identify the structural dimension of the conflict, understood as strategic competition for global supremacy. At the same time, it falls short in capturing the complexity of the symbolic, technological, ideological, and cognitive factors at play necessitating an epistemological expansion toward perspectives that integrate multiple rationalities and emergent processes.

Liberal Institutionalism: Normative Erosion and the Decline of Multilateralism

Represented by scholars such as Robert Keohane (1984) and Joseph Nye (2001), liberal institutionalism argues that international institutions reduce uncertainty, facilitate cooperation, and mitigate systemic anarchy. Within this framework, the World Trade Organization (WTO) has served as an arbiter of multilateral trade disputes.

The trade war between the United States and China reflects the erosion of the liberal normative regime. The U.S. bypassed multilateral procedures and adopted unilateral measures, thereby weakening both the WTO and the principle of institutional conflict resolution. The paralysis of the Appellate Body caused by the U.S. blockade of judge appointments illustrates a strategic disaffection with multilateralism (Ikenberry, 2011).

China, in turn, promoted regional alternatives such as the Regional Comprehensive Economic Partnership (RCEP), consolidating its leadership within new institutional architectures. The conflict reveals a dual crisis: one of institutional effectiveness and another of normative legitimacy. The liberal framework yields to hybrid power arrangements, where the primacy of force displaces the force of norms.

Integrative Negotiation Theory: Structurally Inhibited Opportunities

Developed by Roger Fisher and William Ury (1981), integrative negotiation theory posits that disputes can be transformed into agreements by identifying shared interests and generating mutual value. Rather than competing over fixed resources, the parties are encouraged to "expand the negotiation pie" through intelligent cooperation.

The "Phase One" trade agreement, signed in January 2020, included elements aligned with this paradigm: China committed to increasing its purchases of agricultural products, while the U.S. eased certain technological restrictions. These concessions, however, were partial, fragile, and essentially tactical.

Both sides prioritized a zero-sum logic. A strategic environment dominated by distrust obstructed the emergence of substantive cooperation. The absence of credible verification mechanisms, discursive rigidity, and strategic opacity severely constrained the generation of shared value. The integrative approach remained subordinated to the logic of power in a deeply geopolitical scenario.

Constructivism: National Identities, Narratives, and Conflict Legitimation

Constructivism, as articulated by Alexander Wendt (1999), introduces a vital dimension: the social construction of state identity and the performative function of discourse. According to this perspective, state actions are shaped by how countries define their roles within the international system through symbols, narratives, and shared imaginaries.

For China, the conflict aligns with the narrative of "national rejuvenation" promoted by Xi Jinping, which rejects any form of subordination to the Western order. The U.S.-imposed restrictions were interpreted as a civilizational threat. The defense of Huawei gained symbolic value as an expression of technological sovereignty and national pride.

On the U.S. side, the "America First" discourse reactivated an identity rooted in industrial self-sufficiency, distrust of authoritarian powers, and nostalgia for unquestioned hegemony. The clash reflected antagonistic worldviews. This identity dimension hardened positions and deepened polarization, blocking the emergence of a diplomatically viable solution for both sides.

Cognitive Psychology and Game Theory: Strategic Biases and Perception Traps

Insights from cognitive psychology and game theory help explain how cognitive biases and commitment strategies distort decision-making in highly uncertain contexts. According to Schelling (1960), negotiations function as strategic games where actors attempt to influence each other through credible threats and calculated signals.

Throughout the conflict, both actors committed perceptual errors: they overestimated their capacity to withstand economic harm, underestimated domestic political costs, and misinterpreted signals from the opposing side. These patterns are consistent with the studies of Kahneman and Tversky (1979) on the "illusion of control" and the "availability heuristic," which show how pressure disrupts strategic rationality.

The result was an escalation in which concessions were perceived as weakness and threats as demonstrations of strength. Negotiations became a hall of mirrors, where misperceptions fueled mutual distrust. This dynamic reinforced the conflict, further deteriorating global economic stability.

The U.S.–China Trade Conflict through the Lens of Complexity Science

This trade conflict transcends the boundaries of a bilateral dispute over tariffs or trade imbalances. It constitutes a systemic phenomenon characterized by multiple levels of interaction, irregular feedback loops, unpredictable emergent behaviors, and high sensitivity to initial conditions. Analyzing it through the lens of complexity science allows for moving beyond dichotomous narratives by articulating a perspective that integrates actors, processes, and structures in constant transformation.

Complexity science, particularly through the thermodynamics of far-from-equilibrium systems developed by Prigogine and Stengers in 1984, offers valuable conceptual tools to understand how localized disturbances in one subsystem can produce disproportionate effects across the whole. Within this framework, the trade conflict displays features of a dissipative structure. Its evolution unfolds far from any stable equilibrium through bifurcations, successive reorganizations, and feedback patterns that reshape the global system.

Every decision made by the United States or China such as imposing tariffs or enforcing technological restrictions triggered strategic responses that altered bilateral relations, reconfigured global supply chains, generated alternative geoeconomic alignments, and impacted distant markets. China's response included measures such as retaliatory tariffs, import diversification, regional alliance strengthening, strategic investments in sectors like artificial intelligence, advanced telecommunications, and sustainable energy, along with a determined push toward technological self-reliance.

This dynamic confirms the thesis proposed by Holland in 1995: complex adaptive systems learn, transform, and coevolve with their environments. The negotiations evolved through sequences marked by advances, stalemates, and mutual adjustments. The interaction between the involved parties produced effects across strategic, discursive, and cognitive dimensions, giving rise to emergent trajectories that defy traditional analytical frameworks.

Emergence, Feedback, and Reconfiguration

In complex systems, emergence refers to the phenomenon whereby behavioral patterns arise from interactions among components based on their frequency, intensity, and configuration without directly deriving from individual properties. In the case of the U.S.–China conflict, this dynamic gave rise to outcomes that exceeded initial projections, such as new diplomatic realignments, the creation of parallel technological standards, and intensified nationalist discourse in both countries.

China leveraged this context as momentum to enhance its strategic autonomy by significantly increasing investment in basic science, promoting synergies between public and private sectors, and consolidating alliances with emerging economies. These responses emerged as dynamic adaptations to systemic disruptions, rather than as products of pre-established central planning.

The technological restrictions imposed by the United States spurred the accelerated development of domestic solutions within China's innovation system. The containment strategy inadvertently fostered favorable conditions for the endogenous consolidation of strategic capabilities. This process generated intensified feedback: every decision by one actor amplified the other's response, producing unforeseen effects even for those who crafted the original measures.

Interdependence, Networks, and Systemic Sensitivity

One of the core contributions of Complex Thinking is its emphasis on interconnected networks. Donella Meadows, in 2008, explains that complex systems operate through interdependent nodes that generate global patterns. The trade conflict between the United States and China exposed the structural fragility of the international system in the face of disruptions to strategic flows of electronic components, critical minerals, agricultural products, and global supply chains.

The interdependence between both powers extends across cross-border investments, intellectual property, digital platforms, scientific mobility, and financial flows. This dense web of ties turns each decision into an action with multiple ripple effects. China's suspension of agricultural imports impacted rural economies in the U.S. The exclusion of Chinese tech firms from stock markets altered international portfolios. Restrictions imposed on corporations like Huawei shifted the balance of the global digital ecosystem.

To grasp this dynamic, it is essential to consider intermediary actors such as transnational corporations, multilateral institutions, regional governments, and economic blocs. This distributed configuration makes every negotiation a multilevel process whose effects are amplified or dampened depending on the underlying relational architecture.

Adaptability constitutes an essential property of complex systems. Under high-conflict scenarios, this capacity manifests in the reformulation of strategies, the redesign of action repertoires, and the generation of resilient responses to changing conditions. The trade agreement signed in January 2020, known as Phase One, embodied one such form of adaptability. Although limited in scope, it introduced concessions designed to reorganize interaction conditions and reduce system entropy.

These agreements produce moments of stabilization that reconfigure the conflict landscape without closing off its deeper dynamics. Complex Thinking proposes flexible regulatory strategies that maintain constructive tensions without triggering systemic breakdowns.

In 2005, Morin asserted that the challenge lies in learning to coexist with contradiction. This notion calls for the design of open, adaptive organizations capable of accommodating plurality without disintegration. Dialogical spaces, even when fragile, act as tension-release mechanisms in environments exposed to multiple pressures.

Complexity science emphasizes that in systems with high interactive density, accurate forecasting becomes impossible. The U.S.–China conflict illustrates this structural uncertainty. Every decision triggers chains of unintended consequences, magnified by variable conditions and multiple actors.

Herbert Simon, in 1996, noted that decisions in complex contexts emerge from bounded rationalities, partial cognitive structures, and dynamic environments. Actions taken by political leaders, financial institutions, regulatory agencies, and corporate conglomerates are based on incomplete information, under temporal pressure, and within unstable contexts.

Early forecasts predicted a swift resolution of the conflict. Its prolonged persistence revealed a systemic architecture shaped by structural ambiguity. Strategic rationality led to a dynamic with no clear or consistent resolution. Morin, in 2015, reminds us that to understand is never to anticipate. Intelligence rests on continuous epistemic vigilance, without pretensions of total control.

Complex Thinking articulates multiple levels without diluting their specificity. It proposes a critical epistemology that links economics, geopolitics, technology, culture, and subjectivity through an integrative lens that resists arbitrary segmentation.

In contrast to traditional negotiation frameworks focused on fixed positions and quantifiable outcomes complex diplomacy introduces categories such as coevolution, distributed governance, and relational rationality. Rather than rigid oppositions, it envisions spiral dynamics where actors learn, transform, and reframe their strategies.

This approach demands a transformation of existing diplomatic instruments. What is needed are platforms for plural participation, adaptive conflict-resolution methods, strategies of collective intelligence, and validation of diverse forms of knowledge. Morin argues that complexity is not simply a theoretical framework but a profound transformation of thought.

Critical Synthesis and Analytical Projection

The trade conflict between the United States and China transcends reciprocal tariffs and technological disputes. It constitutes a process of systemic reconfiguration that signals the exhaustion of the international order centered on Western hegemony, while simultaneously giving rise to new power geometries, emergent institutional structures, and renewed forms of legitimacy.

This phenomenon demands epistemic approaches capable of integrating multiple dimensions and overcoming frameworks that fragment global interdependence. At stake is the redefinition of the rules, actors, and values that shape the dynamics of the twenty-first century.

From the standpoint of complex thought, this conflict constitutes a multidimensional network in which economic rationalities, geopolitical dynamics, cultural configurations, technological innovation processes, and diverse cognitive frameworks converge.

Unlike traditional approaches in international relations centered on national interest or the accumulative logic of power a complex perspective captures the simultaneity of scales, temporalities, and rationalities in tension. The conflict between the United States and China must be understood as a living system in continuous transformation that exceeds conventional interpretive frameworks.

The analysis through the main theories of international negotiation such as realism, liberal institutionalism, constructivism, game theory, cognitive psychology, and integrative negotiation shows that none of these perspectives offers a sufficient explanation on its own.

Each framework contributes relevant dimensions: realism emphasizes structural competition, liberal institutionalism highlights the stabilizing role of shared rules, constructivism analyzes identities and narratives, psychological perspectives account for perceptual biases, game theory provides strategic interaction models, and integrative negotiation proposes the creation of shared value amid difference.

Interpretive density arises from their transdisciplinary articulation. Complex rationality, as formulated by Morin in 2005, integrates these paradigms within a dialogical logic that allows one to think through their tensions without seeking reductive syntheses. This mode of thinking embraces contradiction as a structural condition of reality and advocates for an approach that combines without confusing, integrates without homogenizing.

One persistent structural trap in the conflict was its framing within an exclusive-sum logic. The prevailing belief was that any gain by one party necessarily entailed loss for the other. This binary rationality deeply rooted in security doctrines and deterministic views of geopolitics blocked the emergence of conditions for a transformative negotiation. The confrontation itself reinforced threat-based narratives and legitimized institutional practices grounded in mistrust. The conflict was shaped as a symbolic and strategic feedback loop that consolidated its own conditions of possibility.

Complex Thinking dismantles the logic of the exclusive sum by demonstrating that in interdependent systems, unilateral gains are illusory. In a context characterized by global supply chains, integrated finance, transnational digital infrastructures, and shared crises in climate, health, and energy, no actor can ensure its own security or well-being by provoking the collapse of another. Protectionist policies and technological sanctions affected China but also impacted U.S. industrial, agricultural, and technological sectors, as well as multiple intermediary actors exposed to cross-cutting externalities.

An adaptive feedback loop emerges from this interaction, in which each move generates reverberations that overflow the original goals. The conflict functions as an accelerator of structural transformation, driven less by deliberate design than by collateral effects and spontaneous reorganizations of the system.

The weakening of multilateral organizations such as the World Trade Organization, the International Monetary Fund, or the G20 during this episode revealed the fragility of the liberal order that emerged after 1945. The replacement of multilateral instances by bilateral or coercive strategies marked a deep mutation in the forms of international governance.

Hegemony ceased to be articulated through exclusive institutional leadership and began to unfold through the design of parallel architectures, such as the Regional Comprehensive Economic Partnership, the Shanghai Cooperation Organization, or emerging frameworks of digital regulation.

From a complexity perspective, this transformation can be understood as a phase of conflictual coexistence between divergent institutional models. Power configurations take on a polycentric character, norms are negotiated across multiple scales, and legitimacy shifts from normative universality to relational effectiveness. Global governance becomes a contested space for emerging powers, regional alliances, and hybrid actors with agency in state, corporate, and technological spheres.

The trade conflict also expressed a struggle over meaning. The United States framed its narrative around the defense of national security, the protection of jobs, and the restoration of its industrial primacy. China, in contrast, constructed a discourse centered on civilizational rejuvenation, technological sovereignty, and the affirmation of global multipolarity. These representations produced conflicting political identities that narrowed the scope for diplomatic maneuvering.

Complex Thinking incorporates this symbolic dimension by recognizing the role of discourses, representations, and collective imaginaries in shaping international scenarios. The trade war constituted a discursive confrontation aimed at contesting the legitimacy of alternative models of development, cooperation, and governance.

Complex Diplomacy and Institutional Coevolution

Within this context, traditional diplomacy proves insufficient. The complexity-based approach proposes a relational diplomacy oriented toward institutional coevolution, the creation of shared deliberative spaces, and the design of flexible mechanisms for conflict management. The goal is to generate conditions that allow tensions to be processed without leading to systemic collapse.

This requires platforms for multilevel interaction, the inclusion of both state and non-state actors, and normative frameworks capable of integrating uncertainty as a constitutive dimension. Diplomacy extends beyond ministries of foreign affairs and formal treaties. It reaches into networks of scientific cooperation, technological consortia, universities, non-governmental organizations, regional bodies, and globally connected social movements. It thus becomes a process of collective construction of governance within radically complex scenarios.

The conflict highlights the urgency of a second-generation political science, capable of operating with nonlinear logics, multiple levels of analysis, and heterogeneous rationalities. This complex political science dispenses with universal laws. Instead, it develops interpretive frameworks that guide action in dynamic, ambiguous, and evolving environments. Its rigor is grounded in contextual, transdisciplinary, and transformation-oriented foundations.

Complex Thinking enables the articulation of understanding and action. In a volatile, uncertain, complex, and ambiguous (VUCA) reality, strategic intelligence is built upon adaptive capacities, continuous institutional learning, and rigorous epistemic vigilance.

Complex Awareness for an Interdependent World

The trade conflict between the United States and China defies any interpretation that reduces it to an isolated event or a situation resolvable through specific treaties or governmental changes. It constitutes the clearest expression of an ongoing civilizational mutation in which the foundations of the international system are being reconfigured.

The tension between these powers reflects the collision of divergent geostrategic interests, competing epistemic models, incompatible rationalities, and institutional architectures that fall short of addressing a global reality marked by deepening interdependence, structural instability, and high-complexity dynamics.

In this context, Complex Thinking as advanced by Edgar Morin and various developments in the sciences of complexity ceases to occupy a marginal place within theoretical discourse. It becomes an epistemological and ethical necessity for interpreting and transforming a world defined by persistent uncertainty, multiscale interrelations, feedback dynamics, and the structural coexistence of systemic tensions.

Transcending the Illusion of Control: Toward a Second-Order Rationality

International decision-making has long been governed by a first-order instrumental rationality grounded in predictability, linearity, and the maximization of interests under assumptions of control and stability. Contemporary conflicts, such as the one between the United States and China, exceed this simplifying logic.

The emergence of unforeseen variables, cascading effects, resistance to stable patterns, and the multiplicity of scales weaken the foundations of any strategy rooted in analytical fragmentation. In the face of this complexity, Complex Thinking proposes a second-order rationality one that is reflexive about its own limits and capable of engaging with uncertainty, contradiction, and emergent phenomena.

This approach avoids treating knowledge as absolute, conceiving it instead as a situated, dynamic, and relational process. Action within open systems requires continuous learning, contextual sensitivity, and sustained interpretive openness.

Complex Consciousness: An Ecology of Thought

To speak of complex consciousness is to propose a shift in mental and cultural states. It entails conceiving thought as a system composed of notions, perceptions, emotions, and cognitive structures in constant interaction. This consciousness integrates without confusing, distinguishes without dividing, and articulates without reducing. It begins with the premise that every social or political phenomenon involves material, symbolic, historical, and relational dimensions that demand multiple approaches and open categories.

In a globalized and unequal world technologically advanced, ecologically degraded, interconnected, and cognitively fragmented complex consciousness becomes a necessary condition for collective lucidity. In contrast to discourses built on simplification whether populist, technocratic, or fundamentalist it proposes an ethics of active doubt, a politics of intercultural dialogue, and an epistemology of entanglement.

Governance, Cooperation, and Diplomacy in a Complexity-Based Framework

The conflict between the United States and China exposed the obsolescence of many traditional tools of diplomacy and international governance. Multilateral mechanisms proved too slow and rigid given the pace of geoeconomic tensions. Aggressive bilateralism intensified confrontation without addressing its structural causes. Win-lose formulas resulted in mutual losses and significant impacts on third-party countries and sectors far removed from governmental domains.

A complexity-based diplomacy is grounded in the construction of shared meanings and coevolutionary relationships. It requires redesigning international interaction platforms to include states, corporations, universities, civil society organizations, Indigenous peoples, and hybrid actors within the digital ecosystem.

Diplomacy ceases to function as an exclusive instrument of state power and becomes a multiscalar practice aimed at managing the commons in scenarios marked by legitimate disagreement and persistent conflict.

International cooperation takes on a strategic role: building institutional sustainability, generating adaptive trust, and developing collective cognitive infrastructures. This involves sharing data, establishing compatible ethical frameworks, and designing protocols capable of responding to systemic complexity. In this context, complex consciousness becomes an indispensable operational condition for governing global systems under increasing risk.

Complexity and Action: The Art of Intervening Without Fragmenting

The frequent critique that complexity fails to translate into concrete action stems from a reductionist misreading. Complexity reshapes the way intervention is conceived. Rather than acting upon closed models or univocal projections, it operates through open hypotheses, constant monitoring, and transdisciplinary deliberation.

This approach requires accepting provisional and context-specific solutions. The effects of a policy can never be fully anticipated, yet they can be observed, analyzed, and learned from. Decision-making incorporates dynamic modeling, scenario analysis, and simulations to accompany transformation processes.

In practice, this leads to the design of modular, adaptive, and experimental policies closer to prototypes than to definitive plans. Decision centers function as spaces for active listening, plural dialogue, and collective learning. This logic configures an experimental mode of governance, where error becomes a valuable source of information, strategic adjustment, and continuous improvement.

Complex Ethics: Responsibility, Relationality, and Not-Knowing

Complex consciousness also expresses a profoundly relational ethic. It acknowledges the radical interdependence among actors, systems, and temporalities. Responsibility expands beyond direct actions to include collateral effects, invisible externalities, and amplified consequences within densely connected networks.

This ethic demands cognitive humility, epistemic vigilance, and a willingness to relinquish the illusion of absolute control as a foundation of legitimacy. It requires openness to marginalized knowledge, diverse perspectives, and insights excluded from dominant frameworks. Complexity fosters the decolonization of thought and the plural recognition of epistemologies oriented toward imagining horizons of justice and sustainability.

Constructing a complex consciousness demands a deep transformation of thought. This transformation extends beyond political or academic elites. It must permeate educational systems, institutional languages, and communication media. An education grounded in complexity cultivates navigational abilities, critical thinking, systemic reading, transdisciplinary connection, and openness to uncertainty.

Forming citizenship in this century entails replacing control logic with a pedagogy of care, the obsession with certainty with an ethic of inquiry, and the exaltation of individualism with an ecology of relationality. More than merely delivering content about complexity, it means creating cognitive ecosystems where people experience the entanglement of knowledge, emotion, and context.

The conflict between the United States and China reveals structural challenges: ecological transformation, technological acceleration, health fragility, forced human displacement, and a crisis of shared meaning. Each phenomenon demands integrative thinking capable of weaving together diverse scales without reducing their specificity.

Technological decoupling may be seen as a strategic issue, yet it also opens space for developing shared digital sovereignties, plural standards, and collaborative systems. Solutions are constructed through the epistemic frameworks that shape our view of the world.

Complex consciousness informs decisions. It enables the evaluation of implications, recognition of interdependencies, and construction of options that integrate ethics, context, and lucidity. It serves as a cognitive compass amid civilizational transformations.

Embracing complexity is a political decision grounded in a commitment to life, plurality, and sustainability. In a reality marked by cascading crises and unforeseen effects, understanding becomes a form of active resistance, and acting with purpose becomes a heightened expression of responsibility.

The conflict between the United States and China signals a structural transformation in motion. More than a contest for power, it challenges how conflict, cooperation, and possible futures are conceived. Within this frame, complex consciousness moves beyond theory and asserts itself as an operational condition for sustaining shared viability.

Complexity enables us to navigate conflict with lucidity, strategic intelligence, and an ethic of interdependence. To understand in uncertain times is an act of resistance against fragmentation. To act with meaning amid transformation affirms life as a common purpose.

Chapter 7

International Negotiation on Environmental and Biodiversity Issues from a Complexity Perspective

International Negotiation on Environmental and Biodiversity Issues from a Complexity Perspective

In the contemporary global arena, the environmental crisis and the accelerated loss of biodiversity represent priority systemic challenges. The magnitude and cross-cutting nature of interrelated phenomena such as climate change, deforestation, ocean acidification, and habitat fragmentation overwhelm traditional analytical approaches. Linear, simplistic, or sectoral frameworks prove insufficient and epistemologically inadequate. The complexity of ecological, political, economic, and cultural interweaving's demands a rationality capable of integrating the diversity of variables involved and their interactions, characterized by the absence of linearity.

In this context, the complex thinking of Edgar Morin and the sciences of complexity introduce a decisive epistemological shift (Morin, 2005). Their approach goes beyond merely adding elements; it seeks to rethink the connections between them, acknowledging interdependencies, recursive loops, and emergent dynamics that shape global environmental problems.

This shift moves from a causal and mechanistic vision toward an integrative and transdisciplinary understanding that embraces uncertainty, multidimensionality, and the absence of linearity as inherent features of socio-ecological systems.

International negotiations related to the environment and biodiversity unfold within this structural complexity. Far from being a purely technical or diplomatic exercise, they involve a multiplicity of actors including states, multilateral organizations, transnational corporations, local communities, Indigenous peoples, governmental and civil society organizations, scientific networks, and climate activists who operate under diverse normative frameworks, often with conflicting interests and marked asymmetries of power.

These actors interact outside equilibrium conditions, within a global system in transformation, marked by multiple crises and increasing planetary interdependence. From this perspective, environmental governance is no longer a technical option but assumes the status of a civilizational imperative. The ability to articulate collective responses to environmental degradation and biodiversity loss constitutes one of the central axes of humanity's shared future.

Consequently, international negotiation must be understood as a dynamic, open, and adaptive process, far from being confined to the aggregation of national interests. It demands the co-construction of meaning, negotiation of values, generation of mutual trust, and articulation of diverse bodies of knowledge.

International agreements on biodiversity such as the Convention on Biological Diversity, the Nagoya Protocol, and the Aichi Targets reveal both progress and limitations of traditional negotiation models. These agreements have established global normative frameworks, promoted technical cooperation, and mobilized resources, yet they also show structural difficulties in effective implementation: lack of political will, uneven institutional capacities among countries, North-South tensions, and fragile monitoring and enforcement mechanisms.

This scenario calls for a theoretical approach capable of transcending the rationalist and realist frameworks prevalent in international relations. Game theory, liberal institutionalism, and constructivism offer valuable tools, though limited when analyzed in isolation. In contrast, the sciences of complexity enable a reconceptualization of international negotiation as a complex adaptive system, where outcomes no longer derive linearly from initial intentions but emerge from the interaction of multiple variables in contexts of high uncertainty.

Within this framework, it becomes essential to incorporate concepts such as self-organization, nonlinearity, emergence, positive and negative feedback, and systemic resilience. Negotiation processes, for example, display bifurcation points where minimal variations produce significant changes in the trajectory of agreements. Similarly, dynamics of trust or mistrust among actors can reinforce and amplify themselves, directly affecting the viability of the commitments made. These dynamics elude the explanatory capacity of linear or deterministic models.

From the standpoint of complex thought, it is crucial to acknowledge the plurality of rationalities at play. Negotiations involve heterogeneous actors who interpret problems through divergent worldviews, value systems, and strategic priorities. This epistemological and cultural diversity constitutes a structural condition of international dialogue and should in no way be perceived as an obstacle. The construction of agreements therefore demands the creation of spaces for intercultural translation, plural deliberation, and mutual learning.

This approach seeks to articulate classical theoretical frameworks of international negotiation with the contributions of Complex Thinking to offer a more robust and critical understanding of the mechanisms shaping global environmental governance. Specifically, theories such as bounded rationality, integrative negotiation, the transformative approach, and the theory of complex adaptive systems will be examined in relation to environmental and biodiversity agreements.

The role of international institutions, particularly the United Nations and its specialized agencies, will also be analyzed with regard to the development of environmental cooperation frameworks, along with the challenges involved in effective implementation of agreements, such as the mobilization of financial resources, accountability mechanisms, and participatory monitoring.

Key actor dynamics will be explored with emphasis on tensions between the Global North and South, the relevance of traditional knowledge systems, and the urgency of fostering a polycentric, inclusive, and adaptive model of governance.

Integrating the complexity perspective enriches academic analysis and offers more effective guidance for political and diplomatic action. Conceiving environmental negotiations as nonlinear, interdependent processes subject to the emergence of unforeseen dynamics requires a reconfiguration of intervention strategies, shifting from prescriptive approaches to adaptive models that acknowledge contingency, ongoing evolution, and the imperative of continuous learning.

Theories of International Environmental Negotiation

International environmental negotiation transcends transactional logic between States. It constitutes a complex arena where strategic interests, normative regimes, diverse rationalities, and symbolic disputes converge. Traditionally, international relations theory has approached these processes through three primary frameworks: realism, institutional liberalism, and constructivism. In light of the multicausal and nonlinear dynamics of contemporary ecological crises, these approaches require reinterpretation through a transdisciplinary logic that incorporates the epistemology of complexity.

Realism: Sovereignty, Power, and Geostrategic Calculation

Realism assumes that States, operating in an international system lacking a central authority, prioritize autonomy and survival (Morgenthau, 1948; Waltz, 1979). Environmental negotiations are thus interpreted as strategies aimed at minimizing costs and preserving the status quo, rather than as commitments oriented toward the common good. This perspective helps explain why major powers condition their participation in environmental agreements on the behavior of other influential actors.

The dynamics among the United States, China, and India directly shape the pace and ambition of multilateral negotiations. The principle of "common but differentiated responsibilities," formulated at the 1992 Rio Conference, reflects this logic as a pragmatic concession to historical emission imbalances and is often invoked to limit the scope of binding commitments.

Realism also reveals the limits of normative idealism in contexts defined by competition over strategic resources. Factors such as energy security, access to clean technologies, and positioning within global value chains directly influence foreign environmental policy decisions. This approach, however, shows analytical limitations in addressing the rise of new agendas, the growing protagonism of diverse actors, and the progressive transformation of international normative frameworks.

Institutional Liberalism: Multilateral Governance and Technical Cooperation

From the perspective of institutional liberalism, environmental cooperation becomes viable when institutions are able to reduce uncertainty, regulate interactions, and establish shared incentives, as theorized by Keohane (1984) and Nye (2001).

This framework has been central to understanding the formation of international regimes such as the United Nations Framework Convention on Climate Change and the Convention on Biological Diversity agreements that have institutionalized standards, financial mechanisms, and global monitoring systems.

The 2015 Paris Agreement exemplifies this logic through an institutional design based on nationally determined contributions, periodic reviews, transparency mechanisms, and climate finance. Its architecture combines normative flexibility with outcome-oriented requirements and creates spaces for the participation of multiple actors, allowing for differentiated adjustments according to national contexts.

Nevertheless, this approach tends to obscure the structural asymmetries embedded in the international system. The costs associated with climate adaptation and mitigation vary substantially across countries, as do their institutional capacities. The influence of corporations on multilateral bodies and the subordination of environmental agendas to financial or extractive interests undermine the notion of technical and neutral governance.

Liberal logic remains effective in scenarios where cooperation unfolds progressively, but it loses traction in the face of phenomena that manifest systemic collapse or fundamental disputes over the global development model.

Constructivism: Subjectivities, Norms, and Cultural Disputes

Constructivism introduces a central dimension: interests are shaped through ideas, norms, and identities (Wendt, 1999). Environmental negotiations function as arenas where definitions of what constitutes a problem, the values that guide collective action, and the actors deemed legitimate to influence global governance are constantly redefined.

This approach enables the identification of emerging normative principles such as climate justice, intergenerational equity, and the rights of nature. It also facilitates an understanding of how traditional knowledge systems, youth demands, and Indigenous claims are integrated into the institutional design of multilateral agreements. The Nagoya Protocol (2010) exemplifies this orientation by establishing fair access to the benefits derived from the use of genetic resources as a collective right of the communities that safeguard them.

From this perspective, dominant discourses such as sustainable development, resilience, or climate neutrality are socially constructed and subject to processes of appropriation or reinterpretation. Constructivism provides analytical tools to understand the dynamics of legitimation, symbolic contestation, and identity transformation that shape both States and transnational networks of activism, scientific production, and organized civil society.

However, this approach tends to downplay the material and institutional constraints that limit the effective implementation of normative principles. Discursive performativity alone lacks the capacity to produce redistribution or structural transformation of dominant productive and energy models.

Epistemology of Complexity: Articulating Rationalities and Levels of Analysis

Each theoretical framework offers valuable insights into the phenomenon from its particular lens. Rather than selecting one over another, Complex Thinking proposes an epistemological articulation that connects strategic, institutional, and symbolic levels as interdependent expressions of a dynamic and multiscale system (Morin, 2005).

From this standpoint, international environmental negotiation is understood as a complex adaptive system, where decisions emerge from interactions among structural factors, contextual constraints, and historical contingencies. Linear causality is replaced by feedback loops, emergent dynamics, and processes that evolve through cycles of learning and continuous transformation.

Complex rationality repositions classical approaches within a transdisciplinary logic. Realism contributes essential elements on power dynamics. Liberalism elucidates institutional design and its incentives. Constructivism highlights struggles over meaning, the shaping of political subjectivities, and normative transformations. Integrating these perspectives enables the construction of more nuanced interpretations that are sensitive to uncertainty, rational diversity, and actor plurality.

This approach transcends dualisms. The boundary between State and society becomes blurred. The divide between strategic calculation and ethical horizon is addressed as a constitutive tension. Structures are interpreted as evolving environments of possibility, and agency acquires meaning in relation to the cultural, ecological, and technological conditions that shape it.

Within this framework, international negotiations function as arenas of institutional coevolution, intercultural coordination, and political experimentation. They are dynamic processes in permanent adjustment, where agreements result from evolving balances among interests, values, and diverse knowledge systems. Approaching them through Complex Thinking is a necessary condition for engaging lucidly in an interconnected, uncertain, and civilizational shifting world.

Milestones in International Environmental and Biodiversity Negotiations: Key Agreements

The trajectory of global environmental diplomacy reflects a progressive process toward institutionalized forms of planetary governance. Over the past five decades, various summits and multilateral conferences have produced foundational agreements that constitute an increasingly sophisticated normative and institutional framework. This process reveals both meaningful progress and persistent structural tensions within the architecture of the international system.

United Nations Conference on the Human Environment (Stockholm, 1972)

This event formally inaugurated the environmental agenda within the realm of global diplomacy. For the first time, the environment was recognized as an issue of planetary scope, transcending national jurisdictions. The final declaration articulated fundamental principles concerning the interrelation between human development and ecological stewardship, emphasizing the notion of shared but differentiated responsibility among nations.

Among its main contributions was the establishment of the United Nations Environment Programme (UNEP), an entity tasked with coordinating global efforts and producing periodic environmental assessments. This conference laid the conceptual foundations for future negotiations by asserting that processes of ecological degradation structurally constrain the conditions for development, particularly in historically excluded contexts.

Earth Summit (Rio de Janeiro, 1992)

The United Nations Conference on Environment and Development (UNCED), widely known as the Earth Summit, represented a defining milestone. This gathering led to the adoption of three key instruments:

Agenda 21, conceived as a comprehensive action plan for transitioning toward a sustainable development model encompassing economic, social, and ecological dimensions.

The United Nations Framework Convention on Climate Change (UNFCCC), which became the core platform for future negotiations aimed at reducing greenhouse gas emissions.

The Convention on Biological Diversity (CBD), designed to conserve the planet's biological diversity, promote its sustainable use, and ensure the fair distribution of benefits derived from genetic resources.

The Earth Summit elevated the global relevance of the principle of common but differentiated responsibilities (CBDR), referring to structural inequalities in both the historical generation of ecological impacts and the institutional and technological capacities available to address them. This principle linked environmental justice with geopolitical asymmetries, shaping a normative architecture that remains contested to this day.

Kyoto Protocol (1997)

As the first legally binding instrument arising from the UNFCCC, the Kyoto Protocol marked a turning point by defining mandatory emission reduction targets for industrialized countries, grounded in their historical responsibility for greenhouse gas accumulation. Its design introduced market-based mechanisms, including emissions trading and the Clean Development Mechanism, to provide flexibility through investments in mitigation projects in the Global South.

Its overall impact was limited by the withdrawal of influential actors and the absence of commitments for emerging economies with high emission levels. These omissions raised concerns regarding its distributive legitimacy and structural effectiveness.

World Summit on Sustainable Development (Johannesburg, 2002)

Held a decade after the Rio Summit, this gathering sought to reinvigorate international commitments by articulating social justice, equitable access to resources, and ecological sustainability.

Although it did not produce new binding treaties, it consolidated an integrated agenda in which environmental stewardship is recognized as a constitutive dimension of human development and a condition for long-term economic viability.

This summit reflected a shift from a vision focused exclusively on ecosystem protection to an understanding that connects poverty, inequality, and environmental degradation as interdependent phenomena.

Nagoya Protocol (2010)
Framed within the Convention on Biological Diversity, the Nagoya Protocol institutionalized the rights of megadiverse countries, local communities, and Indigenous peoples over their genetic resources and traditional knowledge. Its main objective is to correct historical imbalances that enabled extractive bioprospecting practices, by requiring prior informed consent and mutually agreed terms for access and benefit-sharing.

From a complexity perspective, this treaty transforms traditional conceptions of knowledge and biodiversity by incorporating legal, ethical, and epistemic criteria that make visible the plurality of rationalities involved in global environmental governance.

Paris Agreement on Climate Change (2015)
Adopted by 196 parties at COP21, this agreement established the goal of limiting the global average temperature increase to below two degrees Celsius, while pursuing efforts to restrict it to 1.5 degrees above pre-industrial levels. Unlike the Kyoto Protocol, the Paris Agreement is based on voluntary commitments presented as Nationally Determined Contributions (NDCs), subject to periodic updates.

This flexible architecture responds to criticisms of earlier models, whose rigidity generated exclusions and political deadlocks. The agreement signals a transition toward a polycentric, adaptive, and relational form of governance aligned with the principles of complex systems. Its implementation demands closing gaps in financing, technical capacities, and the distribution of responsibilities in terms of climate justice.

United Nations Decade on Ecosystem Restoration (2021–2030)
Launched in response to the degradation of planetary ecosystems, this global initiative aims to restore at least 350 million hectares of degraded land by 2030, generating significant environmental, social, and economic benefits. Its implementation involves multiple actors: governments, multilateral agencies, business sectors, local communities, and scientific networks.

From the standpoint of complex thought, this decade represents a shift: the focus moves from the conservation of pristine spaces to the active regeneration of human-impacted ecosystems. It acknowledges the co-evolutionary capacity of human communities and their fundamental role in reconfiguring the relationships between culture, nature, and sustainability.

Critical Assessment and Emerging Challenges

Despite institutional and normative advances, the effectiveness of international environmental agreements remains controversial. A persistent gap exists between stated commitments and effective transformations, alongside the unequal capacity of countries to implement agreed decisions. The co-optation of multilateral processes by corporate interests, the progressive weakening of multilateralism, and the rise of discourses that undermine scientific evidence constitute significant barriers. From a complexity perspective, these tensions reflect the structural limitations of an environmental governance model that still operates with fragmented, predictive, and linear logics. Prevailing modes of intervention neglect the interdependence of systems, the emergent nature of ecological processes, and the epistemic volatility that characterizes the global context.

Environmental agreements require transformations deeper than the mere accumulation of clauses. A redefinition of the relationships between knowledge, power, and collective action is imperative, grounded in transdisciplinary articulation and epistemic pluralism. This task calls for abandoning the incremental paradigm in favor of new forms of political, ethical, and cognitive rationality capable of embracing the diversity of actors, scales, and temporalities that structure socio-ecological systems. From this horizon, environmental negotiation is conceived as an evolutionary process that generates relational institutions, shared learning dynamics, and deliberative practices aimed at shaping scenarios of planetary viability.

Environmental Governance through the Lens of Complexity

Global environmental governance, shaped by uncertainty, interdependence, and accelerated transformation, demands an epistemological shift. Complex thought, developed by Edgar Morin alongside the sciences of complexity, goes beyond criticizing reductionist approaches by proposing new ways of understanding, intervening, and connecting knowledge with systemic phenomena.

Its application to international biodiversity negotiations enables the transcendence of linear analytical frameworks and embraces the evolutionary and unpredictable nature of multilateral processes.

Complex Thinking does not merely identify multiple factors it articulates their relationships and incorporates uncertainty, contradiction, and multicausality as constitutive elements of knowledge. Morin (2005) asserts that to understand is to contextualize, globalize, and interrelate. Knowledge is constructed through the integration of a living, unstable, and transformable organized whole. This perspective is essential when addressing environmental challenges where ecological, social, political, and economic variables interact in intertwined and recursive ways.

Complex Systems and Emergent Relationships

In the sphere of international negotiations, this articulation is crucial. Decisions must be evaluated based on their capacity to foster ecosystem regeneration and environmental justice across multiple scales. State logic and institutional frameworks are integrated as components within broader relational processes.

The sciences of complexity enrich this perspective by analyzing systems composed of interrelated elements whose interactions generate emergent behaviors that cannot be reduced to their parts. This logic manifests in biological ecosystems, social structures, cooperation networks, and climate governance platforms.

Within these systems, relationships express unstable behaviors far removed from linearity. Minimal variations can produce disproportionate effects, while larger disruptions may be absorbed through resilience mechanisms. Environmental negotiations operate within this logic. Their outcomes emerge from historical, political, and symbolic interactions among diverse actors.

Open Trajectories and Institutional Learning

In contrast to deterministic approaches, Complex Thinking conceives of institutional trajectories as open-ended. Environmental negotiations are structured through feedback processes in which each decision transforms the very conditions of the process. A partial agreement may trigger synergies that foster new consensuses or block them by exacerbating imbalances or undermining trust.

The most significant environmental agreements emerge during moments of convergence between social pressure, ecological crisis, and strategic realignment. This emergent logic requires abandoning static models and adopting approaches centered on adaptability, institutional resilience, and continuous learning.

Multiscalarity and Relational Rationality

One of the core contributions of Complex Thinking lies in its capacity to interpret phenomena across multiple scales. The global affects the local, and the local reshapes the global. Biodiversity loss in a tropical forest impacts the communities who inhabit it, alters the planetary climate, compromises food security, and modifies biogeochemical cycles. This interdependence calls for decisions articulated at different levels, respecting territorial specificities while acknowledging systemic connections.

Complexity does not represent a technical sophistication. A complex approach entails adopting a relational, situated, and transdisciplinary rationality capable of integrating diverse forms of knowledge, asynchronous temporalities, and heterogeneous actors.

Institutional Transformation and Planetary Consciousness

Applying Complex Thinking to international negotiation shifts the focus from immediate outcomes to processes of sustained institutional transformation. In complex systems, stability depends on the capacity to learn, reorganize, and adapt to changing environments. This learning spans technical, political, cultural, and ethical dimensions.

Rather than establishing rigid normative frameworks, environmental negotiations are conceived as processes that integrate iterative evaluation, periodic review, deliberate inclusion, and collective learning. Institutions are understood as living systems endowed with regenerative capacities in constantly evolving ecological and social contexts.

The environmental crisis reflects a crisis of thought. The fragmentation of knowledge, hyper-specialization, and reductionist approaches have constrained the understanding of complex global problems. Complex Thinking proposes an alternative rationality that redefines the relationship between science, politics, and life. Incorporating this rationality into environmental diplomacy entails revising content, reformulating procedures, and re-signifying languages and frameworks of meaning. It involves replacing the logic of control with that of care, calculation with cooperation, and short-term interest with planetary responsibility.

Biodiversity and Living Systems: A Complex Vision of Ecological Challenges

Biodiversity transcends the mere sum of species. It is a dynamic manifestation of living systems in continuous interaction. From the perspective of complex thought, ecosystems are no longer seen as stable structures but as webs of relationships in constant transformation. Ecological functions such as climate regulation, soil fertility, and hydrological balance emerge from multiple interactions governed by nonlinear dynamics. The loss of biological diversity qualitatively alters the planet's self-organizing and resilient capacities.

Biodiversity degradation must be understood in relation to other planetary crises. Accelerated species extinction, habitat fragmentation, and genetic homogenization arise from the same civilizational logic that drives climate change, food insecurity, and the spread of zoonotic diseases. These manifestations stem from an unbalanced civilizational model rooted in the domination of life.

From the complex perspective, these collapses express fractures in our relationship with life. Biodiversity ceases to be viewed as a manageable resource and is instead recognized as a fundamental condition for existence. Its deterioration reduces the potential for continuity of life across biological, cultural, epistemic, and symbolic dimensions.

Biogeochemical cycles such as carbon, nitrogen, and phosphorus illustrate the systemic interdependence that sustains life. Their disruption, caused by human practices like industrial agriculture, mining, and fossil fuel extraction, triggers far-reaching effects. These transformations simultaneously alter biodiversity, climate, human health, and governance structures.

Understanding these processes requires the integration of diverse spatial and temporal scales. Local interventions generate global consequences. Effective responses emerge from territorial articulations built upon specific ecological and cultural conditions.

The Complex Approach: Emerging, Situated, and Co-evolutionary Responses to the Biodiversity Crisis

The complex approach invites the construction of emerging, situated, and co-evolutionary responses to the biodiversity crisis. This perspective challenges models that insist on fixed targets or idealized forms of restoration. Flexible strategies are required ones that acknowledge the irreversibility of certain processes, the structural nature of uncertainty, and the urgent need to regenerate conditions for habitability.

Ecological restoration is redefined as an ongoing relational process between human societies and living systems. The United Nations Decade on Ecosystem Restoration promotes this transition by shifting the focus from conserving the untouched to fostering active regeneration, in which communities play a fundamental role in co-evolution with their environments.

The complexity of socio-ecological systems demands distributed governance grounded in networks of cooperation among diverse actors. Local communities, Indigenous peoples, public authorities, civil society organizations, and productive sectors collaboratively develop diagnostics, goals, and forms of collective action.

This logic is reflected in frameworks such as the Nagoya Protocol, which recognizes collective rights over traditional knowledge and genetic resources. Beyond its normative function, this instrument represents a conceptual transformation wherein biodiversity is conceived as a relational fabric of vital reciprocities.

The creation of territorial cooperation networks makes it possible to connect scales, integrate ancestral and scientific knowledge, and foster lifeways tied to ecosystems. These practices reinforce an ecological rationality oriented toward care, interdependence, and mutual recognition among living forms.

Approaching biodiversity through Complex Thinking entails an epistemological and ethical transformation. Protecting biological diversity requires reconstructing the conditions that make life possible. This transformation challenges resource-centered approaches and proposes a vision of existence grounded in relationships and cohabitation.

This transition also calls into question dominant notions of development, progress, and security that have historically justified systemic forms of biological destruction. Complex Thinking opens space for new questions, new forms of interpretation, and new relationships. It functions as a compass for navigating a present shaped by uncertainty and for imagining futures grounded in regeneration, justice, and sustainability.

Complex Dynamics and Structural Challenges in International Biodiversity Negotiations

International negotiations on biodiversity unfold within a dense web of multiscale interactions. Agreements are shaped through dynamic processes of adjustment, confrontation, and institutional transformation. Overcoming conventional analytical limitations requires recognizing that the primary challenges stem from entrenched structural imbalances rather than mere circumstantial divergences among actors.

One of the most critical factors is the deep asymmetry between states. Disparities in technological capacity, financial resources, scientific infrastructure, and regulatory robustness create unequal conditions for engaging in negotiations, proposing solutions, or fulfilling commitments. Regions with high levels of biological diversity often overlap with territories historically subjected to extractive dynamics, geopolitical marginalization, and economic subordination.

From this perspective, the demands of the Global South regarding access to benefits derived from genetic resources and climate financing are grounded in historical trajectories of dispossession. The evasive stances of certain Northern countries toward concrete obligations or substantive resource transfers reflect a broader dispute over global environmental justice.

These inequalities are compounded by corporate interests in multilateral negotiations. Transnational companies associated with extractive, agri-food, or biotechnological industries exert direct influence on state positions. Such interference is channeled through favorable regulatory frameworks, conditional financing, and active participation in technical platforms.

As a result, objectives aimed at conservation and equity are often displaced by logics of profitability. This distortion widens the gap between what is formally agreed upon and what is actually implemented. The legitimacy of multilateral frameworks is weakened by a fragmented institutional architecture and by the distrust generated by limited outcomes.

Even in cases where ambitious commitments are reached, implementation faces persistent barriers. Legal provisions often lack robust enforcement mechanisms. Clauses are ambiguous or open to multiple interpretations. Political will is shaped by shifting domestic contexts and budgetary constraints.

The current structure of international environmental governance continues to rely on voluntary agreements. Shared targets are projected without sufficient material backing or the technical infrastructure required for their realization. This situation produces institutional fragility in scenarios marked by economic crises, political polarization, or nationalist retrenchment.

Planetary goals such as restoring strategic ecosystems or protecting significant portions of territory face a disjunction between the scale of their aspirations and the means available for their execution. This gap reveals a structural contradiction that can only be resolved by transforming the framework through which global biodiversity policies are conceived and managed.

Environmental Negotiation as a Complex Adaptive System

Framing environmental negotiation as a complex adaptive system fundamentally reshapes both its interpretation and practical orientation. In such systems, actors operate from variable interests and contingent trajectories that are continuously redefined through interaction, feedback, and institutional reorganization within dynamic settings (Holland, 1995).

Negotiations evolve through cycles marked by rupture, learning, and reconfiguration. The Paris Agreement, reached in 2015, emerged after the exhaustion of the Kyoto regime, a realignment of geopolitical forces, and mounting global social pressure. This logic calls for structures capable of responding to shifting conditions, sensitive to initial configurations, and able to accommodate transformations that alter the rules of the game.

Applying this understanding requires the establishment of guiding principles for designing and operating within multilateral contexts:

• Material and cognitive interdependence. Ecological consequences transcend borders, scales, and legal frameworks. Local decisions impact global structures, while global dynamics require territorial grounding.

- Institutional adaptability. Legal and political frameworks must incorporate mechanisms for learning and reorganization. Negotiation architectures must evolve in response to emerging scenarios.

- Deliberative multi-actor inclusion. Local communities, Indigenous peoples, scientific networks, and civil society organizations must participate as actors with epistemic voice and decision-making capacity. Diversity strengthens the process and expands the range of alternatives.

- Recognition of critical thresholds. Ecological, social, and political tipping points should be viewed as signals of normative reconfiguration. Identifying such moments opens space for institutional innovation.

- Ethics of uncertainty. In unpredictable contexts, a logic grounded in care, co-responsibility, and critical vigilance is prioritized over exhaustive control or standardized responses.

The most transformative multilateral agreements in recent years such as the Kigali Amendment or the Kunming-Montreal Global Biodiversity Framework emerged from structurally unstable situations. These agreements were catalyzed by the convergence of social mobilization, scientific evidence, and cultural awareness rather than by routine technical-administrative procedures. Their value lies in having sparked unprecedented institutional arrangements. The capacity of these processes to integrate new forms of articulation, responsibility-sharing, and epistemic recognition shaped arenas of genuine diplomatic innovation.

Environmental diplomacy gains vitality when it loosens rigid structures, when it is organized around dynamic principles, and when it incorporates diverse actors with complementary perspectives. What drives its effectiveness is the system's openness to emergent trajectories and novel forms of legitimacy.

Towards a Resilient and Transformative Environmental Governance

The challenge of contemporary environmental diplomacy lies less in the legal drafting of complex treaties and more in the construction of resilient governance systems. This demands adaptive capacity in the face of uncertainty, integration of diverse knowledge systems, and anticipation of ecological and social disruptions.

Advancing toward ecological and social effectiveness requires shifting the focus from interstate legality to forms of governance that are polycentric, intercultural, and regenerative. From this perspective, resilience is not merely a technical attribute but a political, ethical, and cultural capacity to sustain life amid ongoing transformation.

The transition to a complex environmental diplomacy extends beyond technical or epistemological frameworks. It involves a deeply political transformation shaped by power relations, colonial legacies, and civilizational dilemmas. Within this framework, ethics becomes a structural dimension of diplomatic processes: it defines the common good, recognizes otherness, and redistributes historical responsibilities.

A complex ethics avoids homogeneous principles or abstract prescriptions. It unfolds as the capacity to hold tensions between conflicting interests, incommensurable scales, and divergent temporalities. As Edgar Morin (1999) asserts, such ethics inhabits contradiction lucidly, recognizing that every environmental decision simultaneously demands the preservation of ecosystems, the promotion of social justice, respect for cultural diversity, and anticipation of viable futures.

From this standpoint, environmental diplomacy requires political sensitivity to the structural injustices experienced by sacrificed territories, the systematic exclusion of subalternized knowledge systems, and the burden of intergenerational ecological debt. The task is not merely to redistribute burdens or resources, but to reconstruct the conditions of legitimacy for multilateral dialogue based on principles of reparation, recognition, and shared responsibility.

Emerging Planetary Governance: Toward a Polycentric Diplomacy

The architecture of environmental diplomacy based exclusively on interstate models has been surpassed by the magnitude and complexity of the global ecological crisis. The traditional notion of national sovereignty as the sole axis of decision-making proves insufficient in the face of phenomena that demand coordinated responses across multiple levels.

This gives rise to the need for polycentric and rhizomatic governance, in which state and social actors converge, regional and transnational platforms operate in tandem, and formal legal agreements coexist with experimental arrangements. Such governance decentralizes the state and redefines sovereignty in terms of systemic interdependence.

Examples such as the IPCC, subnational networks like C40 Cities, and corporate initiatives aligned with climate metrics (e.g., Science Based Targets) reveal a progressive reorganization of authority and legitimacy. These processes are structured through flows of knowledge, affect, and multiple forms of validation, within arenas marked by persistent asymmetries and dynamic conflicts.

The political challenge surpasses the effectiveness of responses and shifts toward their procedural legitimacy: who decides, based on whose knowledge, and through what mechanisms of accountability and epistemic justice? A complex environmental diplomacy embraces these questions as foundational conditions for democratic sustainability at the planetary scale.

Complex Indicators for Evaluating Environmental Negotiations

Evaluating the effectiveness of environmental negotiations from a complexity perspective requires moving beyond quantitative fetishism and designing tools capable of capturing qualitative transformations, emerging relationships, and institutional co-evolutionary processes. Rather than relying solely on conventional indicators such as conservation target compliance or emission reductions there is a need to incorporate analytical dimensions that reflect the actual dynamics of multilateral processes.

- Institutional Learning Indicators. These indicators identify transformations in the capacity of actors to interpret their environments, revise strategies, and adapt to dynamic contexts. They are reflected in the reconfiguration of narratives, the adoption of innovative regulatory frameworks, and the integration of failures as inputs for political redesign.

- Trans-scalar Interaction Indicators. These evaluate the quality of connections across different levels of decision-making and the coherence between diverse regulatory frameworks. They measure the extent to which environmental policies succeed in articulating from the local to the global, and how these interactions manage tensions and generate effective synergies.

- Epistemic Inclusion Indicators. These measure the substantive recognition of alternative knowledge systems such as ancestral, community-based, feminist, or technical perspectives in decision-making. Beyond formal inclusion, these indicators capture the degree to which such perspectives effectively influence resulting institutional frameworks.

- Normative Innovation Indicators. These identify deep transformations in legal or institutional frameworks. They are expressed in the emergence of novel conceptual principles, such as recognizing nature as a subject of rights or incorporating intergenerational care as a foundation for political action.

- Structural Resilience Indicators. These analyze the negotiation system's capacity to adapt, reorganize, and maintain functionality under disruption.

> These indicators relate to actor and institutional diversity, the equitable distribution of adaptive capacities, and the legitimacy of processes in contexts of high uncertainty.

The development of these types of indicators requires qualitative, interpretive, and participatory methodological approaches. They must emerge from collaborative processes among diverse actors, be developed in situated contexts, and be grounded in principles of critical reflexivity and epistemic justice.

Conflict as a Vector of Systemic Transformation

From a complexity perspective, conflict constitutes a generative force intrinsic to living systems. Environmental arenas bring together territorial interests, divergent worldviews, incompatible economic models, and ethical-ecological commitments in tension. Rather than signaling dysfunction, these elements reveal the dynamic, mutable, and relational nature of ecological-political systems.

Over recent decades, significant advances in environmental policy have emerged from moments of institutional friction and social contestation. Legal actions led by affected communities, mobilizations against extractive megaprojects, demands over the appropriation of ancestral knowledge, and diplomatic clashes around climate justice all illustrate how episodes of tension generate normative openings and discursive reorganizations.

Managing conflict through the lens of complexity involves creating deliberative spaces where deep-seated tensions become drivers of institutional innovation. Negotiation is understood as a process of collective creation in which difference, rather than being neutralized, contributes to the construction of new interpretive frameworks, normative arrangements, and strategic alliances.

In this context, the role of the negotiator is redefined as an agent capable of facilitating improbable connections, identifying emergent meanings, and synchronizing heterogeneous temporalities. This role requires narrative sensitivity, an understanding of historical trajectories, and an ethical disposition grounded in care, reciprocity, and transformative openness.

Environmental negotiations express sociopolitical processes in constant reorganization. The interaction between global ecological pressures, concrete territorial demands, and histories of exclusion gives rise to change dynamics that cannot be reduced to linear sequences. Complex thought, together with the sciences of complexity, makes it possible to apprehend this movement through a systemic, transdisciplinary, and situated perspective.

From this viewpoint, diplomatic processes are defined as relational entanglements, where multiple decisions, shifting contextual conditions, and contested power structures converge. This relational density transcends the one-dimensional explanations offered by realism, liberalism, or constructivism and enables a richer understanding of the factors at play.

Contemporary environmental diplomacy requires a multiscalar disposition and an inter-actor praxis that incorporates diverse knowledge systems. Governments, local communities, Indigenous peoples, scientific collectives, social movements, and business networks co-create strategies, values, and transformative horizons. This relational plurality is anchored in an ethic that acknowledges the fragility of ecosystems, the complexity of identities, and the urgency of responding through collaborative and sustainable frameworks.

The value of a diplomatic process transcends its formal outcomes. What matters most is its capacity to generate normative reorganizations, inter-institutional learning, and regenerative cooperation circuits. In this regard, traditional indicators prove insufficient. Assessing the transformative potential of a process requires observing the quality of its relationships, the openness of its languages, and the depth of the commitments it mobilizes.

Decision-making processes, the actors involved, the interpretive frameworks legitimizing agreements, and the structural impacts they unleash all gain prominence. This shift towards valuing the process itself makes it possible to recognize conflict as a source of political creativity, emotions as catalysts of change, and shared imaginaries as symbolic anchors of the emerging future.

In this context, Complex Thinking operates as a tool for intervention. Its relational and evolutionary approach enables operational methodologies to map actors, identify transformation thresholds, articulate heterogeneous knowledges, and design deliberative dynamics that are open, experimental, and regenerative.

Rather than offering fixed solutions, the task is to open horizons of possibility. What is urgent is the construction of conditions that allow situated, ethical, and resilient responses to emerge in a world marked by profound and unpredictable transformations. Within this horizon, environmental negotiation is embraced as a living practice of institutional co-evolution, political imagination, and collective care for life.

Complexity as a Compass for the Uncertain

Environmental diplomacy, inspired by complex thought, requires moving beyond rigid normative frameworks, repetitive procedures, and stagnant institutional architectures. In their place, open, resilient, and just processes must emerge capable of incorporating the world's pluralism and the density of socioecological conflicts.

In the face of highly complex challenges, simplified responses lose transformative efficacy. A relational, ethical, and situated orientation becomes imperative one that enables understanding without reduction, action without imposition, and deliberation without foreclosing possibilities.

Diplomatic practice grounded in this perspective privileges the regeneration of bonds, the deliberative articulation of diverse actors, and the construction of legitimacy woven through mutual recognition, difference as creative power, and care as a structuring principle.

Complexity provides a framework for inhabiting uncertainty with lucidity. It allows for sustaining tensions, integrating multiple knowledges, and tracing open-ended trajectories of collective learning. Along this path, conflict becomes a transformative force, dissent a possibility for reconfiguration, and diplomatic action an ethical exercise in planetary co-evolution.

Approaching environmental diplomacy from the standpoint of complexity demands a transformation of both conceptual frameworks and institutional practices. It requires redefining the role of the negotiator, the procedures of dialogue, and the architecture of decision-making. The following strategic guidelines are directed toward negotiators, advisors, and multilateral policy designers committed to action grounded in the logic of complexity.

1. Replace zero-sum logic with plural rationalities. Competitive negotiation frameworks limit the sustainability of agreements. It is essential to design systemic co-benefit frameworks that align environmental, social, and economic interests. Cooperation becomes a strategic imperative for managing planetary commons.

2. Map networks, actors, and narratives. Before initiating any negotiation process, it is crucial to map the ecosystem of actors involved considering institutional power, symbolic density, epistemic influence, and mobilization capacity. Including Indigenous communities, territorial collectives, social organizations, and committed scientific and business sectors enables the construction of representative and resilient agendas.

3. Cultivate sensitivity to ecological and social thresholds. A perceptive negotiator identifies inflection points and anticipates scenarios of vulnerability. Environmental diplomacy requires action proportionate to the alerts of living systems, guided by ethical responsibility and transformative effectiveness.

4. Design open, iterative, and adaptive processes. In dynamic contexts, stable solutions lack efficacy. Negotiations must be conceived as evolving trajectories, responsive to emerging evidence, social pressures, or institutional shifts. Operational flexibility ensures viability amid change.

5. Foster collective learning. Complex diplomacy creates spaces for exchange among diverse knowledges, situated perspectives, and plural strategies. Such learning is built through active listening, intercultural translation, and co-creation of knowledge overcoming disciplinary, sectoral, and jurisdictional fragmentation.

6. Integrate systems and foresight analysis tools. The negotiator's methodological toolkit includes simulations, network analysis, controversy mapping, narrative scenario construction, and participatory methodologies. These tools help trace trajectories, anticipate blockages, and activate strategic reconfigurations.

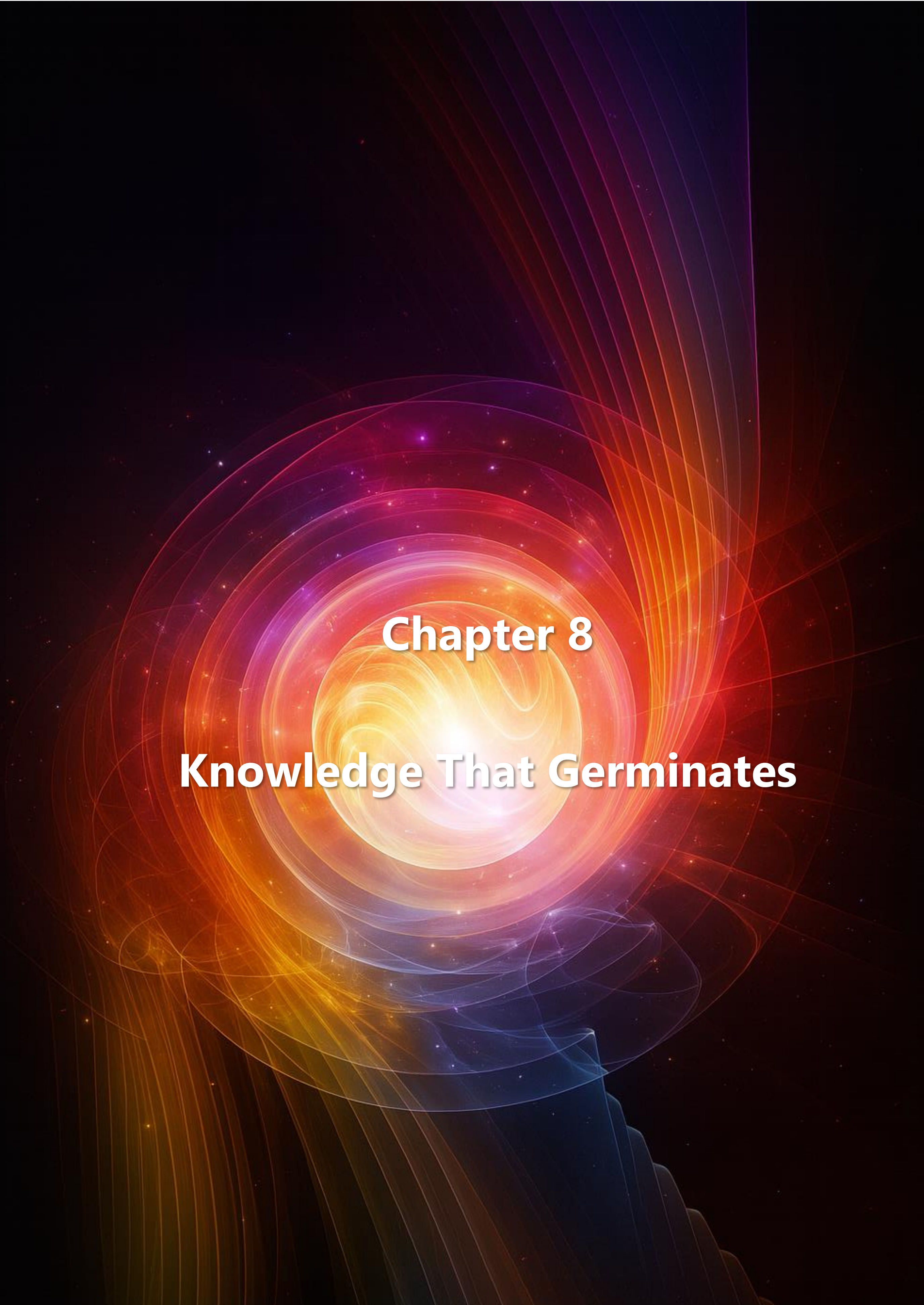
7. Act from uncertainty as a creative stimulus. Uncertainty is embraced as a constitutive dimension of the process. Rather than seeking total control, an experimental logic is cultivated based on feedback loops, situated learning, and reflexive decision-making. This approach strengthens adaptive and innovative capacity.

8. Repoliticize without paralysis. Conflict offers constitutive energy to the diplomatic system. Embracing it as a generative condition enables the

activation of fertile tensions. Disputes surrounding environmental justice are addressed as structural dimensions of multilateral dialogue.

9. Acknowledge the affective dimension of processes. Emotions such as grief, hope, territorial pride, indignation, or love of life function as vectors of meaning and mobilization. Integrating them into diplomatic analysis and action enhances relational sensitivity and strengthens the transformative legitimacy of the process.

10. Promote an eco-reflexive and ethical diplomacy. The complex paradigm calls for an ethics grounded in planetary solidarity, differentiated responsibility, and epistemic humility. Diplomatic representation is built from the awareness of inhabiting an interdependent world, where the regeneration of life sustains any civilizational horizon.



Chapter 8

Knowledge That Germinates

Knowledge That Germinates

Complexity, Resistance, and Critique of Technocracy

Throughout the twentieth century and with greater intensity in the early decades of the twenty-first the global development imaginary has been sustained by an unshakable confidence in technical-scientific rationality as the preferred path for addressing humanity's challenges. This confidence crystallized into the technocratic paradigm, grounded in the premise that economic, social, and ecological problems can be solved through objective, neutral, and efficient solutions devised by experts. Ellul (1964) emphasized that this logic exceeds governmental management and shapes a mode of thought that reduces the vital complexity of reality into quantifiable and standardized formulas.

The technocratic paradigm has driven undeniable innovations: intermodal transport networks, robotized hospital infrastructure, and telecommunications that have collapsed planetary distances. At the same time, it reinforces a mechanistic and fragmented view of reality. Morin (2001) warns that specialized technical thinking, focused on efficiency and control, disregards the intricate fabric of socio-ecological phenomena, producing insufficient responses to interdependent challenges such as climate crisis, biodiversity loss, structural inequality, or territorial conflicts. Instrumental logic obscures qualitative dimensions such as subjectivity, affectivity, and meaning, subordinating political deliberation to optimization algorithms presented as neutral.

Against this impoverished horizon, the paradigm of complexity emerges an epistemological and ethical alternative that restores the richness of the real. Inspired by Edgar Morin, Fritjof Capra, Ilya Prigogine, and Gregory Bateson, this approach conceives reality as a web of open, interdependent, and heterogeneous systems characterized by emergence, uncertainty, and self-organization (Capra & Luisi, 2016; Morin, 1999). Unlike the technocratic ideal of total prediction and control, Complex Thinking advocates for inhabiting uncertainty, integrating diverse knowledge systems, and constructing transdisciplinary strategies capable of articulating scales, temporalities, and disciplines. Acknowledging the irreducible heterogeneity of life revitalizes scientific practice through rigorous dialogues with the arts, the humanities, and vernacular knowledge.

In Latin America, the critique of hegemonic technocratic thought is nourished by decolonial, ecological, and feminist perspectives. Leff (2004) identifies techno-economic rationality as an agent of environmental destruction and cultural dispossession, legitimized by the promise of modernization. Sousa Santos (2010) advocates for an epistemology of the South that recognizes peasant,

Indigenous, and popular knowledge as the foundation of an epistemic pluralism with emancipatory potential. Max-Neef (1991) proposes a human-scale economy focused on satisfying fundamental needs within ecological limits, displacing the obsession with unlimited growth. These voices converge with complex thinking by denouncing the commodification of cultural diversity and demanding development models rooted in environmental justice, social participation, and respect for the vital cycles of ecosystems.

This debate takes on particular intensity in the Urabá-Darién region of Colombia, a subregion with one of the greatest biocultural riches on the continent, marked by historical violence, massive displacement, and ongoing territorial disputes. Development policies implemented in recent decades have replicated technocratic logics: large-scale road infrastructure projects, expansion of banana and oil palm monocultures, construction of deep-water ports, and land-use planning designed from decision-making centers disconnected from the territory.

In the name of competitiveness, these initiatives displace local knowledge, undermine community autonomy, and exacerbate ecological impacts. Watersheds are fragmented, humid forests replaced by homogeneous crops, and the land market dismantles ancestral agroecological practices. The promise of formal employment translates into precarious jobs, while available income proves insufficient amid the loss of essential ecosystem functions.

The Technocratic Paradigm and Its Limits in Subregional Contexts

Technocracy places technology at the center as the dominant mediator in the organization of social life. It operates under the assumption that public problems can be addressed through scientific procedures guided by criteria of efficiency, objectivity, and neutrality. Its fragility becomes especially evident in contexts marked by uncertainty, persistent conflict, and emerging dynamics, where variables act in discontinuous and interdependent ways. By reducing nature to an inventory of resources and communities to homogeneous users, technocratic planning neglects power relations, subterranean memory flows, and ecological networks that transcend conventional frameworks. Standardized indicators obscure inequalities of gender, ethnicity, and generation. Cost audits marginalize intangible dimensions such as care, rootedness, and sense of place. The result is a form of management that imposes rigid infrastructures, lacking the capacity to adapt to climate variability or sociopolitical transformations.

In the Urabá-Darién subregion, this rationality manifested through the implementation of the Autopista al Mar (Highway to the Sea), the port of Tribugá, and the expansion of oil palm monocultures as symbols of progress. These decisions were legitimized while disregarding the ecological value of mangroves, the functionality of jaguar corridors, and the strategic role of Afro-descendant collective territories in shaping the landscape. Technical standardization ignored the region's ethnic plurality, where Emberá, Gunadule, and peasant communities coexist and are organized at multiple scales. Environmental impact studies were limited to applying risk matrices and excluded processes of cultural significance: river funerals, harvest songs, foundational narratives that sustain local cosmologies. The enclave model transferred benefits to large corporations while dispersing ecological costs and disarticulating reciprocity networks essential for food security and social cohesion.

Technocracy, by severing the connection between economy and ecology, externalizes harms that return as unforeseen consequences: sterile soils, cyclical flooding, polluting emissions, and territorial tensions that feed into dynamics of violence and displacement. In its pursuit of precision, accounting rationality overlooks the complexity of the systems it claims to manage. Algorithms designed to optimize routes cannot restore destroyed wetlands or heal fractured communities. Recognizing this paradox is essential to open pathways toward alternatives where environmental justice, human dignity, and technological prudence operate as interwoven principles. Without this integration, the pursuit of efficiency ultimately undermines the very foundations of resilience it claims to protect.

The paradigm of complexity offers an epistemological and political pathway in response to these limitations. It replaces the aspiration for total control with a situated practice of knowledge dialogue and adaptive governance. As Morin suggests, to know is to organize, and every form of organization is grounded in ethical decisions subject to critical scrutiny. A complex perspective acknowledges the inseparability of systems and posits the need to comprehend the whole without erasing singularity. Prigogine demonstrated that systems far from equilibrium tend to generate novel forms of order. Under this logic, public policy ceases to impose definitive structures and instead orients itself toward reversible experimentation and collective learning. Incorporating feedback cycles, contextual monitoring mechanisms, and deliberative practices transforms uncertainty into a source of shared institutional innovation.

Complexity as a Lens for Regenerative Transitions in the Urabá-Darién Region

For the Urabá-Darién region, adopting this perspective entails mapping feedback loops among agrarian policies, migratory flows, hydrological dynamics, and collective memory. It requires understanding that mangroves buffer storms, that diversified agroforestry systems preserve soil and sequester carbon, and that traditional forest uses regulate water availability and mitigate zoonotic risks. Recognizing these interdependencies enables the design of adaptive management strategies grounded in scenario planning, critical thresholds, and early warning mechanisms. In this way, governance evolves in synchrony with the ecosystem and the aspirations of the communities inhabiting it.

A complex reading of the economy displaces the obsession with perpetual growth and centers on ecosystem regeneration. Raworth proposes the doughnut model: an economy that operates between a safe environmental ceiling and a just social foundation. Kauffman suggests that innovation emerges at the edge of chaos, where diversity fosters unexpected solutions. These approaches resonate with existing practices in the Urabá-Darién, such as agroecology, artisanal fishing, and community-based tourism. By combining well-being metrics with indicators of ecological resilience, economic surplus becomes a resource to restore biological corridors, implement participatory sanitation plans, and strengthen bilingual education programs with an intercultural focus. Prosperity is measured through indicators of territorial health and relational fulfillment, beyond production volume or monetary income.

Advancing toward regeneration demands moving beyond expertocracy and fostering the co-production of knowledge. Participatory action research and community monitoring contribute to building robust data while simultaneously enhancing local capacities. Modeling developed with communities supported by remote sensing and cultural mapping facilitates the exploration of alternative scenarios and informed decision-making. By weaving school and territory together, these processes cultivate ecosystem literacy and reinforce a sense of shared responsibility.

To embrace complexity is to coexist with uncertainty and respond through transformative action. Rather than promising universal solutions designed in distant centers of power, the complex paradigm proposes situated, adaptive, and deliberative processes. In Urabá-Darién, this translates into regenerative economies, shared governance, and decolonial pedagogies that honor the diversity of life.

Nurturing these knowledges constitutes a form of resistance and a promise for the future: sowing today the collective intelligence necessary to flourish tomorrow on a finite planet. Paradigm shifts occur when cultural, ecological, and cognitive conditions mature. The current task lies in accompanying that transformation toward more just, plural, and resilient realities. This transition is already underway.

The global ecological crisis, along with persistent inequalities, reveals the exhaustion of an economic model disconnected from the planet's biophysical limits and the sociocultural conditions of territories. Amid this progressive collapse, inclusive regenerative economics emerges as a proposal aimed at restoring ecosystems, strengthening community ties, and fostering territorial equity. Unlike extractive models focused on perpetual expansion, this alternative is grounded in diversity, cooperation, and ecosocial reciprocity.

Rooted in complexity, the regenerative approach moves away from linear and prescriptive frameworks. From this perspective, economic systems are understood as subsystems intertwined with broader ecological systems. To regenerate means to rebuild social bonds, revalue place-based knowledge, and consolidate local autonomy. This holistic vision holds that each territory is a living system with specific dynamics that must be interpreted from within, through relational logics that transcend any reductive reading.

Foundations of an Inclusive Regenerative Economy

A regenerative economy is guided by the resilience of living systems as its structural principle, displacing the primacy of technical efficiency. As proposed by Fullerton, Mang, and Haggard, this approach draws from ecological principles such as the circularity of flows, continuous adaptive capacity, and dynamic interdependence. It promotes the closure of energy and material cycles, development rooted in place, and planning that respects ecosystem boundaries as long-term guiding criteria.

This perspective encompasses both ecosystem health and cultural revitalization, along with the creation of conditions for the economic self-determination of communities. Unlike the conventional concept of sustainability, often co-opted by technocratic approaches, regenerative economics is grounded in a deep critique of the dominant paradigm. It advances a praxis in which care, shared responsibility, and ecosocial diversity constitute essential foundations.

The Urabá-Darién as a Field of Complex Regeneration

The Urabá-Darién region of Colombia, a territory of high biocultural richness and geopolitical significance, stands as a privileged setting for activating regenerative processes through a complex logic. Historical interventions through infrastructure megaprojects, export-oriented crops, and territorial control mechanisms have produced transformations that demand approaches capable of integrating ecological justice, economic sustainability, and ethnic diversity.

In response to the environmental and social deterioration inherited from the extractive model, a territorially grounded regenerative economy activates circular circuits such as agroecology, local bio-industries, and community-based tourism rooted in the cultural heritage of the Atrato River and the banana-growing landscape. These strategies rebuild synergies between culture and nature, generate employment with collective meaning, and re-signify the territory as a shared space and source of life.

Grounded in complex thought, this proposal integrates a fundamental epistemic dimension. It recognizes Indigenous, Afro-descendant, peasant, and popular knowledge as essential pillars of regenerative innovation. Cognitive justice becomes the necessary foundation for fully integrated social and ecological justice. From this perspective, the dialogue between knowledge systems transcends symbolic inclusion. It becomes a structuring process of territorial intelligence that weaves together technical knowledge, lived experience, and collective memory. This requires displacing the logic of isolated experts and promoting spaces of joint creation where communities themselves define regeneration priorities.

An ethics of care emerges as the foundation of a concept of well-being inseparable from ecosystem balance. Following Max-Neef, fundamental human needs such as meaning, affiliation, subsistence, and participation are fulfilled through deep bonds with ecological and cultural contexts. This understanding demands relational economies, attuned to diversity and rooted in territorial realities.

In terms of governance, the regenerative proposal rejects any vertical or universalizing architecture. It advocates planning processes built through direct participation, collective monitoring, and adaptive capacity. Ecological variability, structural uncertainty, and sociocultural plurality demand flexible deliberative frameworks capable of evolving alongside social processes.

The challenge in Urabá-Darién exceeds ecological or economic frameworks. It is a civilizational issue. Abandoning the extractive logics that have fragmented the territory and cultivating, from its roots, an alternative that articulates sustainability, shared meaning, and justice constitutes an urgent task. The complex regenerative economy proposes deeply situated pathways, where regeneration is conceived as a cultural, political, and ethical act.

Advancing in this direction requires strengthening solidarity-based productive networks, revitalizing ancestral languages and worldviews, restoring biological connectivity, and incorporating appropriate technologies in the service of collective well-being. It also involves transforming evaluation criteria: replacing gross domestic product with ecosystem resilience, export volumes with the strength of community networks, and financial profitability with the dignity of inhabiting living, diverse, and sustainable territories.

Regenerative economics proposes a systemic transformation in response to the environmental and social exhaustion of the hegemonic economic model. Its approach seeks to restore ecosystems, strengthen community ties, and reconfigure production through principles of circularity, resilience, and multiscalar cooperation (Fullerton, 2015; Mang & Haggard, 2016). Rather than a normative proposal, it constitutes an adaptive and situated process that emerges from the concrete conditions of each territory.

From the perspective of complex thought, regeneration entails far more than ecological repair. It involves revitalizing entire life systems. This outlook requires a relational approach in which scientific knowledge dialogues with local wisdom, and solutions emerge from the living, contextualized practices of each territory. The proposal transcends traditional dichotomies between economy and ecology, technology and culture, by embracing the constitutive interdependence of nature, society, and politics.

The Colombian Urabá-Darién region marked by exceptional biodiversity and a history of persistent conflict offers a strategic scenario to explore regenerative approaches. Technocratic interventions promoted monocultures, large-scale infrastructures, and production models disconnected from territorial fabric, deepening long-standing social and ecological fractures. A complex lens enables recognition of both the traces of accumulated degradation and the resilient dynamics that arise amid adversity: peasant agroecology, ethno-community governance, and intergenerational practices of care.

In this context, regeneration is conceived as an endogenous process, rooted in trajectories of territorial self-organization, knowledge exchange, and deeply situated ecosocial bonds. This approach shifts the image of Urabá from a space subordinated to external directives to a living system whose transformation requires interpretation of complex interactions, cascading feedback loops, and multiscalar dimensions of meaning and impact.

One of the major challenges in regenerative contexts lies in designing evaluation methods that avoid reductive approaches. From a complex perspective, three heuristic axes can be defined:

- Functional diversity, expressed across biological, productive, organizational, and cultural dimensions. Territories with greater heterogeneity tend to exhibit higher resilience in the face of systemic disturbances.

- Feedback capacity, observable through active participation mechanisms, socio-environmental monitoring systems, and deliberative spaces that enable continuous adjustment of strategies in response to changing conditions.

- Cognitive justice, manifested in the effective integration of multiple knowledge systems across all phases of planning, management, and evaluation. This dimension demands the validation of consultation protocols, the strengthening of designs informed by local epistemologies, and the promotion of intercultural learning processes.

These indicators are constructed in a situated manner. Rather than applying universal standards, they are developed through dialogue with territorial actors, understanding evaluation as a reflexive practice that accompanies ecosocial transformation from within.

Regenerative Experiences in the Urabá-Darién Region

Concrete initiatives are already underway that embody regenerative principles. The APAT Association in Turbo promotes sustainable agroecological practices with a community-based approach. The Community Council of the Cacarica River has consolidated an autonomous governance system that integrates ecological conservation with ethnic justice. In Necoclí, a model of community tourism generates local income while protecting the territory's cultural and ecological integrity.

These experiences, diverse in form and approach, share a common logic: they emerge from within communities, integrate ancestral knowledge, and promote solidarity-based economies. More than replicable formulas, they are living processes that demonstrate how regeneration can be woven through a complex lens. They represent what Boaventura de Sousa Santos describes as "sociologies of emergences": knowledge that germinates under adverse conditions as forms of resistance and collective creation.

The regenerative paradigm faces substantial challenges. Institutional co-optation of its language through hollow environmental discourses can neutralize its transformative force. Additionally, epistemic and organizational plurality often generates internal tensions that must be addressed through sustained intercultural deliberation.

In many regions, material, technical, and political limitations persist, weakening the continuity of such initiatives. Without adequate resources, critical training, and institutional support, these processes remain vulnerable to structural fragility that threatens their sustainability.

Even Complex Thinking demands critical vigilance. Its strength lies in reflexivity the ability to continually revise itself and remain open to creative interaction with other forms of knowledge. Regenerative economics maintains its transformative potential to the extent that it is cultivated as an open, situated, and self-critical process.

Complex thought, in Edgar Morin's formulation, resists closed formulas. It acts as an ethical and epistemic compass that guides navigation through living, interdependent, and unpredictable systems. In territories such as Colombia's Urabá-Darién where structural violence, biocultural wealth, and territorial disputes converge this perspective offers critical insights for reimagining development as a situated process of ecosocial regeneration.

With the institutional appropriation of sustainability, often used to mask extractive logics with environmental rhetoric (Shiva, 2016), regeneration through complexity demands a profound epistemological rupture with the dominant development model. It is not about rebranding the same structure but about redefining criteria of value, agency, and legitimacy. This involves recognizing communities as epistemic subjects capable of creating resilient and desirable ways of life from their own horizons of meaning.

In Urabá-Darién, Complex Thinking destabilizes the hegemonic cartography that portrays the territory as a space available for productive use, ignoring the layers of memory and meaning that give it depth. Port initiatives, logistics corridors, and monoculture zones are legitimized through standardized environmental assessments that overlook cumulative effects and the intricate web of social, ecological, and cultural interdependencies. This practice constitutes a form of epistemic violence that erases the active presence of Black, Indigenous, and peasant territorialities.

Building an inclusive regenerative economy demands methodologies attuned to the complex density of the territory. Socioecological network analysis allows for mapping relationships among water systems, agri-food practices, power structures, and institutional circuits, facilitating the identification of critical points and potential synergies. The reciprocal validation of scientific, technical, and ancestral knowledge becomes a cognitive necessity rather than a symbolic gesture of cultural recognition.

This perspective calls for a transformation of institutional frameworks. Territorial planning, instead of operating from a technical deficit addressed by external experts, must be restructured as a process of epistemic construction that is distributed, situated, and adaptive. Initiatives such as community observatories, participatory research protocols, and local early warning systems help consolidate territorial resilience by strengthening a form of collective intelligence capable of adapting without losing memory or identity.

Within this framework, critical pedagogy becomes central. Inspired by Paulo Freire, regenerative pedagogy activates processes of reflection, memory, and collective projection. In territories such as Urabá, this is expressed in spaces where traditional agricultural knowledge is reconstructed, relationships with nature are re-signified, and decolonized futures are envisioned. Regeneration begins when communities recognize themselves as authors of their own history.

The aesthetic dimension of this process is inescapable. Technical languages, institutional maps, and bureaucratic narratives must be surpassed by storytelling capable of hosting contradictions, emotions, metaphors, and memories. Maps of ancestral land use, oral archives, and community audiovisual productions represent forms of knowledge that re-enchant the connection with the territory and broaden the horizon of what is possible.

Transformation lacks linearity and unfolds amid tensions. Diversity may generate friction, participation may be co-opted, and horizontality may clash with historical inequalities. These paradoxes constitute the very structure of complex rationality. Territorial governance must operate within ambiguity, understanding that order emerges through the negotiation of differences rather than through homogenization.

What is at stake is a dispute over meaning. While technocracy leans toward control and linear forecasting, Complex Thinking proposes a politics of care: care as an epistemic practice, as a redistribution of power to define what matters, and as a reconstitution of the bond between humans and other forms of life. In Urabá-Darién, where dispossession has been systematic, care becomes both a form of resistance and a promise of justice.

The regenerative transition requires a profound transformation in the ways of knowing, planning, and inhabiting territories. In this process, Urabá-Darién ceases to be a passive periphery and emerges as an epistemic and political vanguard.

Recognizing its complexity is the first step toward building, from within, habitable futures.

Translating the principles of an inclusive regenerative economy into effective territorial transformations requires moving beyond normative frameworks through concrete tools. This demands the establishment of operative categories, relevant indicators, and institutional conditions capable of guiding, monitoring, and sustaining ecosocial transitions. In contexts such as Urabá-Darién, these elements must be anchored in the region's specific territorial, relational, and adaptive conditions.

A central category is territorial resilience, understood as the capacity of socioecological systems to adapt to change while preserving their identity. Assessing it requires moving beyond ecological data to also consider community networks, local governance, sustainable productive practices, and levels of social cohesion. Another fundamental principle is cognitive justice, which calls for the integration of Afro-descendant, Indigenous, and peasant knowledge systems as sources of symbolic legitimacy and epistemic foundations for decision-making.

Structural diversity ecological, cultural, organizational, and productive is another essential dimension. Protecting it involves preventing homogeneous economic models from dominating the landscape and displacing multiple forms of life. This demands policies that promote agroecology, artisanal fisheries, solidarity-based economies, and cultural production generated from within communities.

These principles can be articulated through platforms for collaborative innovation. A promising strategy involves the creation of Living Laboratories for Territorial Innovation: spaces where communities, researchers, and policymakers converge to co-create solutions grounded in territorial rootedness. In parallel, Dynamic Biocultural Maps, developed through participatory cartography, oral memory, and geospatial technologies, document territories while activating processes of reappropriation, pedagogy, and collective foresight.

In the face of institutional co-optation risks, it becomes crucial to activate mechanisms of social oversight and environmental justice that reinforce accountability from within the communities. Experiences such as grassroots oversight committees, citizen audits, and participatory monitoring demonstrate that democratizing territorial process surveillance is feasible when there is social organization, access to information, and effective deliberative capacity.

The creation of Regenerative Transition Councils is proposed, with normative and budgetary authority, composed of state, community, academic, and productive sector representatives. These bodies must operate with a logic of multilevel articulation, recognizing that territorial dynamics are shaped by global flows, historical conflicts, and emergent behavioral variables.

A strategic component lies in strengthening deliberative capacities through training mechanisms such as Popular Schools for Regenerative Governance. These spaces blend critical theory, practical experience, and the construction of autonomy, enabling communities to engage in strategic thinking, make informed decisions, and formulate collective alternatives grounded in real-world conditions.

Regeneration also demands focused attention on the material conditions that sustain it. The lack of basic infrastructure such as access to energy, connectivity, and adequate means of mobility undermines the viability of any transformative strategy. Accordingly, the design of adaptive infrastructure is proposed, based on appropriate technologies, decentralized renewable energy systems, sustainable river transport, and open digital platforms managed through community structures.

These infrastructures should be conceived using participatory system modeling tools that allow for anticipating impacts, visualizing interdependencies, and building robust scenarios in highly uncertain contexts. The use of causal maps, dynamic simulations, and multi-actor assessments supports more precise interventions without resorting to analytical simplifications.

In terms of financing, transformative financial mechanisms are required: community-managed revolving funds, locally scaled green bonds, social currencies, and alliances between public institutions and community structures. These strategies must support long-term processes that, while they fall outside conventional profitability metrics, are essential to sustaining life. Wealth must be measured in terms of ecosystem health, the strength of social bonds, and intergenerational equity.

Sustaining these processes also demands a territorial ethical infrastructure composed of mutual trust, shared values, and cultural codes that guide communal life. Regeneration requires respect, reciprocal care, and symbolic processes that restore the ties between body, land, and community.

For this reason, art, memory, and spirituality play a strategic role. Practices such as the rituals of the Cuerpo Territorio collective or the oral archives of Afro-descendant communities must be understood as affective and political technologies. Their presence deepens the meaning of regenerative processes and opens space for imagining futures beyond technical calculation.

Territorial regeneration calls for a living operational architecture that weaves together ecological, cognitive, political, symbolic, and infrastructural dimensions. Meaningful transformations emerge from interconnected strategies developed in close dialogue with the unique dynamics of each territory.

Urabá-Darién stands as a privileged setting for this transition. Its vital force stems from the richness of its memories, the persistence of its struggles, and a creativity that flourishes amid tensions. Complexity, far from being an abstract theory, becomes an indispensable tool for overcoming failed historical patterns. To regenerate is to open oneself to the knowledge of the territory, to listen to the resonances of the land, and to follow the trajectories that communities have long been tracing through their lived experience, their affective strength, and their dignity.

Toward a Regenerative Transition Through Complex Thought

The technocratic paradigm centered on efficiency, quantification, and expertocracy has proven insufficient to address the systemic challenges facing Urabá-Darién. Its fragmented outlook, guided by control and standardization, has rendered invisible the region’s cultural and ecological diversity, exacerbated social tensions, deepened ecosystemic imbalances, and limited the possibilities for building sustainable futures.

Against this logic of simplification, the paradigm of complexity, in the tradition of Edgar Morin, offers an epistemological and political alternative that embraces uncertainty, interdependence, and self-organization as constitutive dimensions of reality.

Throughout this reflection, it has been sustained that an inclusive regenerative economy, understood through the lens of complexity, constitutes an ethical, situated, and transdisciplinary praxis that redefines the economic in terms of sustaining life. Rather than seeking to restore static equilibria, it aims to create vital conditions that enable the articulation of ecological justice, social equity, and territorial autonomy. This orientation opens the possibility for a civilizational transformation that confronts the hegemony of capital, challenges instrumental reason, and displaces the supposed neutrality of dominant knowledge systems.

In Urabá-Darién, this transition becomes both strategic and urgent. For decades, the territory has been subjected to extractive logics that advanced infrastructure megaprojects, industrial monocultures, and energy developments, with direct impacts on ecosystems and communities. These interventions intensified dispossession, fragmented ecological webs, and deepened forms of territorial violence. Yet Urabá also holds generative power, sustained in its biocultural diversity, communal memory, agroecological practices, and forms of social organization, offering fertile ground to imagine and experiment with regenerative pathways.

Thinking through the complexity paradigm demands acknowledging that territories are living systems, woven through ecological relations, historical memory, and multiple forms of knowledge. It becomes unviable, therefore, to plan from centralized schemes or apply unidimensional metrics. Regeneration requires constructing an ecology of knowledges in which ancestral wisdoms, popular practices, scientific insights, and technical tools are articulated without hierarchical imposition. As Boaventura de Sousa Santos argues, social justice can only be achieved through cognitive justice. From this standpoint, peoples are understood as epistemic and political subjects, with full legitimacy to define from their own horizons what must be preserved, cared for, and cultivated.

Adaptive institutions are essential to respond to changing contexts, articulate multiple scales of governance, and act with ecological sensitivity. Their effectiveness depends on transcending bureaucratic rigidity through forms of collaborative, deliberative, and experimental governance that align with the dynamic complexity of territories.

Territorial ethical infrastructure encompasses social norms, bonds of trust, shared values, and commitments that sustain caring relationships between human beings and the living environments they inhabit. This dimension is built through pedagogical processes, symbolic practices, and experiences of coexistence, distancing itself from all forms of standardization or imposed protocols.

Situated planning requires multiscale tools co-created with local actors. Biocultural maps, living laboratories, community alert systems, and participatory observatories are instruments that help visualize interdependencies, anticipate impacts, acknowledge the intangible, and democratize territorial decision-making.

In the financial realm, systems oriented toward regeneration are necessary. Community-managed revolving funds, ethical banks, local green bonds, and social currencies offer viable alternatives to sustain slow processes aimed at resilience rather than immediate profitability.

Complex Thinking calls for abandoning the search for one-size-fits-all solutions. Instead of fixed formulas, it seeks to strengthen the capacity to dwell in uncertainty, think through paradox, and act with critical openness. Regenerative processes unfold through tensions: between speed and depth, between authentic participation and instrumentalization, between legitimate diversity and operational coordination. Embracing these tensions as constitutive elements of a vital political rationality means directing action toward the sustainability of life in all its plurality. To prevent the regenerative paradigm from becoming a discursive repertoire at the service of a greenwashed extractivism, it is essential to establish mechanisms of social oversight, community monitoring, citizen auditing, and epistemic autonomy. Territorial regeneration must be rooted in local contexts, led by those who inhabit them and recognize themselves as political agents of care, meaning, and transformation.

This perspective also reshapes the modes of learning and knowledge production. Universities, research centers, and educational spaces must transcend fragmented, hierarchical, and territory-disconnected logics. A deep curricular transformation calls for integrating systems thinking, participatory methodologies, critical pedagogies, and ties to ecological cycles, local histories, and emancipatory processes. Popular Schools of Regenerative Governance and Territorial Curricula become learning spaces aligned with the living complexity of places, capable of generating cognitive autonomy and transformative action.

All regeneration requires an aesthetic and affective dimension. Sensible narratives, collective imaginaries, symbolic practices, and poetic languages mobilize shared desire, reconfigure the bond with territory, and enable sustained processes. Community documentaries, oral archives, artistic expressions, and territorial rituals serve as symbolic technologies that expand the horizon of the possible. The transition toward an inclusive regenerative economy, through the lens of complexity, involves a profound reconfiguration of how we conceive, plan, and transform the world. Rather than reducing the diversity of reality to closed operational formulas, this path calls for deploying open, relational, and multiscalar architectures that foster regeneration from the innermost layers of each territory.

In this context, Urabá-Darién emerges as a living territory with the capacity to lead this transition. Its transformative potential stems from the vital density it safeguards: deep-rooted memories, diverse knowledges, and insurgent creativity. From this foundation, a complex regenerative economy is propelled as a collective practice that arises amid the remnants of collapse and the active hope of those who cultivate more dignified and habitable futures.

Chapter 9

The Symbolic Contradiction of the Vatican Fumata Signal

The Symbolic Contradiction of the Vatican Fumata Signal

An Ecotheological Analysis through the Lens of Complexity Theory

The twenty-first century places religious institutions at a historical crossroads: preserve the symbolic power of their ancestral rites or radically transform them in response to the ecological and civilizational challenges of the Anthropocene. In this context, the Vatican both a spiritual and geopolitical axis of Catholicism constitutes a central node for examining the tension among the sacred, the ecological, and the complex. This text proposes a critical reassessment of the Vatican Fumata ritual from an ecotheological perspective informed by complexity theory, in dialogue with the principles articulated by Pope Francis in Laudato Si' (Francis, 2015).

The smoke signal emerging from the roof of the Sistine Chapel to announce the election of a new pontiff represents one of the most recognizable liturgical images of contemporary Catholicism. Through a dichotomous visual code, white smoke signifies election, while black smoke signals postponement, condensing a moment of profound spiritual significance. From a critical ecotheological standpoint, this act assumes a paradoxical character. Amid a climate crisis, the ritualized burning of ballots treated with chemical compounds as a sign of transcendence starkly contrasts with the Vatican's denunciation of the technocratic and extractive logics that underpin such practices.

From the perspective of Complex Thinking developed by Edgar Morin (2007), this tension exceeds anecdotal interpretation and reveals profound fractures within the Church's symbolic and institutional system. The smoke ritual belongs to a web of practices, meanings, and organizational structures that interact as an adaptive system. Its analysis demands abandoning linear or reductionist approaches and embracing a systemic lens capable of grasping the multiple feedback loops, bifurcations, and circuits of meaning that shape it.

The contradiction intensifies when considering that Laudato Si' offers a forceful critique of the technocratic paradigm, understood as the belief that technology alone can solve human problems while subordinating ethics, politics, and ecology. From this angle, the smoke ritual reproduces a symbolic logic rooted in industrial modernity: combustion, emission, verticality, spectacle. Its aesthetics evoke the imaginary of the industrial revolution, in open dissonance with the spirit of ecological conversion proclaimed by the Pope.

This tension transcends formal aspects and enters the theological domain. The rite, as a performative act, communicates a message and produces reality: it institutes a worldview, legitimizes an order, and shapes subjectivities. When the liturgical gesture embodies a fossilized form of mediation with the sacred, its persistence diminishes the symbolic plasticity that ecclesial institutions require to respond to the present. Institutional resilience depends largely on their capacity to reconfigure meanings.

From the perspective of autopoietic systems, rituals operate as semiotic configurations that generate meaning within a collective (Luhmann, 1998). When these configurations cease to resonate with their natural, cultural, and spiritual environment, they tend to fossilize. In this sense, the Fumata emerges as a fossilized sign a symbolic form that has lost connection with the ecology of the present.

The critique of the Fumata ritual diverges from any iconoclastic impulse. Its aim is to regenerate the symbolic at its root. The challenge lies in transforming liturgy while preserving its profound meaning, in renewing the sign without emptying its spirituality. The task is to unfold an eco-centric liturgy that embraces the sacred in harmony with ecosystemic principles.

Alternatives exist that preserve the transcendent dimension while engaging in dialogue with the principles of integral ecology. For instance, beams of light projected into the sky, acoustic resonances composed from natural frequencies, or visual codes powered by solar energy offer pathways to reconfigure the ritual through an alliance of technology, aesthetics, and spirituality, without resorting to combustion or polluting emissions.

This symbolic re-signification can be constructed from the foundations of the Christian tradition itself. The Gospels abound in natural imagery: water as a sign of life and purification, wind as an expression of the Spirit, the seed as a promise of transformation, the mountain as a site of revelation. These symbolic forms, far from being poetic embellishments, function as theological vectors capable of reuniting the spiritual with the biological, the rite with the ecosystem, the message with its medium.

It is crucial to recognize the ritual richness of base ecclesial communities, particularly those located in regions of high biodiversity and deep ancestral roots. These communities have woven syncretic liturgical forms deeply attuned to natural cycles, which can inspire a theology of territorial incarnation. Their experience constitutes a valuable reservoir for co-designing symbolic practices that are environmentally sensitive and aligned with the call to ecological conversion.

This process of liturgical innovation requires a participatory methodology grounded in active listening, collective discernment, and contextual creation. Participatory Action Research (PAR) provides a fertile approach for articulating theological insights, ecological knowledge, and community practices in a shared effort to imagine and experiment with new forms of spiritual expression that are both sustainable and deeply meaningful.

Laudato Si’: An Ecotheological Compass for Symbolic Transformation

The encyclical Laudato Si’ represents a doctrinal and pastoral milestone that can guide the process of symbolic re-signification. Its call for an integral ecology interweaving environmental, social, cultural, and spiritual dimensions offers a robust theological and ethical framework for rethinking liturgical practices through a complex lens.

One of its most significant contributions lies in its critique of misguided anthropocentrism, which has legitimized the irresponsible exploitation of natural resources under the logic of unlimited development. Pope Francis proposes replacing this paradigm with a relationship of responsible reciprocity with the world (Francis, 2015), in which human beings recognize their belonging to the web of life through a custodial role, grounded in ecosystemic interdependence. This ontological shift also demands a reconfiguration of the liturgical imaginary, moving from symbols of domination to symbols of communion.

The encyclical emphasizes the importance of ecological education and a spirituality grounded in care. These dimensions must be embodied in concrete practices, coherent ways of life, and transformative forms of celebration. Liturgy, as a space of symbolization and affectivity, can contribute meaningfully to this formative process. A liturgy attuned to integral ecology strengthens communities capable of living an authentic and engaged ecological spirituality.

Revisiting the Vatican Fumata ritual through the lenses of complexity thought and ecotheology is a propositional gesture aimed at symbolic innovation. In the face of planetary urgency, liturgical gestures must reflect a spiritual commitment to the regeneration of the world, moving beyond forms that evoke fossil logics. This horizon gives rise to a performative ecotheology capable of expressing, with aesthetic, spiritual, and political coherence, the ecological transformation demanded by the present historical moment.

Catholic symbolism, with its millenary depth, harbors a latent potential for renewal. Reactivating this potential requires critical will, theological imagination, and openness to inhabit contemporary complexity. From this disposition, it becomes possible to weave together tradition and transformation, faith and ecosystem, the sacred and the urgent.

The encyclical Laudato Si’ (Francis, 2015) constitutes one of the Vatican’s most significant interventions in the field of ecological justice. Through the concept of integral ecology, the Pope articulates a critique of the technocratic paradigm and an exhortation to an ecological conversion that transcends the individual sphere to drive transformations of an economic, cultural, institutional, and spiritual order. The encyclical’s most reiterated maxim, “everything is connected” (Francis, 2015, n. 91), operates as a guiding principle of a relational logic aimed at reconfiguring the human understanding of its interaction with the world.

From a reading informed by critical ecotheology and complexity thinking, the text reveals zones of ambiguity, substantive omissions, and performative contradictions. While it adopts a prophetic tone, Laudato Si’ avoids directly confronting the structural foundations of the modern civilizational model. It denounces the effects of extractivism capitalism such as environmental degradation, social exclusion, and loss of meaning without explicitly naming the system that generates these dynamics. As noted by Leonardo Boff (2014), Vandana Shiva (2020), and Enrique Leff (2021), this omission weakens the political force of the encyclical and reinforces its pastoral rather than transformative character.

One of the document's substantive contributions is the formulation of the concept of integral ecology, which interweaves dimensions traditionally treated as disjointed: the natural environment, human life, social structures, and spirituality. This approach represents an innovation within the Church's magisterium by overcoming the traditional divide between nature and humanity. Even so, the proposal remains incomplete, as it operates within a framework that conceives of Earth as divine creation subordinated to human care. Theological limitations persist that prevent a full embrace of the Earth as a living subject bearing its own rights.

From a more radical perspective, such as that of Shiva (2020), this vision remains captive to a form of functional anthropocentrism: the logic of domination is abandoned, yet the hierarchical position of the human being as the "rational steward" of the world is retained. In contrast, feminist and decolonial ecoethics call for the dismantling of all forms of verticality, recognizing reciprocity, interdependence, and the sacredness of life in all its manifestations. Within this framework, the relationship with nature ceases to be a moral obligation and becomes a mode of embodied, experiential, and relational knowledge.

A major limitation of Laudato Si' is its weak incorporation of an intersectional approach. While the text acknowledges that the poor disproportionately suffer the effects of the ecological crisis, it scarcely addresses how the vectors of gender, race, and class intersect in this context. Peasant, Indigenous, and Afro-descendant women have historically been guardians of ecosystems while also being victims of the devastation wrought by extractivism, agribusiness, and structural violence. The encyclical refers to these actors and their knowledge only tangentially, without incorporating them as epistemic sources or central political subjects.

Shiva (2020) and other ecofeminist thinkers denounce this omission as a manifestation of patriarchal and Eurocentric logics still embedded in institutional discourses. The exclusion of movements committed to global ecological justice such as La Vía Campesina, Indigenous peoples of Abya Yala, and ecofeminist networks reveals a structural imbalance. These collectives have developed theoretical frameworks and practices of resistance with a political depth that surpasses many of the formulations contained in Laudato Si'. The absence of their voices exposes a structural limit: the Church positions itself as a moral authority without fully sharing epistemic power.

Laudato Si' presents a severe critique of the dominant development model by highlighting its predatory logic, ecological unsustainability, and indifference to human suffering. This critique is articulated within an ethical and spiritual register that avoids directly challenging the global capitalist system. According to Enrique Leff (2021), the lack of explicit naming weakens its transformative potential. Rather than advocating for "more human development," what is needed is the dismantling of productivity epistemologies, instrumental rationality, and the systemic commodification of life that underpin contemporary capitalism.

From this perspective, Laudato Si' refrains from advancing toward structural alternatives such as degrowth, economic decolonization, or the restitution of the commons as an organizing principle. Nor does it delve into debates on appropriate technologies, energy transitions, or redistributive policies. Instead, it promotes a shift in values and attitudes through appeals to individual conscience and political will. While meaningful, this orientation proves insufficient in the face of the magnitude of the civilizational crisis.

One of the most widely recognized merits of the encyclical is its proposal of an ecological spirituality, understood as a way of inhabiting the world through gratitude, simplicity, contemplation, and responsibility. This spirituality is presented as an integral response to the crisis, capable of transforming external structures, emotional dispositions, everyday practices, and the relationship with the sacred. Pope Francis calls for a "conversion of the heart" that embraces the radical interdependence among all living beings and fosters a culture of care.

This ethical-spiritual dimension unfolds in an exhortative tone, with limited political articulation. The text addresses individuals and communities yet avoids directly confronting the primary agents responsible for ecological collapse: transnational corporations, financial systems, and geopolitical alliances. Spirituality, as a vector of transformation, demands active politicization. An inner disposition of respect acquires full meaning when embodied in collective strategies of disobedience, organization, and structural reconfiguration. On this plane, the encyclical reveals significant limitations.

Despite its constraints, Laudato Si' offers a conceptual architecture open to reinterpretation from more complex frameworks. Read through the epistemology of complexity (Morin, 2005), it becomes a dynamic textual system that generates diverse resonances depending on the reader. Liberation theologians, Indigenous activists, climate scientists, Afro-descendant communities, ecofeminists, and posthumanist philosophers may find in its pages points of anchorage for critical, situated, and divergent readings.

This polyphonic character is one of the document's most valuable traits and demands a rigorous hermeneutic reading that avoids functionalist simplifications. Laudato Si' stands as a singular piece within the Church's corpus, whose value lies in its capacity for religation in the sense developed by Edgar Morin: an ability to weave together epistemic, ethical, political, and spiritual dimensions that modernity fragmented.

From this vantage point, the encyclical transcends its doctrinal form and becomes a fertile platform for transdisciplinary dialogue. Laudato Si' represents a significant step toward an ecotheology with planetary reach. To respond effectively to the challenges of the Anthropocene, it must be critically contextualized, enriched with historically silenced voices, and connected to concrete territorial struggles.

Its power lies in its heuristic openness rather than in normative closure. A decolonial and complex reading of the text allows for an understanding of ecological conversion as a profound transition linked to structural transformations in the configurations of power, knowledge, and spirituality shaping the contemporary world.

Since its publication in May 2015, the encyclical has had a remarkable impact on the global debate around climate change and environmental justice. Signed by Pope Francis, it revitalizes the Church's social doctrine and positions the Vatican as an influential actor in the ethical, political, and epistemic disputes concerning the planet's future. In a context marked by ecosystemic collapse, ideological polarization, and institutional inertia, Laudato Si' offers a narrative that integrates spirituality, ecology, and social justice into a matrix of common and articulating meaning.

Integral Ecology

The concept of integral ecology, the backbone of the encyclical, represents an epistemological rupture with the fragmented vision that dominates modern thought. Francis (2015) proposes a systemic and interdependent understanding of the relationships among nature, culture, economy, politics, and spirituality. This perspective enters into dialogue with proposals such as buen vivir, the rights of nature, or the paradigm of living well in Latin American contexts (Gudynas, 2011). By transcending the dichotomy between the human and the non-human, Laudato Si' enables a relational ethic that reconfigures traditional frameworks of sustainability.

This rethinking carries profound implications: every intervention in the environment involves a reorganization of social relations, a revision of cultural narratives, and a reconfiguration of subjectivities. From the standpoint of complexity theory, this kind of approach recognizes the nonlinearity of social processes, the emergence of unexpected phenomena, and the need to address the civilizational crisis through a transdisciplinary logic (Morin, 2005). In this sense, Laudato Si' denounces and proposes a new grammar of the possible.

One of the most influential dimensions of Laudato Si' is its contribution to the ethical reconfiguration of climate change. Rather than treating it as an exclusively technical challenge, the encyclical frames it as an urgent moral issue. Francis notes that the effects of global warming disproportionately impact the most impoverished peoples those who contributed least to the crisis but suffer its most devastating consequences (Francis, 2015, n. 48). This ethical reading has shaped various international forums, positioning intergenerational responsibility and climate justice as inescapable dimensions of environmental debate (Le Quéré et al., 2018).

The spiritualization of environmental justice strengthens its political dimension by endowing it with an ethical depth that transcends normative frameworks. The encyclical employs theological language as a vehicle for global interpellation, positioning faith as a force capable of articulating transformative commitments. This orientation has resonated across both religious and secular sectors, fostering the formation of transversal alliances that recognize care as a guiding principle for an alternative civilization.

Beyond the ecclesial sphere, Laudato Si' has had notable influence on public policy. At the Paris Summit (COP21), it was cited by global leaders as a moral rationale for endorsing the Paris Agreement. Various sustainable development strategies adopted by states and cities over the past decade have incorporated elements of the integral ecology approach: intergenerational justice, community participation, territorial resilience, and environmental equity (Sachs, 2016).

This influence has acquired a strategic character. Laudato Si’ has helped shape what various analysts describe as a “moral geopolitics of climate,” in which political decisions demand ethical legitimacy. With this encyclical, the Vatican challenges the dominant narrative surrounding energy transition and climate governance, confronting the technocratic discourse with categories such as care, communion, conversion, and limit.

One of the most significant effects of Laudato Si’ has been its impact on the field of education. Catholic and secular institutions around the world have developed training programs in integral ecology, including diploma courses, seminars, pedagogical materials, and territorial learning experiences. These initiatives have translated the encyclical’s proposal into concrete practices of learning, action, and transformation (Cullen, 2020).

Simultaneously, the encyclical has revitalized the spiritual dimension of the bond with the Earth. The concept of “ecological spirituality” (Francis, 2015, n. 216) refers to a contemplative, grateful, and committed attitude in which the world is perceived not as a resource to be exploited but as a sacrament of divine presence. This spirituality of care has permeated numerous faith communities, fostering both individual and collective transformations. The message is unequivocal: environmental justice demands a radical metamorphosis in how we feel, name, and inhabit the world.

Laudato Si’ has also served as a catalyst for ecumenical, interreligious, and secular alliances in defense of the commons. The Global Catholic Climate Movement, the Pan-Amazonian Synod, and numerous territorial initiatives have turned the encyclical into an ethical platform to denounce extractivism, promote territorial sovereignty, and demand climate justice. These networks have shown that faith can be a mobilizing source of meaning, capable of energizing processes of organization, resistance, and political and spiritual regeneration.

Here lies one of the most impactful effects of Laudato Si’: its ability to articulate spiritual language with the demands of ecosocial struggle. By calling both believers and non-religious individuals to an ethical pact for the future of the planet, the document transcends doctrinal boundaries and stands as a manifesto for life.

This discursive and political transformation brings relevant tensions to the fore. One example is the Vatican Fumata Ritual, in which the election of a new pope is announced by releasing white or black smoke from the Sistine Chapel. Although the gesture carries considerable symbolic weight, it appears discordant in a context where the Vatican identifies air pollution as one of the great evils of our time.

From the perspective of complexity thinking, this dissonance goes beyond institutional incoherence and reveals a structural tension between ritual permanence and the need for transformation. The Fumata is inscribed within a semiotic network where historical identity, media logic, and sacrality converge. By employing combustion as liturgical language, it activates imaginaries that contradict the principles of integral ecology. This performative paradox weakens the symbolic coherence of the ecclesial institution.

The solution lies in its re-signification. As Morin (2005) suggests, living systems tend to reorganize in response to change. Symbolic emergence consists of recomposing inherited forms in light of new historical and ecological conditions. Projecting beams of light, integrating soundscapes, using vegetal symbols, or incorporating digital art can express an ecosystemic spirituality while preserving the sacred density of the rite.

This redesign must embrace the logic of participation. Rather than imposing a new form from the Vatican, a collective deliberation with Catholic communities worldwide could be fostered, allowing cultural and spiritual diversity to enrich the new symbolic configuration. In this way, the ritual would cease to be a vertical operation and become a complex, open, rhizomatic, and ecologically committed praxis.

The impact of Laudato Si' transcends the doctrinal realm. Its strength lies in having opened an ethical, theological, and political resonance space for rethinking the place of the human within the web of life. This opening demands symbolic coherence. In a world where every gesture communicates and every ritual act configures reality, the Church risks compromising its moral authority by preserving fossilized signs that contradict the very principles it proclaims.

The re-signification of the Fumata is more than an aesthetic gesture: it represents an act of fidelity to the spirit of the encyclical. According to complexity thinking, authentic continuity is expressed through transformation that preserves meaning. Reformulating symbols keeps tradition alive by critically updating it.

Symbolic Ecology in the Amazon Synod

The Special Synod for the Amazon (2019), convened by Pope Francis, marked a milestone in the institutional opening toward an embodied and plural ecotheology. This event introduced unconventional ritual practices into the Vatican's liturgical canon: processions with seeds, the use of Amazonian symbols, prayers in Indigenous languages.

Far from being a folkloric gesture, these expressions embodied a logic of spiritual, territorial, and cultural interdependence. Their impact was ambivalent. On one hand, they provoked accusations of syncretism from ultraconservative sectors. On the other, they revealed the transformative potential of a liturgy forged from the periphery as a manifestation of the pluriverse.

From the perspective of complexity theory, this episode can be interpreted as a case of symbolic emergence: new meanings arise from the entanglement of collective memories, ecosystems, spiritualities, and ancestral knowledges. Beyond the aesthetic incorporation of Indigenous elements, it represented a cultural turning point within the ecclesial system. As Boaventura de Sousa Santos (2010) argues, true universality is built upon epistemic plurality. The Synod expressed that constitutive tension: opening the system to diversity implies reorganizing its identity along more complex and adaptive lines.

The methodology of the Synod also constitutes a significant innovation. Bishops, theologians, Indigenous leaders, scientists, and pastoral agents participated in a transdisciplinary deliberative exercise. This process can be interpreted as a systemic experiment in which flows of information, internal tensions, and disruptive proposals converged. From the logic of complex systems, such dynamics can generate structural transformations if they manage to overcome the negative feedback of institutional inertia.

One of the boldest proposals was the creation of ministries for women and Indigenous peoples, along with the opening to context-specific liturgical rites. These initiatives, resisted by conservative ecclesial sectors, point toward a deep symbolic reform aimed at an intercultural and ecological spirituality. The tension between liturgical innovation and preservation illustrates the discontinuous and dynamic nature of institutional transformation processes: every emergence generates friction, and it is precisely within these frictions that evolution takes shape.

Assessing the reach of the Synod requires going beyond discourse analysis to construct a systemic cartography of its effects. This entails identifying centers of power, turning points, feedback circuits, and territories of resistance. What practices managed to consolidate? Which were dismissed? What new symbolic expressions gained recognition within ecclesial institutionality? This approach enables a view of the Church as a complex system, subject to constant tensions between structural stabilization and emergent openness.

Liturgical Technocracy and Systemic Feedback

The technocratic paradigm, described by Francis (2015) as a form of rationality that separates means from ends (n. 122), extends beyond economic and scientific spheres and also shapes how religious institutions manage their symbols. The Vatican Fumata, regarded as a ritual technology, reflects this tension: it achieves media effectiveness while weakening its ethical and symbolic coherence in a world that demands alignment between liturgy and ecological commitment.

From a systemic perspective, the Fumata functions as a mechanism of persistent feedback due to its automated operability, misaligned with the very principles the institution proclaims. Its symbolic transformation, as proposed by ecotheology, could activate creative feedback capable of triggering adaptive reorganizations within the liturgical system.

Thinkers such as Jacques Ellul (1964) and Ivan Illich (1973) warned of the risks associated with the technification of the sacred: when ritual form becomes autonomous and turns into a symbolic machine, it loses its critical capacity and becomes a reproducer of the very order it was meant to challenge. Edgar Morin (1999), for his part, has shown how systems lacking ethical reflexivity tend toward blind self-perpetuation. Viewed through this lens, technocratic liturgy reinforces obsolete legitimizing structures that hinder the symbolic mutation now required.

The technocratic paradigm can be understood as a perverse adaptive system flexible enough to introduce formal innovations, yet obstructing the ethical feedback processes necessary to question its foundational premises. This rationality converts complex problems into technical variables, thereby narrowing the horizon of cultural transformation. For this reason, so-called technological solutions to ecological collapse such as geoengineering or carbon capture mechanisms tend to intensify the crisis by replicating the same instrumental logic that helped produce it.

From this diagnosis, Laudato Si' puts forth the notion of integral ecology as a call for epistemological rupture. The challenge lies in reorienting the ends that guide human action. To produce effective transformations, this proposal must be equipped with evaluative tools grounded in criteria of complexity. Key indicators could include institutional reflexivity, symbolic coherence, interdimensional integration, and situated participation.

- Degree of citizen participation in technoscientific decision-making
- Institutional capacity to integrate local and ancestral knowledge
- Mechanisms for ethical deliberation on emerging technologies
- Democratic oversight of algorithms shaping economic and social life

Without such conditions, the critique of the technocratic paradigm risks becoming a rhetorical exercise. The symbolic becomes a contested domain: it is not enough to proclaim a new ethic if it fails to be embodied in the forms, gestures, and structures that shape collective experience.

Although Laudato Si' has opened a meaningful horizon of reconnection among the spiritual, the ecological, and the social, its epistemic framework retains elements that hinder deep transformation. While it acknowledges the value of Indigenous and peasant knowledge systems, it does so from within a narrative of the common home that presupposes a transcendent moral unity without interrogating its Euro-Christian genealogy.

The epistemologies of the South as articulated by Santos, Leff, and Escobar offer a more radical critique: including other voices holds little transformative power if the ontological architecture that defines what is possible remains intact. Rather than an ecological universalism, they propose a symbolic pluriverse that recognizes multiple ways of inhabiting, knowing, and signifying the world.

This distinction is clear: inclusion without decolonization results in symbolic co-optation. Integral ecology requires interrogating the colonial foundations of ecclesial knowledge and overcoming its claim to moral universality. It is worth asking whether an encyclical produced in the Vatican can truly serve as a platform for epistemic emancipation among historically oppressed peoples. The answer eludes binary logic and demands an examination of concrete practices of reappropriation, resistance, and re-signification.

In Colombia's Pacific region, Afro-descendant communities have invoked principles articulated in Laudato Si', such as intergenerational justice, to support their claims for territorial recognition (Consejo Comunitario del Río Yurumanguí, 2020). Various Indigenous leaders have noted that certain ecclesial formulations tend to render their worldviews invisible, promoting an ecology devoid of peoples a notion of nature without subjects and a spirituality lacking reciprocity.

Rather than invalidating the value of the encyclical, these tensions call for reading it as a situated text, open to re-signification. To treat it as a closed doctrinal corpus nullifies its critical power. Recognizing the plurality of possible interpretations from the margins, from below, from the Other, is essential for ensuring that the ethical message of Laudato Si' is not captured by the very logics it seeks to transform.

Ritual, approached through an anthropology of complexity, transcends any purely conservative function. More than a repetition aimed at maintaining social order, it constitutes a symbolic technology capable of producing significant cultural transformations. In contexts marked by ecosystemic crisis and civilizational collapse, rituals play a strategic role: they update collective frameworks, destabilize hegemonic meanings, and open spaces of transition. Rethinking them requires moving beyond aesthetics and ornamentation. It entails a far-reaching political decision.

From this perspective, the critique of the Vatican Fumata transcends environmentalist concerns. It becomes a direct challenge to the way the Church constructs and communicates its symbolic authority. If the ecological conversion proposed by Laudato Si' is to strive for coherence, it must begin by revisiting the signs it uses to express the sacred. Ritual is never a neutral channel. It functions as a semiotic matrix that shapes how the world is inhabited. Hence the urgency of an ecological liturgy that preaches care and embodies it in its forms, materials, gestures, and relationships with the environment.

Eco-ritualism, developed by grassroots communities across Latin America, promotes a profound reconnection: the integration of natural elements such as seeds, river water, birdsong, or solar orientation as signifying presences that restore the bond between symbol and biosphere. From this perspective, re-signifying the Fumata involves more than replacing a technical medium. It requires establishing a process of symbolic intervention aligned with a complex ecotheology, guided by five operative principles:

- Ethical and symbolic coherence: The act of announcing the papal election must reflect the principles inspired by the encyclical. Employing clean, non-polluting technologies constitutes a spiritual demand with liturgical, political, and ecological implications.

- Pluricultural participation: Diverse communities youths, Indigenous peoples, ecological movements should be invited to imagine new signs from within their own symbolic frameworks. Liturgical creation requires a dialogical, situated approach that honors difference.

- Comprehensive impact assessment: The proposal should include indicators related to communicative effectiveness, ecological footprint, and spiritual resonance. Here, pastoral theology, the sociology of religion, and communication theory converge.

- Experimental ritual prototyping: The redesign must undergo trial-and-error processes in community contexts where reception, adaptability, and the power of the new symbol can be evaluated.

- Adaptive iteration: Like any complex system, symbolic redesign must remain flexible. It requires a feedback mechanism that enables ritual adjustments without losing its ethical-spiritual horizon.

Re-signifying symbols without examining the exclusionary structures that sustain them amounts to an aesthetic gesture lacking depth. Beyond its material form, the Fumata represents a mode of hierarchical, male-centered, Eurocentric centralism that marginalizes women, Indigenous peoples, and Afro-descendant communities from decision-making processes. The critique must go beyond environmental concerns. It must also adopt an epistemological and intersectional lens.

Decolonial perspectives (Anzaldúa, 1999; Lugones, 2008; Escobar, 2016) allow rituals to be interrogated from the margins, exposing their function as devices of symbolic exclusion. What meaning does it hold to change the symbol if the process continues to silence half the believing community? Can there be ecological liturgy without ecclesial justice?

A truly transformative ecotheology must also decolonize meaning. It is necessary to dismantle the symbolic codes inherited from liturgical colonialism. A Fumata turned into an ecosystemic gesture remains insufficient if the Church preserves forced silences, hierarchical spiritualities, and sacred imaginaries closed to difference.

The Fumata is far more than a signal. It is a node within a global symbolic network marked by historical, theological, and cultural tensions. Its persistence expresses a form of institutional inertia, yet it also reveals a possibility: re-signifying it could inaugurate a liturgical ecology in which signs cease to operate as residues of the past and begin to act as vectors of the future.

Complex Thinking teaches that civilizational mutations also manifest as revolutions of the imaginary (Morin, 2011). Changing a symbol transforms the source code of collective identity. In this light, symbolic redesign represents a form of dynamic fidelity an evolutionary bifurcation that honors the original meaning while projecting it toward new possibilities.

The Vatican, as a global semiotic seedbed, holds the potential to inaugurate a generation of signs capable of radiating meaning in a world overwhelmed by technocratic nihilism. Smoke can become light, song, color, dance, or vegetal resonance. It can signify the election of leadership and, simultaneously, affirm another way of inhabiting the Earth. The ecosocial transition requires a planetary liturgy that celebrates life, embodies it through its signs, and safeguards it in ritual expression.

The papal Fumata, as a rite of announcement and continuity, retains undeniable symbolic power. Yet its current form based on combustion clashes with the ecological commitment proclaimed by the Vatican in Laudato Si'. This tension represents a fertile possibility: from the perspective of complexity theory, living systems reorganize their contradictions as sources of transformation. Even religious symbols must evolve in order to preserve their capacity to signify in a world that demands ethical, ecological, and aesthetic coherence.

The articulation between Laudato Si' and Complex Thinking offers a platform capable of renewing the bonds among spirituality, ecology, and civilizational transformation. This chapter has shown that such an articulation requires more than doctrinal exegesis or the accumulation of scholarly references. It demands a critical, situated, and transdisciplinary reconstruction, nourished by insurgent knowledges and territorial experiences that embody alternative ways of inhabiting the world.

First and foremost, the notion of "integral ecology" proposed by Pope Francis requires rigorous epistemological tension. While it marks a significant step forward in recognizing the interdependence between humanity and surrounding life forms, its formulation risks universalizing a normative vision that disregards ontological and cultural differences. The epistemologies of the South and decolonial thought have warned of the danger of turning the "common home" into an architecture imposed by dominant rationality. To attain a truly integral dimension, ecology must open itself to the plural, the situated, and the conflictual. It must sustain a pluralistic, insurgent, and decolonizing orientation.

Second, the critique of the technocratic paradigm contained in Laudato Si', though ethically pertinent, loses strength if it lacks a systemic understanding of its mechanisms of reproduction. From a complexity perspective, technocracy operates as an adaptive network of institutional, semiotic, and technological feedback loops that neutralize the critiques directed at it. Confronting it requires more than moral condemnation: it demands alternative social designs, resilient symbolic structures, and organizational models capable of restoring the link between means and ends. Technocracy is disarmed through ecologies of knowledge, action, and meaning that replace abstract exhortations with concrete transformations.

Third, the exploration of Catholic rituals with emphasis on the Fumata has revealed that symbols function as structuring nuclei of collective subjectivity. Complexity thinking shows that civilizational crises are also semiotic crises, and that the deepest transitions reorganize symbolic systems. Re-signifying a ritual constitutes a form of cultural engineering with direct effects on how communities shape power, spirituality, and life. For this reason, the methodological proposal outlined in this chapter aimed at symbolic redesign from a participatory, interdisciplinary, and ecological perspective constitutes a concrete contribution to the field of ecotheology. Designing symbols entails reorganizing matrices of meaning. Through processes of shared creation that integrate ancestral knowledges, contemporary aesthetics, and ecological principles, liturgy can become a living laboratory of transformative spirituality.

The transition toward a civilization of care, of life, and of complexity requires the language of signs. In a world oversaturated with data and starved for meaning, the struggle for the future is also waged in the terrain of symbols, myths, and rites. For this reason, complexity thinking transcends diagnosis: it becomes poetics, sensitive pedagogy, and Earth liturgy. Knowledge transforms when it becomes loving, and love spreads when it is expressed through symbolic action.

To re-signify the Fumata is far more than a gesture consistent with ecological principles: it is an act of insurgent semiosis, a declaration of belonging to a living world, a spiritual affirmation that reimagines the sacred through the lens of complexity making the planet we share with all beings more habitable, more just, and more worthy of celebration.

Chapter 10

Tariffs, Trade Wars, and Economic Complexity

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A Critical Perspective from Systems Thinking

International trade constitutes one of the structural engines of the contemporary global economy. By facilitating the exchange of goods and services among countries, it generates diverse benefits. It enables access to products not available locally, expands consumer choices, encourages specialization based on comparative advantages, and contributes to overall improvements in living standards. However, it also entails risks and imbalances. Under certain conditions, it can harm smaller economies, intensify inequality, and produce negative externalities affecting both the natural and human dimensions of the environment.

From a historical-political perspective, global trade has oscillated between two antagonistic paradigms: protectionism and free trade. The former relies on the imposition of restrictions such as tariffs, quotas, or subsidies to defend domestic producers from foreign competition. It is a defensive and strategic logic aimed at mitigating the effects of unfair practices or structural asymmetries. The latter promotes trade liberalization through the removal of barriers, trusting in the self-regulation of global markets and in the efficiency derived from productive specialization. Both visions oversimplify a reality that is increasingly interdependent and complex.

According to the 2024 World Trade Report by the World Trade Organization, global trade reached a record of 33 trillion dollars, driven by a 7% increase in services trade and a 2% increase in goods. The report suggests that income gaps between countries are gradually narrowing, though significant inequalities persist within economies. The most relevant finding, however, is qualitative. The report emphasizes that global trade governance now faces unprecedented challenges arising from geopolitics, the energy transition, and technological disputes.

Within this context, the tariff policy of the Trump administration (2017–2021) acquires particular relevance. Under the slogan "America First," a protectionist agenda was advanced with the aim of reducing the U.S. trade deficit, reindustrializing strategic sectors, and containing China's economic and technological rise. Tariffs were conceived as a tactical tool intended to rebalance bilateral trade and redesign the rules of the game in a multilateral system perceived as favoring others to the detriment of the U.S. economy.

Beyond the rhetorical clash between protectionism and liberalism, this episode underscores the need to adopt a more robust analytical framework capable of capturing the systemic complexity of global interactions. Trade wars exceed direct and measurable impacts such as changes in prices or trade flows. They trigger feedback loops, indirect effects, and emergent behaviors that are difficult to anticipate from a linear logic.

To rigorously assess the impact of Trump's tariff policies, it is essential to go beyond conventional models of economic analysis. Neoclassical economics with its emphasis on individual rationality, market equilibrium, and marginal efficiency is insufficient to explain the interdependence, uncertainty, and complexity that define today's global economic system.

This is where the need for an epistemological shift becomes imperative: moving from a reductionist and fragmented perspective to an integrative and complex understanding. In the words of Edgar Morin, thinking complexity means embracing uncertainty, acknowledging the plurality of causes and effects, and considering the feedback loops that give rise to emergent phenomena. Trade wars, understood in this light, are revealed as multicausal, dynamic, and adaptive processes.

The imposition of tariffs by the United States on Chinese products between 2018 and 2020 generated a series of consequences that illustrate this approach. Initially, the tariffs raised the cost of imports and triggered diplomatic tensions. Indirect effects soon followed: the relocation of supply chains, the strengthening of strategic alliances among affected countries, accelerated investment in national technology, and in some cases, the creation of trade evasion mechanisms. These dynamics were unforeseen by both proponents and critics, highlighting the urgency of moving beyond linear causality frameworks.

From the perspective of complexity thinking, these processes are understood as part of an interdependent global system, where each action generates multiple effects, feeds back into its environment, and alters initial conditions. Thus, what may appear as a rational measure in one context may become dysfunctional in another. This perspective invites a rethinking of economic policy as an adaptive, situated praxis subject to constant revision.

In the face of the Trump administration's aggressive trade policy, reactions across Latin America were diverse though largely reactive. Economies most dependent on exports to the United States, such as Mexico and several Central American countries, sought to mitigate negative effects through renegotiations, market diversification, and subsidy policies. Others, like Brazil and Argentina, saw opportunities to increase their participation in value chains disrupted between the United States and China.

Beyond immediate impacts, the central question is strategic: Can Latin America leverage this new environment to redefine its global positioning? From a systemic perspective, global trade conflicts appear both as threats and as windows of opportunity to design development policies based on endogenous capacities, regional cooperation, and strategic positioning.

This requires moving beyond the logic of short-term reaction and advancing toward a long-term vision grounded in complex analysis and structural policies. It involves articulating strategies for technological innovation, productive transformation, and institutional strengthening within a shared agenda that acknowledges regional differences and interdependencies. Otherwise, Latin America remains exposed to external dynamics beyond its control, perpetuating historical cycles of dependency and vulnerability.

The Origins and Evolution of Global Trade through the Lens of Complexity Theory

The history of international trade must be interpreted as a network of heterogeneous processes shaped by ruptures, contingencies, adaptations, and asymmetries. From the perspective of complexity thinking, this evolution is less a linear path toward liberal perfection and more a trajectory marked by structural tensions, civilizational clashes, and institutional mutations.

The earliest expressions of trade emerged from relationships of reciprocity and subsistence within the framework of early agricultural societies. During the Neolithic period, the surplus resulting from the domestication of plants and animals enabled the exchange of goods between human groups. This practice, based on barter, was sustained by trust, communal bonds, and the complementarity of needs without any orientation toward profit or accumulation.

The emergence of currency initially in the form of precious metals and later as standardized units in Anatolia around the sixth century BCE triggered a radical transformation. Value was abstracted from concrete objects and translated into signs, allowing trade to expand beyond direct exchange. This monetary abstraction was a crucial step in the formation of complex economic networks and generated mechanisms of inequality and control.

Later, in fifteenth-century Europe, the rise of credit formalized a new layer of commercial relations based on time, trust, and risk. The first financial institutions many of them driven by Jewish communities excluded from other economic activities introduced practices such as interest-bearing loans, despite religious prohibitions in Christianity and Islam. These innovations marked the beginning of trade as a technical-administrative system regulated by norms, contracts, and collateral guarantees.

During antiquity, empires organized and controlled transcontinental trade routes such as the Silk Road and Mediterranean maritime corridors. These logistical networks moved goods like spices, metals, and textiles, but also circulated knowledge, religions, languages, and institutional models. The commercial integration driven by Rome, Persia, or China was unequal, as imperial centers dictated the terms of exchange while peripheral regions were exploited as extractive zones.

Within this imperial logic, trade operated as a form of both symbolic and material power. Wealth accumulation in the centers was directly correlated with the subordination of the margins. Edgar Morin proposes understanding this dynamic as part of a world organization in which trade consolidated structures of domination disguised as functional interdependence.

This trend intensified with European expansion between the fifteenth and nineteenth centuries. Commercial enterprises such as the British East India Company not only managed trade routes and goods but also imposed legal, fiscal, and cultural regimes. Trade became inseparable from colonialism, institutionalizing an international division of labor in which countries of the Global South were relegated to raw material production, while the North concentrated manufacturing, credit, and technology.

The British Industrial Revolution of the eighteenth century marked a new milestone in the history of global trade. Mechanized production multiplied manufacturing capacity, intensifying the need for external markets and cheap raw materials. Industry crossed borders and redefined international trade as an extension of industrial processes.

Immanuel Wallerstein, in his world-systems theory, argued that this phase gave rise to a hierarchical global economy in which productive, financial, and commercial decisions were made in a dominant core, while the periphery functioned as a zone of extraction and deposit. Trade thus shifted from being an activity of intermediation to becoming an instrument for reproducing inequality.

Within this context, the liberal paradigm constructed a narrative of economic progress based on openness and efficiency. Historical evidence reveals that such liberalization was neither universal nor symmetrical. Trade segmented the world into zones functional to capital, deepening the technological and financial dependency of less industrialized countries.

After the Second World War, the international economic order was restructured under the aegis of multilateral institutions. The General Agreement on Tariffs and Trade (GATT), and later the World Trade Organization (WTO), promoted a normative framework presented as neutral and universal for regulating trade. Its stated aim was to reduce barriers, harmonize rules, and foster a predictable environment for exchange.

In practice, multilateralism proved highly functional to the interests of major powers. While Northern countries liberalized sectors in which they were competitive such as industry, services, and technology they maintained barriers in critical areas for the Global South, such as agriculture and intellectual property. Promises of equity were systematically betrayed by selective policies and disguised protectionist mechanisms.

Regional treaties such as NAFTA and the TPP reinforced this logic. Operating outside the WTO framework, they enabled bilateral negotiations more favorable to countries with greater bargaining power. Far from constituting spaces of horizontal cooperation, these agreements consolidated new forms of flexible dependency. Developing countries were inserted into global value chains controlled by transnational corporations, with minimal decision-making power over prices, technologies, or labor conditions.

In recent decades, global trade has undergone a profound transformation driven by digitalization. Digital platforms, artificial intelligence, and blockchain have redefined logistical flows and the modes of commercial intermediation. Today, algorithms determine prices, routes, inventories, and consumer decisions in real time, displacing human agents and dislocating the locus of decision-making.

This techno-digital shift introduces an additional layer of complexity. Trade infrastructure has ceased to be solely material such as ports or highways and has become informational. Countries that control platforms, data, and communication systems hold a structural advantage in shaping global trade. According to Zuboff, surveillance capitalism transforms information into the principal input and regulator of exchange.

From the perspective of complexity thinking, this situation entails a cybernetic reconfiguration of trade. Self-regulated, feedback-driven, and distributed systems emerge, operating under the principles of algorithmic governance. This transformation lacks neutrality or universality. It reproduces pre-existing inequalities and generates new digital, cognitive, and regulatory divides across countries, sectors, and social groups.

In its current form, global trade also produces systemic ecological impacts. Maritime transport the backbone of international trade accounts for nearly 3% of global CO_2 emissions, not including the environmental effects of intensive export-oriented production or the waste generated by planned obsolescence. The logic of maximizing exchange has systematically ignored the planet's biophysical limits.

In this context, the concept of eco-complexity, developed within the framework of complex thought, becomes particularly relevant. This approach recognizes that every economic system is also an ecological system, and it demands a rethinking of trade success indicators. Measuring only growth or surplus is insufficient. It is essential to incorporate ecological footprint, process sustainability, and the resilience of the territories involved.

Embracing this perspective requires redesigning trade policies according to principles of sufficiency, regeneration, proximity, and shared responsibility. It entails replacing the paradigm of unlimited growth with one grounded in systemic sustainability. It also calls for a new epistemological contract that replaces economic reductionism with an integrative, critical, and situated perspective.

Globalization and Governance: A Process of Phases and Bifurcations

According to Ocampo, globalization must be understood as a multidimensional process shaped by technological, financial, cultural, ecological, and political transformations. This heterogeneous character generates internal tensions and structural contradictions that directly affect the mechanisms of trade governance.

Historically, three distinct phases of globalization can be identified. The first phase, from 1870 to 1913, was characterized by high mobility of capital and people, driven more by declining transportation costs than by free trade policies. This stage was interrupted by World War I and collapsed definitively with the Great Depression of 1929.

The second phase, from 1945 to 1973, was grounded in the creation of multilateral institutions such as the IMF, the World Bank, and the GATT, sustained industrial growth in developed countries, and low capital mobility. This period, known as the golden age of capitalism, ended with the oil crisis and the collapse of the Bretton Woods system.

The third phase, from 1973 onward, has been marked by financial liberalization, the rise of transnational corporations, and the proliferation of free trade agreements. This stage exhibits increasing homogenization of economic models and a deep asymmetry in access to the benefits of globalization.

This trajectory reveals that globalization has been an intermittent process, subject to systemic shocks and ongoing disputes over its normative direction. Trade governance emerged as a contingent and contested response to its multiple externalities.

The Great Depression of 1929 marked a turning point. Triggered by the stock market crash in New York, credit contraction, banking collapse, and overproduction, this crisis unleashed a sharp contraction of international trade. The result was a wave of protectionism led by the United States through the Smoot-Hawley Tariff Act, which amplified the effects of the recession and exposed the urgent need for cooperative global mechanisms.

This need eventually gave rise to the Bretton Woods architecture. However, this architecture has proven fragile in the face of new types of crises financial, sanitary, environmental, and geopolitical. These disruptions reveal that current governance systems were designed for stable scenarios and are incapable of responding to a complex, interconnected, and bifurcation-prone global economy.

Within this scenario, Latin America faces a strategic dilemma: to remain a subordinated link in global value chains or to reconfigure its international integration through a logic of regional cooperation, productive diversification, and technological sovereignty. Globalization emerges as a contested arena. Taking advantage of its opportunities such as access to technology, market integration, and foreign investment requires institutional capacities to mitigate its risks, including dependence, exclusion, and volatility.

As Ocampo argues, this implies strengthening regional production networks, promoting industrial innovation, redesigning trade agreements based on equity and sustainability, and coordinating strategic policies to reduce external vulnerability. Complex Thinking offers both a critique and an operational framework for reimagining trade governance as a regenerative process oriented toward systemic balance and structural justice.

Structural and Emerging Factors in the Configuration of International Trade

Contemporary international trade cannot be understood through simplistic analytical categories or linear causal structures. Its dynamics respond to a system of multiple, asymmetric, and constantly evolving interactions, where state, corporate, technological, ecological, and symbolic actors coexist within a global ecosystem marked by tensions, contingencies, and uncertainties.

Far from the determinist logic of supply and demand, Complex Thinking demands that trade be analyzed as a relational, emergent, and feedback-driven phenomenon in which the conditions of possibility are continually redefined.

This analysis explores six key factors whose interplay shapes current forms of international exchange. These factors should be interpreted as interconnected nodes within a global systemic network.

1. Geopolitics of Trade: Asymmetric Power and Strategic Rationality. Far from being a neutral space governed by economic efficiency, international trade is deeply shaped by geopolitical power structures. States, regional blocs, and multinational corporations vie for control over the rules, standards, and platforms that structure global exchanges. Agreements such as the USMCA, RCEP, and CPTPP are driven more by strategic influence, access to critical technologies, and containment of systemic rivals than by purely mercantile logic.

From this perspective, the tariff policies adopted by the Trump administration between 2017 and 2021 were conceived as tools for reconfiguring the global production system, aiming to contain China's rise, redefine technological dependence, and reassert a narrative of national sovereignty in economic governance. These kinds of interventions demonstrate that trade is also a contested space for shaping the meaning of globalization.

Complex Thinking allows these tensions to be interpreted as a field of shifting relations, where diverse actors deploy adaptive strategies, multilateral alliances, and cultural counter-hegemonies.

2. Digital Revolution and Infrastructural Mutation. The digital transformation constitutes one of the most powerful vectors of change in global trade. The expansion of digital platforms, logistical automation, cross-border e-

commerce, and the integration of technologies such as blockchain, artificial intelligence, and big data have created a new trade infrastructure less visible but more decisive than maritime routes or tariff agreements.

Corporations like Amazon, Alibaba, and Google mediate products, organize market access, manage strategic data, and design algorithmic architectures that determine consumer preferences and distribution patterns. In doing so, they control global power infrastructures.

These technologies produce systemic effects, concentrate informational rents, generate network economies with thresholds of irreversibility, and create new technological dependencies for countries in the Global South. Added to this is increased vulnerability to cyberattacks, data manipulation, and disruptions in logistical flows. The digitalization of trade represents a structural transformation with far-reaching political, economic, and cultural implications.

3. Financialization and Structural Fragility. Since the 1970s, international trade has become subordinated to the logic of financial markets. Capital liberalization, banking deregulation, and the expansion of derivative instruments have largely decoupled trade flows from their productive foundations, generating structural volatility that affects entire countries, sectors, and populations.

Speculative funds, credit rating agencies, global banks, and trading platforms intervene in key markets such as currencies, interest rates, insurance, and futures, altering the relative prices of traded goods and directly impacting the trade balances of the most vulnerable countries.

This financialization produces a widening gap between the real economy and the symbolic economy. Investment decisions respond less to productive needs than to expectations shaped by algorithms, ratings, and stock market narratives. This disconnect heightens systemic instability, fuels speculative bubbles, and triggers cyclical crises that disproportionately affect countries with limited control over their monetary and fiscal policies.

4. International Norms: Standardization, Conflict, and Coevolution. Global trade is governed by a dense and hierarchical web of regulations, agreements, dispute resolution mechanisms, and technical standards. From the multilateral principles of the WTO to bilateral treaties with investor–state

dispute settlement clauses, the institutional architecture of trade shapes the conditions of exchange.

These norms are neither neutral nor universally beneficial. Countries with greater diplomatic, legal, and technical capacity impose standards in areas such as intellectual property, environmental regulation, labeling, or digital services that reflect their structural interests. Frequently, these standards function as de facto tariff barriers that undermine the competitiveness of developing countries.

Complex Thinking encourages an understanding of this normative dimension as a subsystem in tension within the broader global economic system. Formal rules interact with informal practices, corporate interests, citizen demands, and institutional asymmetries. As such, the legitimacy and effectiveness of trade norms depend on their ability to adapt to diverse contexts, engage with cultural pluralism, and coevolve alongside systemic transformations.

5. Ecological Dimension of Trade: Sustainability Crisis. The acceleration of global exchanges has placed increasing pressure on ecological systems. Intensive export-oriented production, the expansion of monocultures, open-pit mining, long-distance maritime transport, and planned obsolescence have turned international trade into a critical driver of ecological collapse.

The environmental footprint of trade is systemic: it generates greenhouse gas emissions, promotes an extractivist logic that erodes soils, contaminates water sources, and displaces communities. This externalization of ecological costs serves the dominant economic model, yet it is unsustainable in the medium term.

Initiatives such as green labeling, emissions trading schemes, and carbon border adjustments have emerged as attempts to internalize these externalities. However, many of these mechanisms have been co-opted by corporate logics or transformed into instruments of normative power by Northern powers.

From the standpoint of complex thought, it is essential to reinsert trade as a subsystem of the biosphere. This implies designing trade agreements that include ecological metrics, promoting the relocalization of supply chains, prioritizing the circular economy, and recognizing the planet’s biophysical limits as fundamental parameters for the organization of the global economy.

6. Cultural and Civilizational Dimension: Trade as a Carrier of Meaning. Trade is more than the exchange of goods it also entails the exchange of symbols, values, ways of life, and worldviews. The expansion of global brands, cultural platforms, and standardized products fosters the homogenization of consumption patterns and the erosion of local identities.

This phenomenon raises critical questions: What is lost when imaginaries are homogenized? What models of subjectivity are promoted by global consumer culture? How do these dynamics affect care economies, ancestral knowledge, or traditional food systems?

From a decolonial perspective, global trade can be interpreted as a device of symbolic colonization, where Northern ways of life are imposed as a universal model. Complex Thinking calls for a revaluation of epistemic diversity, the recovery of local economies, and the construction of trade agreements that integrate cultural and ethical principles of plurality, equity, and sustainability.

Globalization as a Complex, Historical, and Civilizational Process

Globalization lacks univocity and linearity. It is a historical, multicausal, and deeply ambivalent process that interweaves economic, technological, political, cultural, symbolic, and ecological dimensions. Its analysis cannot be reduced to the economistic discourse of the free market or the technocratic narrative of progress. On the contrary, it demands an epistemology of complexity capable of grasping its internal tensions, emergent effects, and multiple possible trajectories.

From the perspective of complex thought, globalization is conceived as a dynamic system of recursive interactions between local actors and global structures, in which the whole cannot be explained by the mere sum of its parts. This requires an approach that recognizes the synergies, contradictions, and bifurcations that characterize the globalization process.

1. Nonlinear History of Globalization: Cycles, Ruptures, and Discontinuities. Globalization is often presented as a continuous and inevitable process. Its historical evolution reveals distinct phases marked by systemic ruptures, geopolitical reconfigurations, and technological transformations. Identifying

these phases helps denaturalize the present and open the possibility of alternative futures.

The first wave of globalization took shape in the nineteenth century, driven by the Industrial Revolution, European imperial expansion, the development of steam transport, and monetary integration through the gold standard. This phase established a global network of exchange based on the colonial division of labor: Southern countries supplied raw materials, while industrial metropolises produced manufactured goods. This early globalization was sustained by openly colonial and racialized structures.

World War I marked the collapse of that first cycle. Global supply chains fractured, capital flows were interrupted, and a new phase of nationalist retrenchment emerged. The Great Depression of 1929 deepened this crisis by unleashing a wave of economic protectionism and geoeconomic fragmentation that reached its apex with World War II. This period demonstrated that economic interdependence, without adequate mechanisms for international regulation, can become a source of systemic instability.

The postwar era ushered in a second wave of globalization under U.S. leadership. The Bretton Woods system, with its key institutions the IMF, the World Bank, and the GATT sought to create a stable monetary and trade order that would avoid the mistakes of the past. This institutional architecture promoted multilateral trade, European and Japanese reconstruction, and a relative degree of international economic coordination. It remained an exclusionary order for most countries of the Global South, whose structural interests were left outside decision-making processes.

This model remained relatively stable until the early 1970s, when the oil crisis, the end of the dollar–gold standard, and growing inflationary pressures triggered a mutation in the logic of the system. Thus began a third phase: neoliberal globalization.

2. Hyperglobalization and Its Structuring Logic. Since the 1980s, global capitalism has entered a phase marked by financial deregulation, aggressive trade liberalization, massive privatization of public goods, and the hegemony of transnational corporations. This period, known as hyperglobalization or neoliberal globalization, radically transformed the foundations of the world economy.

Backed by institutions such as the IMF, the World Bank, and the WTO, countries in the Global South were subjected to structural adjustment programs under the promise of growth, competitiveness, and modernization. In practice, these policies led to the dismantling of state capacities, the loss of economic sovereignty, the concentration of wealth, and the reproduction of dependency structures.

One of the cornerstones of this phase was the establishment of global value chains. By fragmenting production across multiple countries, corporations optimized costs, reduced taxes, and maximized profits. This strategy primarily benefited core economies, which retained control over patents, finance, design, and intellectual property, while peripheral regions were relegated to extractive, assembly, or low value-added logistical functions.

From the perspective of complex thought, these dynamics must be understood as interdependent and hierarchical systems, where apparent efficiency conceals structural imbalances, power asymmetries, and hidden vulnerabilities. The COVID-19 pandemic exposed these fractures starkly: saturated logistics chains, extreme technological dependence, food insecurity, and the collapse of essential services.

3. Global Culture and Symbolic Homogenization. One of the least explored yet most significant effects of globalization has been its capacity to impose hegemonic cultural patterns on a planetary scale. International trade not only moves goods but also disseminates values, lifestyles, imaginaries, and subjectivities.

Transnational cultural industries such as television, film, music, social media, video games, and fashion have expanded a consumerist monoculture that devalues local knowledge, displaces indigenous languages, and homogenizes ways of life. English as the global lingua franca, the Western urban model, the globalized hypercaloric diet, and the aestheticization of consumption exemplify this trend.

This symbolic dimension of trade functions as a device of epistemic colonization. Narratives about development, success, progress, and modernity are constructed from centers of power that present their references as universal. The mass diffusion of these models shapes a global common sense that renders alternatives invisible, silences resistance, and discredits diverse ways of life.

In response to this phenomenon, Complex Thinking and the epistemologies of the South advocate for a revaluation of the cultural pluriverse, recognizing that multiple pathways to development and different ways of inhabiting the world exist. Cultural diversity is a necessary condition for sustainable civilizational futures.

4. Global Governance and the Crisis of Legitimacy. Neoliberal globalization consolidated a supranational institutional architecture that regulated trade, financial, and technological flows, yet failed to create effective mechanisms for redistribution, inclusion, or global justice. Organizations such as the WTO, IMF, and OECD operated under technocratic principles that responded more to the priorities of transnational capital than to the social or environmental demands of peoples.

This model of governance now faces a profound crisis. Trade tensions between the United States and China, the paralysis of the WTO, the failure of multilateral rounds such as Doha, the proliferation of bilateral treaties, and setbacks in climate cooperation all reveal the dysfunctionality of the current system. Globalization has become a space without real governance, dominated by powerful actors who bear no democratic responsibility.

From a complex perspective, the challenge lies in constructing a multilevel, flexible, and ethical form of governance capable of articulating the local and the global, the state and the community, the technical and the symbolic. This requires abandoning the idea of a single order and moving toward polycentric forms of coordination that acknowledge the plurality of knowledges, actors, and territories involved in the global economy.

5. Glocalization: Creative Bifurcation and Contextual Appropriation. The concept of glocalization, introduced by Robertson (1995), offers a decisive analytical lens for understanding the differential effects of globalization. Rather than operating in a homogeneous manner, global flows are reinterpreted, translated, and re-signified by local actors who adapt, resist, or reconfigure their meaning according to specific contexts.

This dimension is particularly relevant for Latin America and other regions of the Global South. Rather than accepting globalization as an inevitable external force, many local actors transform it into an opportunity for contextual innovation. From fair trade networks to open-source software platforms, from popular economies to ecofeminist movements, diverse practices emerge that link the global and the local in creative, critical, and regenerative ways.

Glocalization makes it possible to envision forms of international integration that avoid reproducing systemic hierarchies and instead foster relational, equitable, and sustainable models. From this standpoint, trade is understood as a means to secure territorial autonomy, community well-being, and ecological sustainability.

6. Technology, Power, and New Architectures of Global Trade. One of the fundamental vectors of contemporary globalization has been the exponential advance of information technologies, automation, and artificial intelligence. These developments accelerate the flow of goods, capital, and services while transforming both the material and immaterial foundations of international trade.

The so-called Fourth Industrial Revolution has generated qualitative transformations: the rise of the digital economy, the proliferation of transnational platforms, the expansion of cloud services, the automation of manufacturing, the development of blockchain, and the emergence of an algorithmic economy controlled by a handful of global actors.

Companies such as Amazon, Alibaba, Microsoft, Meta, and Google dominate markets and control critical infrastructures, massive data sets, reputation systems, and proprietary legal architectures.

This process creates a new layer of dependence for peripheral countries: digital subordination. Without sovereign access to technology, adequate data regulation, or endogenous innovation capacity, many economies become trapped in a dual condition: providers of strategic raw materials such as lithium, rare earths, and energy and passive consumers of foreign technologies.

From the perspective of complex thought, technology must be understood as a socio-technical dimension. It embodies rationalities, interests, and worldviews. As Morin warns, modern technoscience has operated as a device of simplification, externalizing ecological, cultural, and social impacts. Overcoming this logic requires the development of appropriate, ecological, plural, and relational technologies capable of integrating into the productive and symbolic fabric of each territory.

7. Critical History of Globalization: Cycles, Crises, and Lessons Learned. Understanding the current configuration of the global order requires examining its foundational moments, particularly those marked by systemic crises. The Great Depression of 1929 and World War II constitute key turning points in the evolution of the international economy.

The 1929 crisis emerged as the expression of accumulated vulnerabilities: unregulated financial speculation, massive debt, structural inequality, and the absence of international coordination. Its outbreak collapsed markets, reduced international trade by over 50%, and triggered a wave of protectionism and autarky. The infamous Smoot-Hawley Tariff Act in the United States, with more than 20,000 duties, unleashed a chain reaction that further fragmented the global system.

This period demonstrated that interdependence without governance leads to chaos. In response, following World War II, the victorious powers promoted an institutional architecture aimed at stabilization: the 1944 Bretton Woods system, including the IMF, the World Bank, and a dollar-anchored monetary regime. The 1947 GATT as the first multilateral trade mechanism. And the Marshall Plan, which reconstructed Western Europe and anchored its economy to the Atlantic axis.

This order enabled three decades of sustained growth, known as the Trente Glorieuses, although under exclusionary conditions: U.S. hegemony, Global South subordination, intensive fossil fuel use, and suppression of alternative models through Cold War strategies and domestic control. The neoliberal globalization that emerged in the 1970s deepened this matrix through privatization and deregulation.

From a complexity perspective, these historical cycles are interpreted as complex adaptive systems. Each crisis generates mutations, reorganizations, and partial learning. Today, amid new climatic, financial, and health-related turbulences, the challenge is to reimagine the foundations of the international system on new ethical, ecological, and epistemological grounds.

8. Strategic Opportunities for Latin America in a Turbulent World. Latin America has been deeply affected by the asymmetries of globalization. It has also demonstrated resilience, innovation, and regional coordination capacities. From a complexity perspective, the region’s opportunities are conceived as dynamic potentialities that depend on political decisions, social pacts, and institutional reconfigurations.

- Expanded Market Access and Geoeconomic Diversification

Trade liberalization enabled several Latin American countries such as Mexico, Chile, Peru, and Colombia to integrate their exports into global value chains. Although this generated foreign exchange and employment, the challenge lies in diversifying the productive base, avoiding reprimarization, and advancing toward sectors with higher technological content, such as biotechnology, renewable energy, or digital services.

- Building Endogenous Technological Capabilities

Cases such as Uruguay in software, Brazil in aerospace, and Costa Rica in medical devices show that, with deliberate innovation policies and technical education, it is possible to accumulate domestic capabilities. Achieving this requires protecting local knowledge, fostering public-private alliances with national objectives, and developing autonomous scientific systems that strengthen technological sovereignty.

- Digital Economy and Transnationalized Services

The growth of remote work and e-commerce has enabled professionals, small enterprises, and cooperatives to access global markets without exporting physical goods. This phenomenon, supported by strategies for digital inclusion, data protection, and fair taxation, can serve as a lever for inclusive development.

- Biodiversity and Ancestral Knowledge as Strategic Assets

The region harbors one of the planet's richest biodiversities. In the context of the global ecological crisis, this heritage can become the foundation of a regenerative economy, with emphasis on ethical biotrade, ancestral pharmacology, sustainable tourism, and food sovereignty. This requires respect for territorial rights, prior consultation, fair benefit-sharing, and protection against biopiracy.

- Political Influence in Global Governance

Latin America has the conditions to lead global institutional reforms through platforms such as CELAC, a rebuilt UNASUR, ALBA, or the G77. Proposals like ecological debt, buen vivir, international tax justice, and food sovereignty are emerging from the Global South as real alternatives to the dominant model. The legitimacy of these agendas depends on their internal coherence, regional articulation, and social support.

- Diaspora as a Transnational Development Network

Migrant communities contribute through remittances, but also create networks of entrepreneurship, knowledge exchange, cultural interaction, and informal diplomacy. Transforming these diasporas into active agents of transnational development requires specific public policies that integrate education, culture, economy, and decentralized cooperation.

9. Thinking from the South: Narratives, Policies, and the Reconfiguration of Meaning. One of the main obstacles to harnessing the opportunities of globalization has been a narrative deficit. Latin America's economic and political elites have often adopted Northern discourses uncritically, importing models without contextual adaptation or social participation. Complex Thinking calls for the decolonization of development imaginaries, the rejection of technocratic linear progress, and the construction of narratives that integrate diversity, interdependence, and justice.

Emerging proposals from social movements, territorial feminisms, community economies, Indigenous peoples, and urban youth show that alternative forms of organization exist, capable of uniting economy with affectivity, production with care, and technique with spirituality. Though fragmented, these experiences represent seeds of an alternative globalization oriented toward the common good, ecological reciprocity, and relational autonomy.

Globalization, understood through the lens of complexity, is an open, uncertain process filled with tensions. It constitutes a field of contestation. Rather than assuming it as an inevitable destiny or rejecting it as an absolute evil, the ethical-political challenge lies in reconfiguring it on new foundations: ecological sustainability, structural equity, epistemic plurality, and global democracy.

Latin America, with its history of resistance, its biocultural diversity, and its experience in community-based alternatives, plays a key role in that transformation. To achieve this, it is essential to build cognitive sovereignty, technological autonomy, and institutional coherence, while sustaining planetary interdependence.

Morin affirms that humanity is experiencing a moment of "polycrisis" and bifurcation. Positive evolution appears as a novel possibility to reinvent civilization. Reaching it requires complex thinking, political will, and collective creativity.

Governance Mechanisms of Global Trade and Their Complex Reconfiguration

Following the geopolitical cataclysm of World War II, an institutional architecture emerged to stabilize the global economic order. Within this framework, the General Agreement on Tariffs and Trade (GATT), signed in 1947 and in effect since 1948, constituted the first multilateral regime of trade governance. Its objective was clear: to reduce tariff barriers, foster economic recovery, and establish core principles such as non-discrimination and reciprocity. More than a mere technical treaty, the GATT inaugurated a new logic of multilateral cooperation, based on collectively negotiated rules and dispute resolution mechanisms.

For nearly five decades, the GATT operated through successive rounds of negotiation. The most ambitious the Uruguay Round (1986–1994) culminated in the structural transformation of the system through the creation of the World Trade Organization (WTO) in 1995. This institutionalization of global trade governance expanded the regime's scope by incorporating services, intellectual property, and formal dispute settlement mechanisms.

The chronology of the Uruguay Round reflects a discontinuous process, marked by deadlocks, tactical advances, and key political agreements, such as the Blair House Accord between the United States and the European Union on agricultural issues. These dynamics illustrate how trade governance truly functions: far from following a technical progression, it emerges as a web of interests, disputes, and power balances in which final decisions result from the strategic interaction of dominant actors.

The World Trade Organization currently operates with 166 members, representing more than 98% of global trade. Its formal objective is to facilitate international exchange under conditions of transparency, predictability, and fairness. Its functioning, however, reveals deep tensions between its foundational principles and contemporary geoeconomic realities.

A central critique concerns the way agreements are negotiated often through small groups of powerful countries that set the agenda and draft proposals before presenting them to the rest. This phenomenon, known as minilateralism, sidelines developing countries that lack the technical, diplomatic, or economic capacity to meaningfully influence negotiations. Hopewell argues that the WTO faces a structural dilemma: its claim to universality conflicts with practices that reinforce institutional inequality.

The dispute settlement system, one of the WTO's cornerstones, has been paralyzed since 2019 due to the blockage of its Appellate Body, primarily led by the United States. This dysfunction exacerbates the organization's legitimacy crisis and exposes its vulnerability to tensions among state sovereignty, corporate interests, and international law. Organizations such as La Vía Campesina criticize the WTO for undermining food sovereignty, promoting industrial agricultural models, and contributing to the dismantling of peasant economies. More than 50 civil society organizations denounce the WTO as a catalyst of inequality, promoting unsustainable consumption patterns, marginalizing Global South voices, and subordinating social and ecological rights to the imperatives of global trade.

The World Customs Organization (WCO), successor to the Customs Cooperation Council established in 1952, plays a less visible yet fundamental role: standardizing procedures, modernizing control systems, and improving the traceability of goods in transit. In a world where logistical efficiency determines market access, the WCO acts as a technical guarantor of trade flow, strengthens customs security, and combats illicit practices.

Although it refrains from setting substantive trade rules, the WCO contributes to shaping the institutional infrastructure of global trade. Its guidelines, codes, and interoperability platforms are integrated into national and regional systems, effectively shaping the competitive conditions among countries. From a complexity perspective, the WCO functions as a technical subsystem whose relative autonomy influences the behavior of the broader economic system.

The Economic Complexity Index as a Structural Compass

The Economic Complexity Index (ECI), developed by Hausmann, Hidalgo, and collaborators, has emerged as a key tool for understanding the structural evolution of productive systems. This index measures the productive knowledge embedded in traded goods. Countries with high ECI scores export sophisticated and uncommon products, while those with low ECI scores rely on raw materials or low value-added goods.

When applied to tariff analysis, the ECI enables a deeper understanding of how trade policies affect the flow of goods and the architecture of national capabilities. For instance, if the United States imposes tariffs on electronic inputs from China, it may inadvertently discourage local production of complex technologies when there is no robust industrial base to replace them. At the same time, low-complexity sectors such as extensive agriculture are particularly vulnerable to retaliation, revealing the limitations of strategies based solely on traditional competitive advantages.

Complex Thinking invites us to move beyond immediate, linear effects to examine structural consequences, time lags, and hidden interdependencies. A tariff is more than a variable in a supply-and-demand equation. It is an intervention capable of disrupting, restructuring, or regenerating entire productive ecosystems. Its impact depends on timing, context, available capacities, and the global network in which it operates.

This reinforces a central thesis: international trade requires analytical tools suited to dynamic, evolving systems. The global economy today functions as a complex adaptive system, subject to feedback loops, asymmetric shocks, unexpected bifurcations, and governance crises. In this context, trade decisions such as tariffs must be conceived as systemic interventions within a framework of strategic intelligence.

This implies integrating economic data, technological structures, geopolitical tensions, cultural narratives, and ecological conditions into a single analytical framework. It demands an inter- and transdisciplinary praxis that transcends orthodox economics and draws from the epistemology of complexity: embracing uncertainty, valuing emergent phenomena, avoiding analytical fragmentation, and recognizing the historicity of each event. From this perspective, it becomes possible to design trade policies that are truly sustainable and consistent with the interdependent, volatile, and fragile reality of the twenty-first century.

The Economic Complexity Index, or ECI, has become a key analytical tool for interpreting international trade from a systemic and non-reductionist perspective. Developed by Hidalgo and Hausmann in 2009, the ECI is based on a central premise: a country’s economic development depends on the diversity and sophistication of the productive capabilities revealed by its export structure. What a country produces and exports is an indirect manifestation of the collective knowledge it has accumulated and articulated internally.

This approach contrasts with traditional theories of international trade, which explain trade flows based on static comparative advantages such as factor endowments, climate, or geography, or on sectoral differences in productivity. The ECI introduces an epistemological shift by asserting that a nation's wealth lies in its ability to combine specialized knowledge, generate complex products, and actively participate in global networks of learning and innovation. In this view, trade entails the circulation of technological, organizational, and cognitive capabilities.

The Index is constructed from two fundamental variables: diversity and ubiquity. The former refers to the number of products a country exports with revealed comparative advantage. The latter indicates how many other countries also export those same products. The more diverse and less ubiquitous a country’s export portfolio is, the greater its economic complexity. Exporting products such as oil or bananas widely distributed among exporting countries reflects a limited technological base. In contrast, exporting semiconductors, medical equipment, or industrial enzymes produced by only a few highly capable countries signals an advanced cognitive infrastructure.

From this perspective, tariff policy must be evaluated beyond its immediate effects on relative prices, trade balance, or sectoral employment. It is essential to consider its impact on the structural evolution of the cognitive-productive apparatus, both nationally and regionally. A protectionist measure may provide relief to a local industry threatened by external competition, yet it may also limit access to technologically advanced inputs, restrict the incorporation of new knowledge, isolate the country from international knowledge flows, and slow its transition toward more sophisticated sectors.

This dilemma is particularly relevant in the case of complex products. In a global economy organized through interdependent value chains, imposing tariffs on strategic inputs such as microprocessors, electronic components, or biomedical technologies generates systemic effects. Final products become more expensive, technological cooperation weakens, learning flows between countries are obstructed, and the ability to move up the complexity ladder is constrained.

One such case was the trade war led by the Trump administration between 2017 and 2020. The United States imposed tariffs on goods from China under the pretext of correcting trade imbalances and protecting manufacturing jobs. Studies by Bown and Irwin highlight counterproductive effects: increased costs for consumers, supply chain disruptions, and disincentives for investment in strategic sectors. The tariff escalation fostered a geopolitical fragmentation of value chains, weakening the U.S. position in key nodes of the global network of complex products.

The Atlas of Economic Complexity by the Harvard Growth Lab (2023) points to a stagnation in the United States' position in the global complexity ranking over the past decade. Despite having highly advanced sectors such as defense, aerospace, and pharmaceuticals, the prolonged offshoring of intermediate activities to Asia combined with adverse trade policies toward key allies has weakened its distributed system of capabilities. This dynamic compromised its strategic autonomy and productive resilience, as became evident during the COVID-19 pandemic.

From the complexity paradigm, economies are conceived as evolving adaptive systems in which every public policy decision acts as a bifurcation point that reconfigures trajectories. In this sense, a tariff ceases to be a mere customs duty and becomes a systemic disturbance that alters incentives, shifts technological paths, transforms actor interactions, and may trigger cascading effects that are difficult to reverse. Therefore, impact assessments must incorporate systemic indicators such as the ECI, which capture long-term dynamics, knowledge flows, and structural capabilities.

This approach enables counterfactual simulations to explore how a country's export profile would change if the production of higher-complexity goods were actively promoted. Instead of maintaining a bias toward primary commodities, sectors such as biotechnology, specialized software, or advanced manufacturing can be incentivized. These projections powered by the ECI and artificial intelligence models facilitate the design of proactive trade policies aimed at strengthening internal capabilities and building inclusive, dense regional value chains.

During the pandemic, this perspective gained particular relevance. Countries with complex export structures such as Germany, South Korea, and Sweden were able to rapidly retool industrial sectors to produce essential medical supplies. This adaptive capacity relied on a reservoir of distributed knowledge, organizational flexibility, and institutional density, enabling the combination of skills, the redirection of processes, and real-time learning. Consequently, the ECI reflects both technical sophistication and adaptive capacity in the face of systemic disruptions.

This is why tariff policies must be formulated with extreme care. A trade barrier can have regressive effects if implemented without robust strategies for strengthening the innovation ecosystem, fostering technological linkages, and promoting public–private collaborative networks. Negative externalities may also arise, including the expansion of informal markets, product triangulation through third countries, or erosion of trust with strategic partners. These effects may become entrenched as structural bottlenecks that inhibit productive diversification.

Complex Thinking provides analytical tools to understand these dynamics through feedback loops. A protectionist policy may yield visible short-term benefits such as reduced imports or improved trade balances while simultaneously triggering adaptive responses that negate its original effects. For example, a domestic firm shielded from international competition may lose its incentive to innovate, reducing its productivity and future competitiveness.

The political effects also require careful attention. Every tariff policy entails a reconfiguration of distributive coalitions, favoring certain sectors or regions while disadvantaging others. This reinforces narratives of economic nationalism, intensifies multilateral tensions, and redefines the boundaries of state action in global governance. These factors are integral to the constitutive complexity of the socioeconomic system.

A trade policy informed by the complexity paradigm must therefore be guided by three principles:

- • Systemic: to consider the economy as an evolving network of interdependent capabilities, where every intervention produces multidimensional effects.
- • Prospective: to orient decisions toward desirable development trajectories, grounded in collective learning, strategic diversification, and sustainability.
- • Ethical: to embrace global interdependence, promote cognitive justice, and foster shared responsibility in the governance of knowledge commons.

The ECI helps operationalize these principles by offering a metric that goes beyond measuring what an economy produces it reveals what it could produce if it mobilized its latent capabilities. It serves as a strategic compass to guide industrial policy, trade diplomacy, and public investment.

If we accept that economic development transcends isolated efficiency and demands the intelligent articulation of knowledge under uncertain conditions, the design of tariff policies must abandon linear logics and adopt complex, relational, and strategic approaches. The ECI stands as a powerful tool to catalyze this analytical and political leap. What is at stake goes beyond trade it defines the position a country will occupy on the cognitive map of the twenty-first century.

Configurational Factors of International Trade from a Complexity Perspective

International trade understood as the cross-border exchange of goods and services follows multiple dynamic logics. It is a structurally complex process, shaped by factors that interact in linear, feedback-driven, and contingent ways. In conventional analysis, these factors are often presented as independent variables: comparative advantage, factor endowments, trade policies, consumer preferences, among others. This classification loses explanatory power in a globalized, interdependent world subject to technological, geopolitical, and ecological mutations.

In this regard, economics must move beyond the treatment of trade as a closed model of perfect rationalities and markets in equilibrium. Comparative advantage the foundation of classical trade theory since David Ricardo must be reinterpreted as a historically constructed outcome based on technological capabilities, educational trajectories, and institutional structures. Factor endowments should be understood as the result of complex processes of knowledge accumulation, access to critical infrastructure, and connections to global innovation networks. Even consumer preferences are mediated by cultural factors, media narratives, and technologies of digital influence.

To this constellation must be added variables such as labor costs, exchange rates, inflation, geopolitical shocks, industrial relocation, logistical disruptions, and climate change all of which configure a thermodynamic and unstable system, rather than an efficient and predictable market. In this context, complex thought, following Morin, emerges as an indispensable epistemological and methodological alternative for analyzing the dynamics of global trade beyond quantitative determinism.

The neoclassical approach defines tariffs as distortions taxes that raise prices, reduce trade volume, and result in net welfare losses. Although logically consistent within general equilibrium models, this formulation is blind to the political, cultural, and technological complexities that such instruments generate in practice. In contrast, the complexity paradigm allows tariffs to be understood as devices with multiple dimensions: economic, symbolic, strategic, and emergent. From this perspective, tariffs are conceived as catalysts of structural transformation. Their imposition can generate feedback loops positive or negative that alter relations between countries, internal productive structures, narratives of economic sovereignty, and collective imaginaries of development. For instance, a tariff on solar panels may induce investment in local manufacturing, shift the energy matrix, provoke diplomatic tensions, stimulate technological nationalism, or accelerate innovation in energy storage.

This type of analysis demands abandoning causal linear reductionism and adopting a systemic outlook in which tariffs function as bifurcation points that trigger new and unpredictable configurations. In this context, the economy more closely resembles an adaptive ecosystem than a machine seeking equilibrium.

Deglobalization or Systemic Mutation?

Much has been written about the alleged deglobalization that would define the twenty-first century. This idea is misleading if interpreted as a linear retreat toward closed or autarkic economies. What has truly emerged is a new form of globalization: asymmetric, politicized, fragmented, and adaptive. Rather than an abandonment of global trade, it is a reorganization of its logics, routes, actors, and technologies, guided by criteria of national security, strategic autonomy, and sustainability.

This phenomenon can be understood as a transition from a globalization driven by efficiency to one governed by resilience. The system behaves like a living organism: it adapts its nodes, redistributes functions, redefines vulnerabilities, and reconfigures critical zones. Trade is now structured by combining comparative advantage with considerations of energy sovereignty, technological dominance, logistical control, and digital governance.

In this new scenario, tariffs function as adaptive signals. They express a strategic rationality aimed at recalibrating external exposure, protecting key sectors, and rebuilding value chains based on their geoeconomic criticality. They are part of a broader process of self-regulation within the global system in response to multiple shocks health-related, military, energy, or climate-related.

Tariff Policy from the Complexity Paradigm

Tariff policy has traditionally been conceived as a technical instrument for intervening in international trade, aimed at regulating the relative prices of imported goods to protect strategic sectors, stimulate domestic production, or generate fiscal revenue. This classical conception reflects a linear and monocausal approach, typical of neoclassical economics, which interprets tariffs as mere variables within supply and demand models, with predictable and quantifiable effects. In a context characterized by systemic interdependence, structural uncertainty, and the rapid transformation of global value chains, this view proves deeply insufficient.

From the perspective of Complex Thinking particularly as developed by Edgar Morin tariff policy must be understood as an intervention within an open, dynamic, feedback-driven, and non-linear system. Far from operating as unidirectional mechanisms, tariffs function as strategic interaction nodes within global networks that encompass governments, corporations, consumers, technologies, political cultures, and institutional regimes. Any disruption to these networks produces effects that are often trivial in appearance yet unexpected, and that feed back into the system, altering its structure.

The difference between the traditional and complex approaches to tariff policy is radical. The former assumes an instrumental logic based on specific objectives such as protecting vulnerable sectors, generating fiscal revenue, or correcting external imbalances and uses predefined tools under assumptions of perfect rationality, symmetric information, and static equilibrium. The effects of a tariff measure are presumed to be proportional and predictable: higher tariffs lead to lower imports, increased domestic production, and an improved trade balance. While this logic may be useful in stable contexts, it proves ineffective in the contemporary dynamics of international trade, shaped by geopolitical shocks, technological shifts, tariff wars, and evolving consumption patterns.

In contrast, the complexity approach recognizes that global trade operates as an adaptive, decentralized, and self-organizing system in which multiple actors interact simultaneously across different levels, generating cumulative effects, feedback loops, and emergent phenomena. In this framework, tariff policy is conceived as a signal within a dense network of meanings, strategies, and interests, capable of catalyzing profound transformations in value chains, investment locations, diplomatic alliances, and risk perceptions.

One example of these dynamics is the trade war unleashed between the United States and China during the administration of Donald Trump. Under the "America First" slogan, unilateral tariffs were imposed on hundreds of Chinese products with the aim of reducing the trade deficit, reshoring industrial jobs, and pressuring for structural changes in China's economic model. The outcomes defied traditional projections: China retaliated with mirrored tariffs, U.S. firms faced higher input costs, farmers lost access to strategic markets, and many corporations opted to reconfigure their supply chains, relocating part of their production to third countries. Far from stabilizing the system, tariff policy triggered a spiral of uncertainty, mistrust, and systemic instability. From the perspective of complex systems theory, this type of dynamic responds to three fundamental principles: feedback, emergence, and coevolution.

- Feedback: Every tariff measure generates effects that, directly or indirectly, feed back onto the actor implementing it. In the case of Trump's tariffs, the attempt to protect the manufacturing sector ended up harming agricultural exporters, generating domestic pressures that led to the adoption of compensatory subsidies. This negative feedback eluded linear models but can be anticipated through systemic approaches that account for the multiplicity of affected actors.

- Emergence: The effects of a tariff measure result from the interactions among multiple variables. For example, tariffs on solar panels altered import prices, slowed the energy transition, affected international climate cooperation, and reshaped investment preferences in clean technologies. These emergent effects must be taken into account when evaluating any tariff decision, as they are irreducible to static welfare calculations.

- Coevolution: International trade actors including firms, states, and consumers function as agents who learn, adapt their strategies, and reshape their environments. A tariff measure can induce processes of innovation, relocation, or productive restructuring that transform the system's architecture. In this sense, tariffs are both defensive mechanisms and tools of evolutionary policy, capable of catalyzing structural change if used strategically.

The complexity paradigm also prompts a rethinking of the methodologies used to design and evaluate tariff policies. In addition to conventional econometric models, it is necessary to integrate mixed approaches combining network analysis, scenario simulations, system modeling, and case studies. For instance, intersectoral input–output matrices can reveal the indirect effects of a tariff on connected sectors. Commercial big data analysis can help anticipate trade deviations or triangulations, while territorial impact studies identify subnational asymmetries. This multidimensional approach enables the assessment not only of a policy's efficiency but also its equity, sustainability, and social legitimacy.

The governance of tariff policy must also be rethought. Instead of centralized, top-down, technocratic decisions, a complexity-based approach suggests participatory, deliberative, and iterative mechanisms, in which diverse actors such as producers, labor unions, consumers, environmentalists, and local communities can contribute relevant knowledge and perspectives. This avoids the capture of policymaking by rent-seeking elites, improves the quality of available information, and enhances the legitimacy of decisions.

For instance, designing a tariff to protect the textile industry must account for labor conditions in the sector, the environmental impact of production processes, international competitiveness, regional integration, the availability of clean technologies, and opportunities for popular and solidarity-based economies. This transdisciplinary approach enables the formulation of tariff policies that serve as levers for structural transformation.

In this sense, tariff policy must be understood as a strategic tool aligned with broader objectives: ecological sustainability, territorial equity, technological innovation, food security, and energy sovereignty. This demands the abandonment of economic reductionism and calls for a rethinking of tariffs through political, cultural, and civilizational lenses.

In energy transition contexts, it may be justified to establish differentiated tariffs on polluting technologies or to create tariff incentives for products that meet circular economy criteria. Similarly, in green reindustrialization processes, tariffs can function as instruments for fostering strategic sectors when coordinated with training programs, research initiatives, and environmental certification systems.

Tariff policy must also adapt to new configurations of digital trade, automation, and the knowledge economy. In this context, traditional tariffs lose efficacy as a stand-alone tool and must be complemented by measures on intellectual property, digital taxation, server localization, data protection, and technological sovereignty.

Tariff policy in Latin America should be conceived through a logic of shared regional sovereignty. This entails coordinating strategies among countries, harmonizing regulations, avoiding destructive competition, and building common platforms to confront external pressures. A coherent regional tariff policy can be key to strengthening the region's position in global negotiations, protecting shared strategic sectors, and reducing dependency on hegemonic centers of economic power.

Seen through the lens of complexity, tariff policy becomes a strategic device for systemic reconfiguration. This perspective demands the integration of multiple forms of knowledge, the recognition of uncertainty as a structural condition, and the design of adaptive, participatory, and transdisciplinary governance mechanisms. In doing so, it can contribute to a more just, resilient, and sustainable form of global integration for the countries of the Global South.

Trade Policy through the Lens of Complexity: Instruments, Disputes, and Transformation

Trade policy represents one of the most decisive instruments through which states shape their global insertion, configure their productive structures, and define their development models. Far from being merely technical devices, these policies embody societal projects, power struggles, and worldviews. In Latin America, their design and implementation have historically oscillated between models of openness and protectionism, always under the influence of a hierarchical global economy in which the region has occupied peripheral and subordinate positions, as noted by Prebisch, Cardoso, and Faletto.

From a Complex Thinking perspective, trade policies are understood as components of broader socioeconomic systems where state actors, corporations, social sectors, regional blocs, technologies, productive cultures, and international norms interact. These interactions generate multiple dynamics, feedback loops, and emergent effects that demand a transdisciplinary, contextual, and historically grounded interpretation, as proposed by Morin.

In general terms, trade policy encompasses the set of measures, norms, and strategies that regulate a country's foreign trade: imports, exports, foreign investment, market access, productive incentives, protection of local industries, and dispute resolution mechanisms. Its stated goal is to maximize national welfare through economic growth, job creation, export diversification, and enhanced competitiveness.

Its real effects, however, are heterogeneous and often contradictory. Free trade may reduce consumer prices while destroying local jobs. Protectionism may safeguard strategic sectors while raising input costs and introducing inefficiencies. Foreign investment may stimulate the economy while also generating technological dependency and profit repatriation. For this reason, trade policy must be evaluated in terms of efficiency, sovereignty, equity, sustainability, and cognitive justice.

Throughout much of the twentieth century, Latin America adopted a protectionist approach through import substitution industrialization (ISI), supported by high tariffs, currency controls, state subsidies, and import barriers. This strategy aimed to create national industries, reduce external vulnerability, and diversify the economy. It achieved some degree of industrialization and urbanization, although its authoritarian, bureaucratic, and debt-dependent implementation led to fiscal imbalances, inflation, and balance-of-payments crises.

The neoliberal turn of the 1980s and 1990s, driven by the Washington Consensus, promoted rapid trade liberalization, deregulation, and financial openness. Free trade agreements were signed, subsidies eliminated, and tariffs reduced. This transition allowed certain economies to integrate into global value chains while also producing premature deindustrialization, labor market precariousness, and productive concentration in extractive sectors. The continued reliance on raw materials and limited technological diversification curtailed the region’s endogenous innovation capacities.

From a complexity perspective, the oscillation between openness and protection reveals a deceptive dichotomy. What proves essential is the design of hybrid, flexible, and context-sensitive strategies that integrate multiple objectives such as external competitiveness, social cohesion, environmental sustainability, and productive sovereignty. This requires a perspective that acknowledges interdependencies among sectors, territories, and scales, while anticipating the systemic effects of each trade measure. Within this framework, a range of trade policy instruments can be identified, whose effects must be assessed in economic, ecological, cultural, and geopolitical terms:

- Tariffs: Taxes levied on imported goods to protect domestic production. Although orthodoxy treats them as distortions, complexity thinking reframes tariffs as strategic tools for productive transition, provided they are implemented with time limits, impact assessments, and alignment with industrial policy.

- Rules of Origin: Define the criteria used to determine the national source of a product, thereby influencing its tariff treatment. These rules may encourage local production while also enabling regulatory dumping practices, such as export triangulation to circumvent trade restrictions.

- Customs Procedures: Beyond their fiscal and security functions, customs processes are essential to trade facilitation. In countries with limited institutional capacity, their complexity becomes a de facto trade barrier and a locus of corrupt practices.

- Public Procurement: A critical instrument for supporting domestic sectors, national technology, and sustainable production. Redesigning public procurement with criteria for local value-added, social impact, and environmental sustainability can act as a structural change engine.

- Investment Promotion: The attraction of foreign capital should be evaluated based on its capacity for technology transfer, generation of quality employment, and creation of productive linkages. Unconditional tax incentives perpetuate extractive logics and foster unfair competition between regions.

- Subsidies: Targeted toward strategic sectors such as green technologies, science, education, and the social economy. From a complexity standpoint, subsidies operate as catalysts of transitions when tied to agendas for structural transformation.

- Import Quotas: While restrictive, these measures are sometimes necessary to protect vulnerable sectors during periods of crisis. Their application requires ongoing evaluation and connection to productive restructuring plans.

- Voluntary Export Restraints: Used as diplomatic tools to avoid harsher sanctions and to stabilize international prices in oligopolistic markets. Notable examples include sectoral agreements in steel, sugar, and textiles.

- Local Content Requirements: Designed to incentivize the use of domestic inputs, fostering supply chain integration and job creation. Effective implementation demands rigorous monitoring, transparency, and oversight to prevent circumvention.

- Anti-dumping Duties: Employed to counter unfair trade practices, although they can sometimes disguise protectionist measures. Their legitimacy depends on technical capacity to assess reference prices, injury margins, and distributive impacts.

Alongside these instruments, contemporary trade policy confronts challenges arising from the digital economy, the energy transition, climate change, and geopolitical conflict. The expansion of e-commerce raises critical questions about platform regulation, digital taxation, and data sovereignty. Disputes over vaccine patents and green technologies have reignited debates on equity in access to knowledge. Trade wars, such as the one led by the United States and China, reveal that global trade is driven by struggles over hegemony, power, and technological control. In this context, Latin America must craft a trade policy rooted in strategic foresight and long-term vision, guided by resilience, diversification, and equity. This entails:

- Designing productive matrices that reduce dependence on commodities and promote knowledge-intensive sectors

- Aligning trade policy with industrial, technological, environmental, and social agendas

- Strengthening regional integration mechanisms with emphasis on complementarity, solidarity, and the protection of commons

- Advancing legal frameworks that uphold Indigenous Peoples' rights, collective ownership of knowledge, and principles of fair trade

- Building institutional capacity for international negotiations, with technical teams capable of representing national interests and defending the common good against corporate agendas

- Democratizing trade policymaking by involving unions, communities, cooperatives, universities, and civil society organizations

Trade policy must cease to be a technocratic tool and evolve into a democratic mechanism for shaping the future. This requires transcending dependency paradigms, challenging the hierarchies embedded in global trade, and reclaiming the capacity to imagine alternatives from and for the Global South. As Morin warns, any truly transformative policy must embrace uncertainty, conflict, and complexity as constitutive dimensions of its design. Only then will it be possible to build a Latin American trade policy capable of overcoming historical asymmetries and opening paths toward a plural, just, and sustainable economy.

Donald Trump's tariff policy as a case study in complexity thinking.

Trump vs. China: A Trade War as a Complexity Laboratory

Between 2018 and 2020, the Trump administration imposed tariffs exceeding $360 billion on Chinese goods, prompting China to retaliate with measures targeting U.S. exports worth over $110 billion. What began as an economic offensive aimed at protecting domestic employment rapidly devolved into a chaotic process of cross-cutting impacts, contradictory subsidies, and geoeconomic reconfigurations.

From a linear perspective, this trade war might be interpreted as a failure: it drove up domestic prices, strained diplomatic relations, and reduced bilateral trade. From a complexity standpoint, however, its significance lies in the systemic transformations it unleashed. Global supply chains diversified, with production shifting to countries such as Vietnam, India, and Mexico.

Compensatory subsidy policies emerged, narratives of technological sovereignty and strategic resilience gained prominence, and international logistics routes were reshaped. The complexity of this conflict resided in its ability to alter the structural conditions of global trade. The United States neither lost nor won in absolute terms the playing field was irrevocably transformed, exposing the fragility of a highly interconnected system.

The tariff policy implemented by Donald Trump between 2017 and 2021 serves as a case study for analyzing the dynamics of international trade through the lens of complexity thinking. Far from representing a mere tariff adjustment, this shift marked a profound reconfiguration of geoeconomic balances, protectionist narratives, and the very conditions for multilateral commercial governance. The unilateral imposition of tariffs on products from China, the European Union, Mexico, Canada, and other strategic partners signaled a mutation in the global system: the return of the state as an interventionist actor in the name of economic sovereignty.

Under the banner of "America First," Trump framed his trade policy as a response to the chronic imbalances affecting the U.S. economy for decades. He argued that unrestrained trade liberalization had destroyed industrial jobs, weakened domestic productive capacity, and jeopardized national security. In April 2025, he reiterated this view in a public statement: "Our new trade policy is a declaration of economic independence. The world has taken advantage of the United States for over fifty years. That's never going to happen again." Controversial as it was, this narrative captured a growing sense of institutional and social discontent within large segments of the population, who perceived globalization more as a dislocating force than an integrating one.

From a traditional standpoint, tariffs are designed to alter the relative prices of imported goods to favor domestic production. This linear logic fails to account for the complexity of today's global trade system, where value chains are deeply interconnected, production processes are geographically fragmented, and flows of information, technology, and capital operate in high synchrony. In this context, a tariff does more than shift import volumes it can trigger nonlinear effects, feedback loops, and evolutionary bifurcations that transform the system as a whole.

One of the most revealing examples was the imposition of tariffs on steel and aluminum, ostensibly to protect industries deemed critical to national security. Far from strengthening the domestic industrial base, this measure significantly increased the cost of inputs used by key sectors such as automotive, construction, and heavy machinery. Many companies, rather than absorbing the additional costs, chose to relocate production abroad, triggering a structural paradox: the protectionist tariffs incentivized the very offshoring they sought to reverse.

This boomerang effect vividly illustrates the thesis that in complex systems, every intervention produces unpredictable collateral consequences. To make sense of these dynamics, it is useful to apply four diagnostic questions inspired by Morin's analytical logic: Where do we come from? Where are we now? Where are we heading? And where should we go?

Where do we come from?

International trade has historically been both a driver of growth and a domain of structural asymmetries. From premodern exchanges based on barter to today's trade networks organized by treaties and transnational corporations, the evolution of trade has been shaped by systemic imbalances driven by the concentration of economic, technological, and regulatory power in the hands of a few countries. Successive waves of globalization those of the 19th century and the post-1945 era expanded trade flows while entrenching the dependence of many countries in the Global South on raw material exports and manufactured goods imports.

The trade liberalization model imposed since the 1980s through the Washington Consensus, free trade agreements, and the consolidation of the WTO promised efficient resource allocation and harmonious integration. In practice, many countries became trapped in suboptimal equilibriums, failing to diversify their productive bases or significantly improve their human development indicators. The emergence of China as a global manufacturing powerhouse, with an aggressive and tightly planned industrial policy, further disrupted the system's rules, intensifying tensions with the United States and the European Union.

Where are we now?

The international trade system is currently undergoing a phase of transition and uncertainty. According to WTO data, in the first quarter of 2024, global trade showed signs of recovery, with 2% growth in the Global South, particularly in South–South exchanges. This resilience coexists with contradictory dynamics: geopolitical fragmentation, selective protectionism, latent trade wars, and a legitimacy crisis for multilateralism. The COVID-19 pandemic and the war in Ukraine deepened the perception of systemic vulnerability, prompting several countries to reassess their international trade strategies, prioritizing productive relocation, food security, and technological autonomy.

In this context, the unilateral decisions taken by the Trump administration were not an isolated aberration but a harbinger of a broader trend: the return of the state as an active regulator of foreign trade under the rubric of strategic sovereignty. The implementation of measures without systemic impact assessments unleashed cascading adverse effects: rising domestic prices, strained relationships with historical allies, loss of competitiveness in key sectors, and retaliatory tariffs that hit U.S. agricultural exports.

Where Are We Heading?

The WTO projects that global trade will grow by approximately 2% annually through 2030. The Global South is expected to increase its share of world exports, driven by Asia's technological rise and the expansion of new regional markets. Partial deglobalization is also anticipated, shaped by the pursuit of resilience, the formation of geoeconomic blocs, and the restructuring of supply chains around geostrategic and environmental criteria. Digitalization, the energy transition, and artificial intelligence will redefine the rules of global competition, favoring countries that succeed in articulating knowledge, infrastructure, and adaptive institutions.

The risk for many peripheral economies lies in being sidelined from these transformations due to the absence of strategic planning, commodity dependence, institutional fragility, or lack of systemic vision. In this regard, Trump's trade war should be interpreted as a warning signal highlighting the fragility of current insertion models. Its aggressive protectionism forces a rethinking of the foundations of international trade and the relative position of each country in the global network of knowledge and value creation.

Where Should We Go?

From the perspective of complex thought, the path forward avoids both autarkic isolation and blind openness to global markets. What is needed are adaptive trade policies aimed at increasing the cognitive density of the productive apparatus, diversifying exports, promoting the knowledge economy, and designing international insertion strategies rooted in relative autonomy, South–South cooperation, and regional integration. This entails moving beyond the logic of passive dependence and developing long-term visions supported by advanced logistics infrastructure, human capital development, energy transition, and the strategic use of emerging technologies.

Institutionally, this requires strengthening state planning, shielding public policies from electoral cycles, combating structural corruption, and establishing multilevel governance agreements that bring together state, business, academic, and community actors. Only then will it be possible to improve the Economic Complexity

Index, enhance domestic value-added, and gain more favorable positions in the global trade architecture.

Trump's trade war must be viewed as a complex event that exposes the fissures and tensions of the current world system. Its contradictory effects demonstrate that trade policies generate multidimensional impacts that must be understood through an integrative and strategic paradigm. Hence the urgency of adopting a complex systems approach in trade strategy design one capable of anticipating systemic effects and constructing more equitable, sustainable, and sovereign futures.

The Impact of the U.S.–China Trade War on Economic Complexity

One of the most insightful analytical frameworks for assessing the structural effects of the trade war between the United States and China is the Economic Complexity Index (ECI), developed by Hausmann and Hidalgo and applied by Harvard University and MIT. This indicator integrates the diversity of a country's exportable products with the ubiquity of those products in other territories, offering a structural approximation of an economy's sophistication and adaptability. The tariff war, by significantly altering trade flows, diversification strategies, and interdependence maps, reconfigured macroeconomic balances and the very logic of economic complexity production.

During the peak years of the conflict, the United States' ECI exhibited a stabilization trend, while China's showed steady progress. This divergence, although subtle, reveals the Asian giant's capacity to redirect its exports toward other Global South economies while simultaneously intensifying its endogenous capabilities in high-tech sectors such as artificial intelligence, 5G, and biotechnology. In contrast, the U.S. economy anchored in complex sectors and dependent on dispersed global supply chains faced greater obstacles in replacing strategic inputs and maintaining the centrality of its export position without compromising prices or efficiency.

A systemic perspective reveals that tariffs redirected bilateral trade flows and transformed the topology of the global trade network for complex products. Countries such as Vietnam, Malaysia, and Mexico emerged as alternative assembly hubs and benefited from the strategic offshoring driven by tensions between Washington and Beijing. This phenomenon amounts to a mutation in the architecture of global production networks: the most trafficked pathways of complex goods are being redistributed, new logistical corridors are emerging, and the strategic value of peripheral territories previously overlooked by global value chains is increasing.

In light of these shifts, the trade war can be interpreted as an accelerator of the international system's transformation from a model centered on dominant hubs to a more polycentric structure in which multiple medium-sized countries gain prominence as production platforms, service centers, or specialized suppliers. This dispersion increases the systemic complexity of global trade: the number of interactions multiplies, each actor's degrees of freedom expand, and the system becomes more vulnerable to desynchronized shocks or technological disruptions.

From the perspective of complex thought, every intervention in a system generates unforeseen effects. The U.S.–China trade war, conceived as a bilateral pressure tactic to restore tariff fairness, triggered a cascade of emergent consequences many of them unexpected even by its initiators. First, it boosted China's technological autonomy, doubling its investment in applied science and reorganizing its internal value chains in critical sectors. Then, it accelerated regional production restructuring in the Asia-Pacific, undermining unilateral U.S. leadership. It also stimulated the formation of alternative trade agreements, such as the Regional Comprehensive Economic Partnership (RCEP), from which the United States remained excluded.

These developments, arising from the interactions among states, corporations, consumers, and multilateral institutions, illustrate the complex nature of the global economic system. In response to tariff stimuli, the system demonstrated a dynamic capacity for reconfiguration that transcended zero-sum logic. Some regions gained advantage, while others transformed their internal structures without aligning strictly with a single bloc. This plasticity reflects a fragmented global economy developing resilient forms of coevolution and rebalancing.

The complexity paradigm calls for overcoming the instrumentalist view of trade policy focused solely on efficiency calculations and balance sheets. It proposes a contextual intelligence that integrates multiple variables, scales, and temporalities. The responses of different countries to Trump's trade war exemplify this epistemological shift. Rather than replicating a uniform model, each economy activated local knowledge, consolidated internal capabilities, and formed specific alliances to mitigate impacts and seize opportunities. This plurality of trajectories reflects what Morin describes as strategies under uncertainty decisions built through progressive adaptation rather than closed forecasts.

In Latin America, several countries capitalized on agricultural trade realignments to increase soybean, corn, and meat exports to China, while others sought to attract investments diverted from the United States. In Africa, some states identified the conflict as an opportunity to relaunch their industrial strategies in sectors where tariff wars reduced Asian competitiveness. This diversity of responses reveals that in complex environments, solutions emerge as situated constructions that blend resources, values, histories, and capabilities.

Applying the Economic Complexity Index to the United States and the Tariff War with China

The Economic Complexity Index (ECI) provides a privileged lens for analyzing the trade tensions between the United States and China, particularly during Donald Trump's administration (2016–2020), when an unprecedented tariff policy was deployed, affecting thousands of products and strategic sectors. Through the prism of complexity, this confrontation emerges as far more than a tariff dispute. It represented a structural conflict between two models of productive, technological, and geoeconomic organization.

Historically, the United States has occupied top positions in ECI rankings due to its export diversity, its network of technological capabilities, and its leadership in high cognitive intensity sectors such as aerospace, pharmaceuticals, computing, and specialized machinery. Since the 1990s, however, the country has shown signs of relative stagnation, while maintaining a persistently negative trade balance.

This stagnation stems less from an absolute loss of capabilities and more from a process of strategic outsourcing. Many complex manufacturing operations were relocated to Asia particularly China in a dynamic of global value chain restructuring. Thus, while the United States retained control over design, intellectual property, and financing, it ceded a significant portion of advanced manufacturing to emerging economies. Although cost-efficient, this production offshoring generated structural vulnerabilities, industrial job losses, and growing external dependence in critical sectors.

The ECI helps illuminate this paradox. Despite a high average complexity, the U.S. productive structure began to show increasing concentration in technological and digital services sectors, while its diversified manufacturing capacity weakened. The result was a rise in structural fragility in the face of global disruptions as demonstrated during the COVID-19 pandemic and a political perception of unjust deindustrialization that fueled the narrative of economic protectionism.

In contrast, China has led the most significant climb in ECI rankings over the past four decades. Once a low-value-added and assembly-based economy, it has evolved into a high-density industrial system capable of leading sectors such as telecommunications, automation, renewable energy, artificial intelligence, and more recently with growing intensity, semiconductors. This qualitative leap has resulted from a deliberate industrial policy rooted in technology transfer, accelerated learning, strategic subsidies, and state control over knowledge.

The Made in China 2025 platform, promoted by the Chinese government, constituted the most ambitious program of technological modernization and productive sophistication ever undertaken by a developing country. Its explicit objectives included reducing dependence on foreign technology, leading in emerging sectors, and ascending the global value chain. Through the lens of the ECI, one can observe how China ceased to be the world's workshop and transformed into a cutting-edge laboratory across multiple domains.

The rise in economic complexity translated into higher GDP and a redistribution of global geoeconomic power. China began to challenge U.S. hegemony not only in trade but also in the governance of technological standards, investment networks, logistical routes, and scientific diplomacy. This transition triggered a structural conflict that materialized in the so-called tariff war.

The trade conflict initiated by Trump in 2018 was more than a temporary response to the bilateral trade deficit with China. It was the manifestation of a systemic struggle for supremacy in the knowledge economy. The unilateral increase in tariffs on Chinese goods affecting over $370 billion in products was accompanied by investment restrictions, sanctions against tech firms like Huawei, and pressure on allied nations to exclude Chinese components from critical infrastructure.

From a complexity perspective, this war represented a decoupling strategy: the United States sought to halt China's technological rise and restore its productive autonomy in strategic sectors. Yet the conflict revealed fundamental limitations. On one hand, many American firms depended on Chinese inputs in their production chains, making tariffs detrimental to their costs and profit margins. On the other hand, China responded with countermeasures, reoriented its markets, and accelerated domestic innovation.

Beyond its immediate effects, the tariff war exposed the structural interdependence of global trade. The United States and China incurred enormous costs in attempting a complete separation. Complex products emerge from global networks of collaboration, and capabilities cannot be quickly replicated without an institutional, educational, and technological foundation. In this context, economic complexity underscores the limits of economic nationalism in an era of structural interconnection.

Empirical Assessment of Tariff Impacts through the ECI

One of the main limitations of conventional economic analysis lies in evaluating the trade war solely based on GDP fluctuations or aggregate trade volumes. The Economic Complexity Index (ECI) provides a more accurate lens, as it enables the observation of tariff impacts on the relative position of the United States in strategic products, identifies which goods gained or lost complexity within the export matrix, and reveals which productive capabilities were either eroded or strengthened.

Recent studies demonstrate heterogeneous effects. Sectors such as steel, heavy machinery, and semiconductors experienced disruptions in their value chains, impairing production capacity and driving up domestic prices. By contrast, some agricultural segments received compensatory subsidies that sustained their export participation. In terms of complexity, the United States registered a mild deceleration in its aggregate index, while China maintained steady growth, particularly in green technologies and smart manufacturing (Friedman et al., 2023).

These findings highlight the ECI's potential as both a retrospective diagnostic tool and an input for designing industrial policies aimed at complex resilience. It becomes possible to identify bottlenecks in critical capabilities, evaluate intersectoral connectivity density, and project pathways for adjacent diversification under various geopolitical scenarios.

The tariff war also triggered indirect effects in Latin America. Some countries capitalized on the opportunity to insert themselves as alternative suppliers in disrupted value chains, especially in agriculture, minerals, and electronics. Others encountered greater trade volatility and growing difficulties in attracting long-term investment due to systemic instability and rising protectionism.

From a complexity perspective, Latin America faces a structural dilemma: either leverage industrial relocation (nearshoring) to ascend the product complexity ladder or become trapped in a renewed division of labor centered on technological extractivism and low-value-added services. The key lies in strengthening endogenous capabilities, aligning industrial policy with education and innovation strategies, and building regional alliances that enhance collective productive density.

The intersection between tariff policy and economic complexity clearly exposes the structural tensions surrounding the transition toward a post-globalized world order. The trade war between the United States and China goes far beyond a dispute over trade balances. It represents a strategic struggle for control over critical technological capabilities within the knowledge economy. In this context, the traditional technocratic paradigm based on linear, siloed, and short-term decisions proves insufficient to govern the interdependent, adaptive, and complex systems that define the contemporary global economy.

The Economic Complexity Index (ECI) emerges in this context as a high-value conceptual and methodological tool. Its ability to map the diversity and sophistication of a country's exports allows for inference about the underlying architecture of knowledge, productive capabilities, and institutional robustness that sustain its economic apparatus. Beyond diagnosis, however, the ECI offers a compass for action: it guides intelligent diversification strategies, identifies structural bottlenecks, and enables ex ante and ex post evaluation of the systemic impacts of trade, industrial, or technological policies.

Analyzing the tariff policy implemented by the Trump administration through the lens of complexity yields three key lessons. First, it demonstrates that the effects of a tariff cannot be understood in binary terms, as they reshape global value networks, destabilize systemic equilibriums, and trigger feedback and adaptation dynamics that alter both the efficiency and resilience of productive systems. Second, it reveals that protectionism, when devoid of deliberate strategies to strengthen technological, institutional, and organizational capabilities, produces ambiguous or even counterproductive outcomes over the medium term. Third, it underscores the need for an ecological and inclusive vision of development, where productivity is linked to social equity, environmental sustainability, and democratic governance.

The trade war also exposes the structural limits of economic unilateralism. In a densely interconnected world, no country can isolate itself without incurring significant costs in terms of technological learning, access to strategic markets, or productive upgrading. Interdependence, far from being a vulnerability, constitutes the essential condition of complexity. Therefore, what is required is not decoupling, but a reconfigured integration oriented toward systemic resilience, social inclusion, and ecological sustainability.

Latin America faces a structural crossroads in this emerging landscape. Historically excluded from the most sophisticated links of global value chains, its export profile remains dominated by low value-added commodities with limited technological intensity. The ongoing reconfiguration of global supply chains, coupled with growing demand for green-intensive complex goods, opens a window of opportunity for more strategic insertion into highly sophisticated production niches. Achieving this requires active industrial policies, sustained investment in science, technology, and innovation, and the promotion of regional coordination that transcends fragmented approaches and revives both mesoeconomic synergies and macrostructural integration.

This transformation demands a profound epistemological innovation. The paradigm of complex thought, as developed by Edgar Morin, provides a theoretical and ethical framework for rethinking development beyond conventional indicators. From this perspective, complexity is not a problem to be solved, but a constitutive condition to be understood, inhabited, and governed. Governing complexity entails weaving together diverse knowledges, embracing uncertainty, fostering collective intelligence, and designing public policies with a transgenerational horizon.

In this sense, the Economic Complexity Index (ECI) must be understood as a strategic instrument for guiding transformative public policy. Integrating it into the analysis of tariff policy shifts the focus from measuring gross trade flows to assessing the structural quality of productive processes, the density of distributed capabilities, the relational intensity of economic sectors, and the ecological viability of development trajectories. This analytical shift is essential for designing public interventions that are effective, legitimate, and sustainable.

The true value of the ECI lies in its potential to reconfigure the core questions that shape economic policymaking: What capabilities do we aim to develop? What forms of knowledge are being activated or marginalized? What institutional arrangements enable or hinder the leap to more complex sectors? What models of cooperation allow for scaling without destroying ecosystems or deepening inequalities? These questions are addressed from a transdisciplinary perspective that brings ethics, politics, and ecology into the heart of decision-making.

Thus, economic complexity becomes a compass for structural development, far removed from being an academic fad or superficial metric. Its adoption entails a commitment to a situated future-oriented vision, where knowledge production is recognized as the foundation of a productive democracy. It means acknowledging that universal solutions and linear pathways are meaningless in contexts where development unfolds through networks, in dialogue with territories, cultures, and social temporalities.

Incorporating the ECI into the design and analysis of trade policy constitutes a substantive contribution to twenty-first-century development debates. Rather than merely growing in quantitative terms, the goal becomes growing more intelligently, equitably, and resiliently. Rather than abstractly pursuing competitiveness, the objective is to strengthen cognitive, technological, and institutional ecosystems capable of sustaining a collective well-being agenda and planetary sustainability.

Complexity, properly understood, ceases to be a technical barrier or an unnecessary sophistication and becomes the fundamental condition of contemporary reality. Governing it transcends the sole responsibility of the state, businesses, or scientists and becomes a shared civilizational task one that demands epistemic humility, political courage, and ethical imagination.

Chapter 11

Modern Agriculture through the Lens of Complexity

Modern Agriculture through the Lens of Complexity

Historically, agriculture has been interpreted through a mechanistic-deterministic paradigm an epistemological matrix that, since the seventeenth century, has guided the development of the sciences. This model privileges the search for regularities and linear causal correlations, generating important advances while falling short in grasping agriculture as an inherently social, ecological, and adaptive practice (Morin, 2007; Gharajedagui, 2008). Far from being a predictable machine, agricultural reality manifests as a web of multidimensional interactions that defy reductionism. In this context, a paradigm shift emerges as necessary from fragmented analysis to complex thought.

This epistemological shift responds to mounting evidence that agricultural activity cannot be understood solely through biophysical or technological variables. A comprehensive approach is needed, one that considers the convergence of ecological, economic, social, cultural, technological, and political factors (Altieri & Toledo, 2011). Contemporary agroecology, in its most critical and transdisciplinary strand, arises as a response to this complexity, transcending the narrow view of the agroecosystem as a mere productive unit to incorporate markets, public policies, traditional knowledge, and local worldviews.

From this perspective, the boundaries of the agroecosystem are understood as epistemic constructions permeated by information flows, power relations, and cultural decisions (León, 2009). Delimiting an agroecosystem involves a theoretical operation: selecting certain elements as relevant while excluding others, based on scientific, political, or ethical criteria. This challenges researchers to reflect on what to integrate within the analytical system and what to consider as its environment, recognizing that every delimitation is partial and situated.

Complex thought, as proposed by Morin (2007), provides a robust theoretical framework for approaching this reality. Rather than dissecting the agricultural phenomenon into isolated components, it invites us to comprehend it as an organized totality of interacting levels and dimensions ecological, technical, economic, social, and symbolic. Agroecosystems, from this perspective, appear as open, adaptive, dynamic, and recursive systems where new properties emerge that exceed the sum of their individual components.

Morin (1993) conceives of these systems as inseparable networks of heterogeneous elements whose understanding demands a rupture with the linear, disjunctive logic of classical science. Knowledge of agriculture, therefore, is generated through a transdisciplinary epistemological architecture that articulates scientific, empirical, and local knowledge systems.

Within this framework, Luhmann's (2006) theory of autopoietic social systems becomes key. He posits that social systems are composed of communications rather than individuals. Accordingly, agriculture is defined by the communicative operations that constitute and reproduce its meaning: technical discourses, regulations, rituals, decisions, debates, and bodies of knowledge. Agriculture is understood as an autopoietic system that produces and reproduces its communicative elements according to its own operational logic.

Applying this theory to the study of agroecosystems requires critical adaptations. Unlike functionally differentiated systems such as law or politics, agriculture involves an inescapable material and biological dimension. For this reason, Luhmann's theory must be complemented with more directly applicable frameworks, such as García's (2008), who conceptualizes the agroecosystem as a complex totality formed by heterogeneous interacting elements. This includes biological, economic, cultural, and social components, whose separation would dissolve the integral meaning of the whole.

According to García (2008), the agroecosystem represents a theoretical cut of agricultural reality that demands methodological coherence and conceptual integration. This organized totality is characterized by its openness, by functional interdefinability where elements are defined through their reciprocal relationships and by its dependence on environmental conditions. These ideas align with the core principles of complexity: feedback, emergence, non-linearity, and self-organization.

The notion of interdefinability implies that components such as soil, water, crops, cultural practices, norms, and actors acquire meaning only in mutual interaction. This perspective requires a departure from sectoral approaches in favor of a systemic and relational view.

From Morin's (2007) perspective, agroecosystems function as open systems that exchange matter, energy, and information with their surroundings. This openness generates a form of dynamic stability based on regulated flows. A system that is excessively open faces risks of disorganization, while a closed system is vulnerable to obsolescence. Stability depends on the dialectic between openness and closure, akin to Luhmann's (2006) notions of operational closure and structural coupling.

In Luhmannian terms, the agricultural communication system reproduces itself through its own communicative operations and couples structurally with consciousness systems, which perceive, interpret, and decide according to their cognitive frameworks. The agroecosystem thus emerges from the articulation between the agricultural communication system and the consciousness systems of those who intervene in it including farmers, consumers, technicians, policymakers, and scientists.

This structural coupling explains the diversity of agricultural practices across contexts. Technological innovations spread based on their capacity to resonate with the cultural and institutional frameworks of their environment. Many technocratic solutions fail due to their inability to integrate into the autopoietic dynamics of the agricultural system.

For García (2008), the agroecosystem is conceived as an open system in dynamic equilibrium, where external information acts as an input that transforms internal processes. Interaction with the environment such as climate, policies, or markets triggers structural reconfigurations once critical thresholds are surpassed.

This perspective aligns with complex adaptive systems theory and enables the analysis of phenomena such as resilience, agroecological transition, and vulnerability to climate change.

According to García, the boundaries of an agroecosystem emerge from the definition made by the researcher based on the significant relationships to be analyzed. This delimitation constitutes an epistemological act that requires embracing partiality, reflexivity, and the political dimension of agroecological knowledge. Every agroecosystem is a situated construction that reflects an investigative intentionality.

Luhmann argues that system boundaries arise from the system's own communicative operations. The distinction between system and environment results from the autopoietic differentiation process, which is continuously reproduced. This difference is constitutive: without an environment, the system would be impossible, and without differentiation, identity would vanish. This constructivist conception reframes the notion of environment as that which the system constructs as distinct from itself.

These theoretical divergences carry significant methodological implications. García enables a pragmatic delimitation of the agroecosystem, suitable for concrete methodological designs. Luhmann demands a more abstract understanding, wherein the agroecosystem manifests as the outcome of structural couplings between social systems and systems of consciousness. From this perspective, agricultural practices emerge as effects of the communication that makes them possible and coherent within a socially shared framework.

Both approaches converge in recognizing that agroecosystems require an epistemology attuned to emergence, complex causality, uncertainty, adaptability, and coevolution as fundamental features. Agroecology, as both an interdisciplinary field and a political practice, constructs its objects of study through this complexity, integrating diverse knowledges, participatory methodologies, and a critical perspective on scientific knowledge itself.

The principle of emergence, a cornerstone of complex thought, posits that agroecosystem properties arise from the interactions among their components. This vision demands abandoning classical predictive models in favor of continuous monitoring, dynamic modeling, and flexible decision-making strategies. The stability of an agroecosystem depends on its capacity to adapt, learn, and transform collectively in dialogue with its environment.

Modern agriculture, within the framework of complex thinking and the sciences of complexity, is undergoing profound transformations driven by digital, biotechnological, and information management technologies. Tools such as remote sensing, artificial intelligence, big data, drones, geographic information systems, and automation platforms are redefining agricultural production frameworks and driving the transition to so-called Agriculture 4.0. This phase entails a comprehensive reorganization of practices, knowledge, social relations, and governance forms within the agroecosystem.

From the perspective of complexity, this transformation is understood as an interconnected process in which every technological innovation interacts with preexisting social, political, and cultural structures, generating feedback dynamics, exclusion, appropriation, or resistance. Analyzing contemporary agriculture thus requires a systemic, transdisciplinary, and contextual perspective that acknowledges the inherent complexity of agroecological systems (Morin, 2007).

Complex Thinking and the sciences of complexity provide a robust interpretive framework for understanding modern agriculture as a complex adaptive system. In such systems, components like soil, crops, climate, technologies, social actors, and institutions interact in relational ways, giving rise to emergent properties that cannot be deduced from a simple aggregation of parts.

Technological adoption within these systems produces multiple effects some anticipated, others unforeseen many of which are mediated by specific contextual conditions.

Precision agriculture has emerged as one of the key developments in this technological evolution. This practice relies on sensors, drones, GPS, satellite imagery, and management software to monitor agronomic variables in real time. Its goal is to identify and manage the spatial and temporal variability of agricultural fields, optimizing the use of resources such as water, fertilizers, and pesticides. This technique acknowledges the heterogeneity of farmland each plot presents unique conditions that affect crop growth.

From the perspective of complex thought, precision agriculture represents an attempt to manage agroecosystem heterogeneity in a localized manner. It enables more specific and effective interventions, although it demands technical capabilities, data infrastructures, and interpretive frameworks, which remain inaccessible to certain actors. It introduces new forms of technological dependency and may reinforce existing asymmetries among producers.

Agroecosystems, understood as open and self-organizing systems, are shaped by decisions that emerge from the data analyses generated by these technologies. These data are always interpreted through cognitive and cultural frameworks. For instance, the decision to apply a particular fertilizer based on satellite analysis is conditioned by economic availability, perceptions of environmental risk, prevailing regulations, and imaginaries of what constitutes proper agricultural practice.

Agriculture 4.0 extends beyond the precision approach. It is based on the full integration of digital systems enabling process automation, algorithmic learning, and permanent connectivity through the Internet of Things. This results in cyber-physical agricultural systems, where every decision is supported by real-time data and predictive models generated through artificial intelligence.

From the perspective of complexity sciences, these systems are understood as distributed adaptive networks that learn, reconfigure themselves, and respond to environmental changes. Although they hold transformative potential, they remain fragile due to their dependence on data quality, technological infrastructure, and institutional frameworks that ensure process governance. The centralization of data in private corporations, the lack of open standards, and the opacity of algorithms pose risks that may undermine the equity and autonomy of local actors (Rotz et al., 2019).

The complexity paradigm invites us to pose fundamental questions: Who designs these technologies? Who gains access to them? What narratives of the future do they promote? These questions are crucial to prevent agricultural digitalization from reproducing exclusionary logics, cognitive extractivism, and structural dependency. Technology embodies values, political decisions, and worldviews.

Luhmann’s theory of autopoietic systems (2006) allows for the analysis of Agriculture 4.0 as a communication system that reproduces itself through its own technological, normative, and discursive operations. This system interacts with its environment composed of farmers, consumers, and institutions through structural couplings that allow the incorporation of external stimuli without altering its internal logic.

Contemporary agricultural technologies optimize processes and also configure new forms of meaning and action. Predictive algorithms, for instance, process data, structure decisions, prioritize certain crops, anticipate scenarios, and condition the actions of stakeholders. The communication system of agriculture operates in closure around these logics and remains cognitively open to the perceptions and decisions of consciousness systems namely, the social actors who interpret, adapt, or challenge it.

A key concept in Complex Thinking is the ecology of action, proposed by Morin in 2007. According to this notion, every action, once initiated, enters a system of interactions that transforms it and generates unintended consequences. In the case of digital agriculture, this means recognizing that technologies produce anticipated benefits as well as negative externalities, such as the erosion of traditional knowledge, the depersonalization of practices, the concentration of power, and the exclusion of small-scale producers.

Therefore, the design and implementation of technologies must be accompanied by adaptive evaluation mechanisms, participatory governance, and impact monitoring. The resilience of an agroecosystem is achieved through collective learning capacity, institutional flexibility, and cultural diversity. A truly sustainable Agriculture 4.0 must embed these principles within its architecture.

The implementation of agricultural technologies varies across contexts. In Latin American rural territories, the appropriation of digital tools is mediated by processes of cultural resistance, territorial defense, peasant economies, and ancestral knowledge. Many communities reinterpret and adapt these tools to their own rationalities, creating unique sociotechnical hybrids.

This process of technological resemantization challenges the discourse of technical universality and foregrounds the need for situated epistemologies, as proposed by Santos (2009). Innovation must be understood as a collective construction of capacities, knowledge, and meaning. Complex thinking demands this contextualization as both a methodological and political principle.

Studying and managing modern agriculture from the standpoint of complexity requires integrative, participatory, and flexible methodologies. Measuring productivity or efficiency through quantitative indicators is insufficient.

Multicriteria approaches are needed that incorporate ecological, social, cultural, and symbolic dimensions. Modeling of socioecological networks, adaptive simulations, participatory diagnostics, and social cartographies are valuable tools for capturing the complexity of digitalized agroecosystems.

It is essential to foster local capacities for data management and interpretation. Digital literacy must be paired with processes of critical training, enabling local actors to understand the how, why, and for what purpose of each technology. This entails promoting open technologies, collaborative platforms, and regulatory frameworks that recognize the technological sovereignty of communities.

Agriculture 4.0 constitutes a complex, multidimensional, and ambivalent phenomenon. It holds the potential to positively transform production systems, enhance efficiency, and reduce environmental impacts. It may also reproduce inequalities, disrupt territories, and erode local knowledge. In the face of this ambivalence, Complex Thinking provides an ethical and epistemological compass to navigate uncertainty.

Beyond an innovation paradigm driven solely by productivity, what is needed is a form of social ecotechnology a way of producing knowledge and technology that articulates principles of justice, epistemic plurality, and sustainability. The agriculture of the future will be more digital and also more democratic, resilient, and aware of its place within complex webs of socioecological relations.

Complex Interactions

The notion of complex interactions among technology, ecosystems, and society forms a central axis for understanding the contemporary challenges facing agriculture within the framework of complex thought. Rather than being conceived as separate or merely interdependent spheres, these three dimensions are understood as open, dynamic, and recursive systems whose coevolution gives rise to unpredictable phenomena and emergent properties. In its digitalized form, contemporary agriculture displays this systemic entanglement with intensity: technological decisions transform ecological and social patterns, while ecosocial contexts condition technological trajectories.

From a Morinian perspective, this entanglement reflects a process of eco-self-organization. The parts construct the whole, and the whole reorganizes the parts (Morin, 2005). Agricultural technology must be conceived as a symbiotic operator that transforms and is transformed by the ecological and social systems in which it is embedded. This perspective transcends the instrumental reductionism that dominated agricultural innovation discourse, in which technical progress was linearly associated with productivity, efficiency, and control.

Technologies such as precision agriculture, environmental sensors, satellite monitoring systems, and climate prediction algorithms reconfigure production practices, ecological balances, and power relations. The expansion of digital agricultural management platforms generates new forms of informational dependence, where small and medium-scale producers become subordinated to corporations that control data, analytical models, and automated decisions (Wolfert et al., 2017). This phenomenon, inscribed in what some authors call digital colonialism, reproduces structures of domination that undermine local knowledge and consolidate logics external to the territory.

Ecosystems are living, complex, and self-organizing systems whose responses to technological interventions are difficult to anticipate. Intensification based on digital technologies may produce unintended ecological impacts, such as disruptions in nutrient cycles, loss of functional biodiversity, shifts in trophic chains, or erosion of ecosystem services. These reactions reflect the adaptive nature of socioecological systems.

From the standpoint of complex thought, it is essential to move beyond the classical dichotomy between the natural and the artificial. Modern agriculture constitutes a hybrid system an entanglement of organic, technical, symbolic, and digital elements that interact in singular configurations.

This condition demands a profound epistemological reappraisal. The mere incorporation of green devices or efficient algorithms proves insufficient. Technologies must be designed to engage with ecological variability, respect the cultural diversity of territories, and strengthen the autonomy of local actors in decision-making processes.

The theory of complex adaptive systems (Holling, 2001) offers valuable tools for advancing in this direction. From this perspective, the resilience of an agroecosystem depends on its functional diversity, internal connectivity, organizational flexibility, and socioecological memory. The evaluation of technological innovations must be guided by broad criteria of dynamic sustainability, including the system’s capacity for adaptation, learning, and transformation in response to disruption.

Interactions among technology, ecosystems, and society are mediated by institutional, regulatory, and political structures. Public policies, technological regulations, and rural development models adopted by States play a decisive role in shaping technological processes. In Latin America, many agricultural modernization policies promoted homogeneous technological packages disconnected from local knowledge, generating resistance, loss of agrobiodiversity, and territorial conflicts.

This has given rise to proposals such as digital agroecology, which integrates technology in a contextualized and participatory manner. This perspective fosters the design of open, adaptable solutions built collectively with territorial actors, combining artificial intelligence with collective intelligence, digital data with peasant memory, and technical efficiency with environmental justice. Digital agroecology emerges as a space of articulation among science, technology, and society, grounded in principles of autonomy, co-production, and epistemic pluralism.

The ethical dimension of these interactions proves essential. Every technological decision reflects a worldview, defines what is desirable, and excludes alternatives. Questions about the type of agriculture being promoted, the ways of life being prioritized, and the knowledge being legitimized take center stage in technical analysis. Complex Thinking places these issues at the core of reflection and promotes an ethics based on precaution, intergenerational co-responsibility, cognitive equity, and intercultural dialogue.

A compelling example arises from intelligent urban agriculture systems that integrate moisture sensors, automated irrigation, native seed banks, direct marketing platforms, and community-based agroecological practices. In these spaces, innovation emerges across technical, symbolic, organizational, and affective dimensions. Technology becomes a tool for rebuilding the social fabric and strengthening urban food sovereignty.

These cases demonstrate that the supposed dichotomy between techno-centrism and eco-romanticism is unfounded. The key lies in articulating technology and nature within ecosocial transformation projects that respond to the complexity of agri-food systems. Achieving this demands relational analytical frameworks capable of identifying feedback loops among technical innovation, ecological processes, and social dynamics. Participatory and reflexive methodologies are required ones that include diverse rationalities and multiple horizons of meaning.

In practical terms, this approach entails redesigning diagnostic, planning, and evaluation tools for agricultural management. Cost-benefit matrices and profitability analyses must be complemented by multi-criteria assessments, qualitative indicators, and territorial narratives that incorporate actors' lived experience.

Innovation processes need to be organized as spaces of collective learning where achievements and difficulties are treated as sources of knowledge.

Technological governance calls for a profound reconfiguration. The concentration of power in transnational digital platforms poses significant risks to territorial sovereignty. It becomes crucial to promote a radical democratization of agricultural technology through free software, open protocols, ethical licenses, community-based data management, and public policies that ensure interoperability, algorithmic transparency, and meaningful participation. In the absence of these conditions, technology may become a vector of exclusion, dependency, and dispossession.

Complex interactions among technology, ecosystems, and society demand an epistemology of uncertainty one that values the limits of knowledge, the contingency of processes, and the importance of cultivating a reflective, critical, and careful stance. Complex Thinking offers tools for thinking through uncertain scenarios, acting in contexts of ambiguity, and building collective responses to open-ended challenges.

Thinking agriculture through the lens of complexity entails recognizing technology, nature, and society as interwoven dimensions of a single living system. This perspective redefines the goals of innovation. Rather than maximizing technical efficiency, it redirects transformations toward strengthening resilience, equity, and long-term sustainability. A truly adaptive agriculture is measured by its capacity to sustain life in all its forms.

Technology, Power, and Inequality in Contemporary Agriculture

The accelerated development of digital agriculture, also known as Agriculture 4.0, has introduced unprecedented levels of sophistication in monitoring, control, and agri-productive management systems. Technologies such as remote sensors, drones, global positioning systems, big data analytics, and artificial intelligence algorithms enable ultra-specific input application, yield prediction, and early anomaly detection.

This hyper-technologization promises greater efficiency, reduced losses, and more rational use of natural resources. From a complexity perspective, this promise requires relational analysis, consideration of unintended consequences, and visibility of the systemic effects it generates.

A first axis of analysis points to the unequal access to these technologies. The question arises: who truly benefits from digital agriculture? Its implementation demands high levels of investment, robust digital infrastructure, advanced technical training, and enabling regulatory frameworks. These requirements tend to favor large agribusiness corporations, deepening the gap with small and medium-scale producers who face structural barriers to adoption. This consolidates a new form of power concentration based on control over land, knowledge, decision-making capacity, and data.

From Morin's perspective, this dynamic reflects a perverse feedback loop. Rather than correcting imbalances, it amplifies them, generating cycles of polarization and vulnerability. Complexity invites us to understand that connections among elements can produce chaotic effects, bifurcations, or collapses when not governed with care, intelligence, and ethical orientation. Technical efficacy becomes inseparable from its impact on equity, autonomy, and territorial sustainability.

A second level of analysis concerns the regime of truth embedded in digital agriculture. The rhetoric of objectivity underlying big data and artificial intelligence contains epistemological decisions that shape how data are collected, processed, and interpreted. Questions arise about what is measured, how it is measured, and who defines relevance. Precision agriculture systems privilege quantifiable variables and simplified causal relations, excluding key dimensions such as traditional knowledge, cultural practices, community bonds, and local worldviews. What is presented as evidence-based decision-making is, in reality, a sociotechnical construction loaded with values and exclusions.

Here, a central epistemological tension becomes evident. While Complex Thinking advocates for epistemic plurality, coevolution, and openness to dissent, the dominant technocratic paradigm operates through standardization, automation, and the subordination of human judgment to algorithms. This tension demands a structural transformation in technological governance, a reconfiguration of institutional frameworks, and a redistribution of cognitive power.

For this reason, re politicizing the debate on agricultural technologies becomes imperative. The discussion must move beyond technical aspects or productivity-centered efficiency. The design, development, and regulation of digital tools must be embedded in democratic deliberation processes that consider principles such as cognitive justice, technological sovereignty, territorial inclusion, and ecological sustainability. This entails fostering open, accessible, and adaptable technologies, establishing ethical protocols for data governance, and ensuring the effective participation of rural communities in decisions that shape their lives and territories.

Some emerging experiences illustrate this horizon. The European project FarmHack promotes the collaborative design of digital tools by farmers, technicians, and activists, generating open-source solutions tailored to specific challenges in the field. In Latin America, networks such as the Articulação Nacional de Agroecologia in Brazil foster technological innovations grounded in autonomy, respect for cultural diversity, and alignment with social movements. These initiatives demonstrate that a different kind of technology is possible one that is situated, democratic, and relational (Giraldo & Rosset, 2018).

From the perspective of complex thought, these practices embody the principles of self-organization the system's capacity to generate order without external direction and dialogical engagement the necessity of articulating partial truths and diverse rationalities to construct provisional agreements. In this framework, technology appears as a relational node whose efficacy depends on its embedding within living networks of meaning, practice, and power.

A frequently overlooked yet fundamental dimension is the affective experience that accompanies technological incorporation. These tools transform technique but also reshape the subjectivities of those engaged in agriculture. They alter relationships with the land, shift labor rhythms, strain intergenerational ties, and shape expectations for the future. The emotional response to technology is ambivalent. There may be enthusiasm about its transformative potential and, simultaneously, apprehension about loss of control, dependency on suppliers, or erosion of embodied knowledge (Klerkx et al., 2019). From an ethics of care, these affective dimensions must be acknowledged, legitimized, and supported as integral components of transitional processes.

For these reasons, it becomes necessary to develop evaluative frameworks that go beyond conventional indicators of productivity or efficiency. Hybrid indicators are needed ones that incorporate criteria of equity, resilience, epistemic diversity, subjective well-being, and ecological sustainability. Technological assessment must be participatory, interdisciplinary, and situated, engaging farmers, researchers, public institutions, and civil society organizations in a collective process of design, monitoring, and adjustment.

Professional education in the agri-food sector requires profound transformation. Engineers, biologists, rural economists, and extension agents need training not only in technical competencies but also in systems thinking, critical epistemology, network analysis, intercultural mediation, and the ethics of knowledge. A pedagogy of complexity must foster sensitivity to diversity, the ability to perceive patterns, openness to dissent, and dialogical engagement with alternative knowledge systems.

Technological transformation in agriculture must be understood within the broader context of multiple global crises: climate, energy, food, health, and geopolitics. The dominant agro-industrial model based on monocultures, cheap oil, internationalized transport, and extractivist technologies reveals a structural fragility. Recent crises, such as the COVID-19 pandemic, exposed the vulnerability of global supply chains, the dependency on external inputs, and the ecological unsustainability of the current agri-food regime (Altieri & Nicholls, 2020).

In this scenario, a fundamental reconfiguration becomes unavoidable. It can only be addressed through a systemic, transdisciplinary, and ethical vision. Agroecology emerges as a complex rationality that integrates peasant knowledge, ecological processes, territorial dynamics, and cultural values into a coherent proposal for social and ecological regeneration. Rejecting digital technology per se is meaningless. What matters is subordinating its use to an agroecological logic that imposes ethical, political, and cultural boundaries on its application (Wezel et al., 2009).

This transition demands new institutional architectures that articulate scales, knowledges, and diverse actors. It calls for multilevel agri-food governance models built on intersectoral consortia involving universities, communities, social movements, responsible businesses, and states. Examples such as the territorial platforms for agroecological innovation in Brazil or the participatory guarantee systems in European networks show that governing complexity is possible through coevolutionary processes, dialogue, and mutual learning (Levidow et al., 2014).

A core component of this shift involves redesigning the agricultural research system. For decades, agri-food knowledge was produced through a linear model of technological transfer, one that disregards territorial complexity and reproduces dependency relations. The paradigm of complexity proposes participatory, situated research open to uncertainty and grounded in the real challenges faced by those who work the land (Méndez et al., 2013).

Methodologically, this implies moving from controlled laboratory trials to real-world field experiences, analyzing multiple ecosystemic interactions, and building dynamic models in dialogue with stakeholders. It also requires horizontal knowledge-sharing networks, where farmers exchange insights, mistakes, and lessons learned consolidating a science of agroecological complexity.

It becomes essential to advance the relocalization of agri-food systems by promoting short supply chains, territorial economies, and food sovereignty. This reduces external dependencies, lowers ecological footprints, and strengthens producer–consumer relationships. Digital technologies must be adapted to this model: they must be appropriate, open, interoperable, and managed by the communities that use them (Schneider et al., 2021).

A complex perspective demands a sustained geopolitical critique. Major digital agricultural platforms are establishing a new regime of data extractivism that dispossesses communities of their knowledge and consolidates corporate control over global food production (van der Burg et al., 2021). In this context, technological sovereignty becomes a necessary condition for a just and resilient agroecological transition.

Algorithmic governance defined as the power exerted by artificial intelligence systems over production decisions must be transparent, regulated, and subject to democratic oversight. Public algorithm audits are needed, along with community participation in software design and legislation that prioritizes the common good over the commodification of knowledge (Bronson, 2019).

Complexity presents itself as an ethics of connection, a politics of care, and a pedagogy of humility. Applied to agriculture, it requires abandoning the illusion of control, recognizing interdependence, embracing uncertainty, and building possible futures through dialogue among knowledges, actors, and territories. Agriculture in the twenty-first century will be defined by its complexity or it will lose its transformative potential.

Agriculture as a Complex Adaptive System

Understanding modern agriculture as a complex adaptive system allows us to transcend the limitations imposed by linear, mechanistic, and sectoral approaches that have historically dominated agri-food analysis. Unlike the classical view that conceives of the agroecosystem as a predictable machine governed by inputs, transformations, and outputs, Complex Thinking emphasizes that agricultural systems function as dynamic, interdependent networks. Within these networks, biological, technological, social, ecological, and cultural elements converge, generating emergent properties that cannot be reduced to the sum of their parts (Morin, 1990).

From this perspective, agriculture is best understood as an autopoietic system, in line with the ideas of Maturana and Varela (1984), that self-produces and self-regulates through internal dynamics, couplings with its environment, and symbolic processes. Agroecosystems metabolize energy, transform matter, and process information, meanings, values, and social representations. They are configured as territories of socioecological co-production, where the technical intertwines with the symbolic, the political, and the subjective.

This framework demands a break with traditional epistemology, which is based on rigid separations between subject and object, science and experience, data and narratives. As Leff (2004) suggests, what is needed is an ecology of knowledge that brings together multiple ways of knowing scientific, local, empirical, intuitive, and ancestral within a horizon of complementarity and mutual respect. Agricultural science, in this light, adopts a reflexive, participatory, and situated stance.

A central concept in the complex reading of agricultural systems is feedback. This concept shows that every action generates effects that feed back into the system, modifying its initial conditions. For instance, the introduction of smart irrigation technologies may initially improve yield and water efficiency. Yet indirect effects such as changes in microclimates, transformations in water-use practices, or shifts in soil biodiversity reconfigure the system in unforeseen directions. These feedback loops can either stabilize or profoundly disrupt the system, and their management requires continuous epistemological vigilance, openness to error, and the ability to reformulate strategies dynamically (Capra & Luisi, 2014).

Classical linearity is superseded by the principle of multiple interactions, in which small actions can generate large systemic effects, while larger interventions may lead to limited or even counterproductive impacts. This phenomenon, linked to the sensitivity of initial conditions, challenges agricultural approaches based on universal formulas, centralized planning, and assumptions of structural stability. Adaptive, flexible, and deeply contextualized governance models are required models that value territorial diversity, local dynamics, and the multiplicity of actors involved.

Complex Thinking converges with the principles of critical agroecology, which for decades has questioned the imposition of homogeneous technological packages and promoted innovation processes built from and with territorial actors, as highlighted by Altieri and Nicholls (2012). The introduction of technology demands a contextualized analysis of local ecosystems and the social and cultural frameworks in which such technologies are embedded.

A central concept is emergence, which refers to the appearance of new properties that cannot be reduced to the isolated analysis of individual components. In agriculture, emergence becomes evident in the resilience of diversified systems facing extreme climate events, in the synergies between crops and animals within integrated systems, or in the creation of collective social innovations during periods of crisis. These emergent properties arise through experimentation, continuous interaction, and joint learning processes.

From a methodological standpoint, embracing the complexity of agricultural systems entails rethinking research practices. Traditional protocols based on disciplinary fragmentation, replicability under controlled conditions, and variable isolation are insufficient to grasp the co-evolutionary dynamics, multiscalar interactions, and entangled causalities that characterize real-world agroecosystems. A transdisciplinary approach is required, one that combines quantitative and qualitative methods, ecological indicators with cultural narratives, and structural analysis with symbolic interpretation, as proposed by Norgaard (1994).

Transdisciplinarity involves the construction of shared languages, conceptual translation processes, and cognitive negotiation between distinct forms of knowledge. This process must be conceived as deliberate, political, and reflexive, promoting the co-construction of interpretative frameworks, research agendas, and intervention strategies through science–community dialogue.

This perspective aligns with participatory methodologies and action research approaches that embrace uncertainty as a structural condition of knowledge. In complex systems, anticipating all consequences or maintaining full control over influencing factors is impossible. The objective of action becomes building adaptive capacities to enable collective learning, revise assumptions, and reconfigure relationships between subjects, territories, and technologies.

This approach also demands an ethic of cognitive humility, acknowledging the inherent limits of all knowledge systems and promoting mechanisms of collective epistemological vigilance. Practicing a science that is self-critical, plural, dialogical, open to public deliberation, and subject to democratic oversight of its technological and political implications becomes essential.

Translating these principles into public policy implies a profound institutional reconfiguration. The hierarchical and sectoral model that currently dominates agricultural management anchored in command-and-control logics, standardized instruments, and vertical planning is dysfunctional in a context marked by interdependence, uncertainty, and dynamic relationships. What is required are polycentric governance networks capable of articulating territorial levels local, regional, national, and global alongside diverse actors including producers, technicians, scientists, consumers, social organizations, and state agencies.

This vision requires a comprehensive revision of evaluation criteria, funding mechanisms, and regulatory frameworks, which currently prioritize uniformity, immediate efficiency, and economic profitability over ecological sustainability, social relevance, and cognitive justice, as Folke et al. (2005) argue. It becomes essential to construct indicators capable of assessing resilience, functional diversity, territorial equity, food sovereignty, and citizen participation in decision-making processes.

Within this framework, rural communities must be understood as active epistemic subjects, endowed with the capacity to observe, interpret, innovate, and manage their productive systems. This view calls for a profound transformation of scientific and technological institutions, shifting from a knowledge-transfer logic to one of situated co-production. Communities take part in every stage: problem formulation, solution design, impact evaluation, and redefinition of objectives.

Complex Thinking does not offer closed solutions or finalized normative models. Its strength lies in fostering a critical epistemological attitude, an open political stance, and an ethic of care within contexts marked by conflict, diversity, and ongoing transformation. Cultivating relational intelligence strengthens dialogue, values difference, acknowledges the coevolution of nature and culture, and supports the construction of alternative futures that dignify life in all its expressions.

Envisioning a truly regenerative agriculture one that nourishes bodies, territories, and relationships requires more than new technologies. It demands new ways of thinking, knowing, and living together. From this perspective, complexity offers an opportunity to reconnect with what is essential: the interdependence that sustains life.

The Economic Dimension of Modern Agriculture

Contemporary agriculture, profoundly reshaped by digital, biotechnological, and automated technologies, presents an economic complexity that challenges traditional analytical frameworks. Far from being an isolated sector governed solely by the laws of supply, demand, and marginal productivity, modern agriculture functions as a subsystem within a network of ecosocial, institutional, and technological interactions. This entanglement includes global capital flows, political structures, digital infrastructures, ancestral knowledge, and ecological dynamics. From this standpoint, the economic analysis of agriculture requires a reinterpretation grounded in the principles of complex thought.

In the classical agro-industrial paradigm, agricultural development was associated with intensive mechanization, crop homogenization, and yield maximization per hectare, under the assumption that technical efficiency would lead to direct and sustainable economic benefits. Empirical evidence contests this logic. Dependence on external inputs, high energy costs, environmental degradation, and market volatility reveal that isolated productivity is insufficient to sustain long-term profitability and economic resilience (Altieri & Nicholls, 2020). The so-called digital green revolution seeks to revive this promise through tools such as big data, artificial intelligence, biotechnology, and automation, though it introduces distributive and structural tensions.

A critical issue arises with the growing concentration of access to advanced technologies. Tools such as remote sensors, crop management platforms, genetic editing, machine-learning-based predictive models, and automated irrigation systems require significant initial investments, robust institutional conditions, and specialized technical skills. This situation generates an agrotechnological gap, as described by Patel (2013), which marginalizes small and medium-scale producers, particularly in the Global South. Many are subordinated to technological infrastructures designed from centers of economic and epistemological power. This inequality operates as a feedback loop, weakening productive diversity and increasing the vulnerability of the global agri-food system.

Agricultural financing exacerbates this problem. The growing involvement of investment funds, banks, and transnational conglomerates in land acquisition, food speculation, and control over value chains transforms food production into a volatile financial asset. This process detaches food prices from real production conditions and exposes them to speculative bubbles, external shocks such as pandemics and wars, and land grabbing (Borras et al., 2011). Agriculture becomes an object of economic extraction, undermining its capacity to ensure food security and sovereignty.

From the perspective of complex thought, this transformation is understood as a web of relationships involving multiple ecological, symbolic, technical, cultural, institutional, and affective factors. Agricultural economics transcends cost-benefit calculations and is conceived as a system of interdependencies where economic decisions emerge amid uncertainty, contradiction, and rational multiplicity.

This plurality is clearly visible in rural territories, where traditional practices coexist with digital technologies, subsistence strategies intersect with global market integration, and collective forms of production converge with entrepreneurial logics. In these contexts, technological adoption is shaped by situated, negotiated, and adaptive decisions. Indigenous and peasant communities, for instance, selectively integrate digital tools such as traceability systems, weather applications, and direct-sale platforms, while maintaining ways of life, agricultural calendars, and local governance systems (Toledo, 2003).

A fundamental aspect neglected by conventional economics is that of externalities. Intensive agricultural practices based on monocultures, agrochemicals, and mechanization generate ecological and social impacts that are not reflected in market prices. These include soil and water contamination, biodiversity loss, greenhouse gas emissions, and deterioration of community health. Such consequences, interpreted as collateral effects in classical analysis, constitute structural costs that undermine long-term system sustainability.

Agroecological systems, although they may display lower immediate yields, produce positive externalities: they strengthen community cohesion, restore ecological cycles, promote food sovereignty, and reduce dependence on external inputs. These benefits rarely receive recognition in dominant economic evaluation frameworks. Complex Thinking proposes overcoming this reductionist view through integrated indicators that encompass ecological, cultural, and social dimensions, allowing for a systemic assessment of profitability.

Ecological economics and critical agroecology contribute valuable elements to this approach by integrating thermodynamic principles, energy flow analysis, nutrient cycling, and regenerative dynamics. From these perspectives, a direct critique emerges of the notion of productivity understood as unidimensional maximization, proposing instead concepts such as adaptive efficiency, functional diversity, and socioecological resilience (Gliessman, 2015). These metrics assess not only how much is produced, but how it is produced, with what impacts, and to whose benefit.

An agricultural system that generates large short-term volumes, depends on subsidies, depletes natural resources, and displaces local communities lacks efficiency from a complex perspective. In contrast, a diversified system with closed nutrient cycles, integration of crops and livestock, short commercialization circuits, and participatory governance offers superior structural profitability in terms of sustainability, autonomy, and social justice.

In this context, the concept of regenerative economics becomes particularly relevant. This vision conceives agriculture as a cyclical, restorative, and relational activity, where economic value is integrated with ecological and social value. Unlike the linear-industrial model, regenerative economics seeks to restore ecosystems, strengthen social capital, and generate distributed and lasting benefits, aligning with the principles of complex thought.

The economic dimension of modern agriculture must be addressed through a territorialized logic. Ecological, cultural, institutional, and political conditions vary substantially across regions and shape the possibilities for technological adoption, organizational innovation, and economic sustainability. In this regard, public policies aim to promote adaptive institutional ecosystems that recognize the specificity of territories, foster productive diversity, and enable bottom-up processes of social and technological innovation.

Key strategies include the promotion of open digital platforms, the democratization of access to agricultural data, the development of public technical support infrastructure, the consolidation of local and solidarity-based markets, and investment in transdisciplinary training. These policies are designed through the active participation of local actors in co-creation processes that integrate scientific, empirical, and community-based knowledge.

Rethinking the economic dimension of agriculture through complexity implies a transformation in professional education frameworks. Agricultural economists, engineers, extension agents, policymakers, and community leaders require conceptual and methodological tools to understand the nonlinearity, uncertainty, recursivity, and coevolution that characterize agri-food systems. Only then can the logic of extractive yield be abandoned in favor of a living economy grounded in ecosystem care, community well-being, and intergenerational sustainability.

Modern agriculture stands at the core of one of the twenty-first century's most pressing challenges: ensuring global food security amid climate crisis, population growth, structural inequality, and ecosystem degradation. Addressing this issue from a reductionist perspective leads to partial and counterproductive solutions. Food security transcends global caloric availability, just as modern agriculture extends beyond mere high-tech production. A new lens is needed one that articulates the interdependence of ecological, technological, cultural, political, and economic factors: a complex perspective.

Traditionally, food security has been structured around four pillars: availability, access, utilization, and stability. Agricultural modernization from the Green Revolution to Agriculture 4.0 has focused primarily on the first, increasing food availability through productive intensification, improved seeds, synthetic fertilizers, and mechanization. This strategy significantly boosted yields of key crops such as wheat, maize, and rice, while leaving other pillars unresolved and deepening inequalities (FAO, 2022).

From the perspective of complex thought, this imbalance reveals an epistemological error: reducing the food phenomenon to a purely technical-productive dimension while ignoring its multiple interconnections. Food access depends on economic capacity, distribution logistics, agrarian policies, and land concentration. Food utilization is shaped by nutritional quality, food culture, and public health. Stability refers to the system's capacity to withstand disruptions such as droughts, armed conflicts, pandemics, or economic crises. All these factors are interdependent, dynamic, and governed by non-linear relationships.

The development of technologies such as artificial intelligence, remote sensing, gene editing, and digital platforms offers valuable potential for food security. This potential is mediated by technological inequalities, asymmetric access to knowledge, and corporate appropriation. Technological innovations are imbued with values and political decisions: their impact depends on how they are designed, distributed, and governed. A complex perspective requires analyzing their technical efficacy and their social, ecological, and ethical implications (Morin, 2005).

Precision agriculture offers a compelling case. These technologies enable efficient input application such as water, fertilizers, and pesticides targeted according to specific conditions. Their implementation requires expensive equipment, digital connectivity, and advanced analytical capacities, all of which remain out of reach for many farmers in the Global South. This technological exclusion reinforces structural inequalities and limits the distribution of benefits, undermining the resilience of the food system.

Complex thinking helps frame the paradox between efficiency and resilience. Many modern agricultural systems exhibit high efficiency under stable conditions but are fragile in the face of shocks. A technified monoculture can deliver high yields, yet it remains vulnerable to pests, droughts, or market fluctuations. In contrast, a diversified agroecological system may yield less per unit but offers greater adaptive capacity and maintains its functionality under critical conditions. Food security, therefore, must be grounded in a dynamic balance between productivity, diversity, sovereignty, and sustainability.

At the global scale, this challenge intersects with the geopolitics of agricultural trade. Economic blocs such as the United States, China, and the European Union use subsidies, impose tariffs, and promote free trade agreements that distort international prices and constrain the food sovereignty of the Global South. Transnational corporations control key segments of the agri-food chain from seeds to digital platforms consolidating a governance architecture centered on profitability and disconnected from the right to food (Clapp, 2016).

A complex view of modern agriculture incorporates the notion of food justice. What matters is not only how much is produced but how it is produced, for whom, under what conditions, and with what ecological and social consequences. This requires integrating Indigenous and peasant knowledge into public policy, democratizing decision-making processes, diversifying production systems, and treating food as a fundamental human right.

The ecological dimension must be considered foundational to food security. Food production depends on essential ecosystem services such as pollination, water regulation, soil fertility, and climate stability. These services are degraded by deforestation, intensive agrochemical use, and urban expansion. An agricultural model that depletes the very resources it relies on lacks structural security. Ecological sustainability is a non-negotiable condition for future food systems.

Productivity Gains vs. Asymmetric Distribution

Advanced agricultural technologies have enabled significant productivity increases, particularly in large-scale production units. These benefits are unequally distributed. While certain regions optimize resources through geographic information systems, automation, and smart inputs, vast rural areas lack basic infrastructure, connectivity, or technical assistance, perpetuating structural asymmetries.

This paradox shows that technical efficiency must be evaluated in light of power relations, ownership structures, and unequal access to technology. Productivity emerges as a relational expression of social, ecological, and technological interdependencies and therefore demands integrative analysis.

Digital agriculture powered by big data, sensors, artificial intelligence, and robotics offers tools to address climate change challenges. Early warning systems, precision water management, and the automation of agricultural practices help reduce the ecological footprint and strengthen agroecosystem resilience. This promise, however, remains constrained by access barriers, regulatory gaps, and the concentration of knowledge.

From the lens of complex thought, climate adaptation appears as a coevolutionary process involving technology, institutions, and knowledge systems. Food security conceived through the pillars of availability, access, stability, and cultural adequacy requires adaptive solutions designed with communities, avoiding top-down impositions. Diversity operates as a strategic principle in complex systems. This includes genetic biodiversity, knowledge heterogeneity, organizational structures, practices, and market circuits. In the face of climatic and economic uncertainty, food systems rooted in diversity prove more resilient.

Local food networks, short supply chains, and cooperative production models reinforce community fabric and food sovereignty while reducing dependence on fossil-based inputs and volatile markets. Valuing these models entails recognizing traditional knowledge, collective rights, and differentiated public policies.

Food governance informed by complexity must account for the multiplicity of scales, actors, and decision-making levels involved in food production, transformation, and distribution. Decisions made at one point in the system such as subsidies, trade liberalization, or monoculture promotion generate feedback loops that amplify vulnerabilities or weaken local capacities. A systemic governance framework rests on multilevel deliberative mechanisms, with effective participation from communities, producer associations, scientific institutions, and state agencies. Tools such as multicriteria analysis, adaptive system simulators, and collaborative cartographies serve as strategic allies for developing food policies attuned to complexity, uncertainty, and diversity.

Challenges and Opportunities Within Complex Systems

Understanding modern agriculture through the paradigm of complex systems constitutes an epistemological imperative in the face of the multidimensional crisis affecting the global agri-food system. Far from operating as an isolated subsystem, agriculture functions as a coevolutionary network that articulates ecological, technical, economic, cultural, and political dimensions, traversed by multiple scales and feedback loops. This structural complexity challenges dominant reductionist approaches, which fragment agrarian knowledge into controllable variables yet fail to address systemic issues such as climate change, biodiversity loss, or territorial inequality.

A central challenge stems from the epistemological integration gap. Traditional agricultural sciences tend to compartmentalize their objects of study such as yields, plant health, or mechanization within linear experimental logics that overlook emergent interactions between system components. This fragmented outlook produces technologically efficient solutions in the short term, although unsustainable over time (Altieri, 2009). There is an urgent need to build transdisciplinary research models that integrate soil ecology, rural sociology, peasant knowledge, and political economy, recognizing the plurality of rationalities embedded in agricultural practice.

Another major challenge involves the dominant innovation model centered on digital agriculture, biotechnology, and automation. This instrumental logic prioritizes technical efficiency over social justice or ecological sustainability and promotes standardized solutions disconnected from territorial realities. From a systemic perspective, these technologies can be reconfigured for the common good. Tools such as big data, remote sensing, or artificial intelligence, when guided by a shared ethic and developed participatorily, can support community-based monitoring, precision agroecology, and transparent traceability (Levidow et al., 2014).

A structural challenge arises from the uncertainty inherent in open systems. Agroecosystems, conceived as complex adaptive systems, respond to multiple shifting and interconnected variables such as climate, markets, policies, and cultures. Therefore, the ideal of control must give way to strategies grounded in resilience, functional diversity, and decentralized decision-making. This systemic adaptability is strengthened through practices of productive diversification, polyculture, agroecological management, and networked articulation of small-scale producers (Gliessman, 2015).

Another key challenge lies in the mismatch between decision-making scales and impact scales. Agricultural policies are designed at national or supranational levels, while their effects manifest in specific local territories. This disconnection generates decontextualized measures that amplify existing vulnerabilities. From a complexity perspective, multilevel governance mechanisms are needed, based on the co-creation of public policies with territorial actors and the recognition of local knowledge as a legitimate source of operational intelligence (Ostrom, 2009).

Delayed feedback constitutes another defining obstacle within complex systems. The consequences of many agricultural practices such as intensive agrochemical use emerge only decades later, by which time water bodies, soils, or entire ecosystems may already be degraded. This extended temporality demands a reformulation of traditional evaluation systems by incorporating indicators of resilience, intergenerational equity, and systemic sustainability.

Complexity requires making indirect and previously invisible causal relationships visible. For instance, fertilizer subsidies may boost short-term productivity while simultaneously generating adverse impacts on human health, aquatic biodiversity, and technological dependence. Addressing these collateral effects calls for the development of systemic simulation models and adaptive learning platforms that facilitate the anticipation of unintended consequences and foster critical reflection among food system actors.

Agriculture must be reimagined through a logic distinct from the technocratic. It emerges as a space of meaning, memory, affect, and culture. Peasant lifeways, Indigenous worldviews, and communal rationalities call for epistemic recognition, avoiding subordination to an instrumental mindset that reduces all value to efficiency. From the perspective of complex thought, this entails advancing toward an ecology of knowledges (Santos, 2009), where diverse ways of knowing, producing, and inhabiting territory are legitimized. Within this framework, a deeply regenerative agroecology can flourish.

Multiple opportunities are emerging. The rise of collaborative digital platforms, growing ecological awareness, and the strengthening of international agroecology networks enable the construction of distributed innovation ecosystems where researchers, farmers, consumers, and policymakers co-create resilient food systems. These networks function as living systems of collective learning, capable of operating through horizontality and diversity.

Complex Thinking is more than a theoretical framework. It constitutes an epistemic ethic a way of thinking that embraces uncertainty, values contradiction, integrates multiple scales, and remains continuously open to dialogue and transformation. Applied to agriculture, it becomes a compass for building food systems that are just, resilient, and rooted in life.

Incorporating Complex Thinking into the analysis of contemporary agriculture is a historical imperative. The prevailing agroindustrial model based on intensive monocultures, technological dependence, extractivist rationality, and epistemic exclusion has proven ecologically unviable, socially fragile, and cognitively narrow. A complex perspective offers conceptual and ethical tools to reconfigure our relationship with the food system.

Agriculture, when understood as an autopoietic system, is conceived as a living network that produces and reproduces its components in interaction with the environment. This conception surpasses the dominant mechanistic-Cartesian view and opens the way to an ecological, relational, and evolutionary rationality. Technologies such as precision agriculture or digital farming acquire significance only when subordinated to principles of equity, territorial justice, and sustainability.

Agroecology, far from being merely a technical alternative to the industrial model, must be embraced as an evolving epistemology. While it has made significant progress, it still faces limitations such as ahistoricism, the absence of a consolidated critical theory, and a certain detachment from debates on power, inequality, and knowledge. In this context, Complex Thinking provides a foundation for a critical agroecology capable of articulating history, ethics, theory, and action.

A methodological transformation is indispensable. Researching from a complexity perspective entails abandoning the vertical transfer of knowledge and adopting transdisciplinary, co-participatory, and territorially grounded approaches. It requires engaging with quantitative data, ethnographic narratives, collaborative maps, and adaptive simulators. It implies acknowledging that valuable knowledge resides in territories, bodies, and memories.

Public policies must align with this transformation. Relying on production subsidies or tax incentives proves insufficient. What is needed are adaptive, multi-scalar, and multi-actor forms of governance, where social movements, local governments, universities, productive sectors, and rural communities jointly articulate strategies for a just transition. Latin American experiences with agroecological networks, solidarity-based local markets, and participatory guarantee systems offer precedents for how to move forward.

Rethinking agriculture through the lens of complexity constitutes a civilizational act. Beyond ensuring caloric intake, it entails regenerating bonds with the land, with communities, and with all forms of life. It involves building systems capable of producing not only food but also meaning, dignity, memory, and future. Twenty-first-century agriculture depends on a profound transformation in how we know, govern, and coexist. Complex Thinking offers a compass a way of seeing, thinking, and acting to navigate the uncertainty of our time with clarity.


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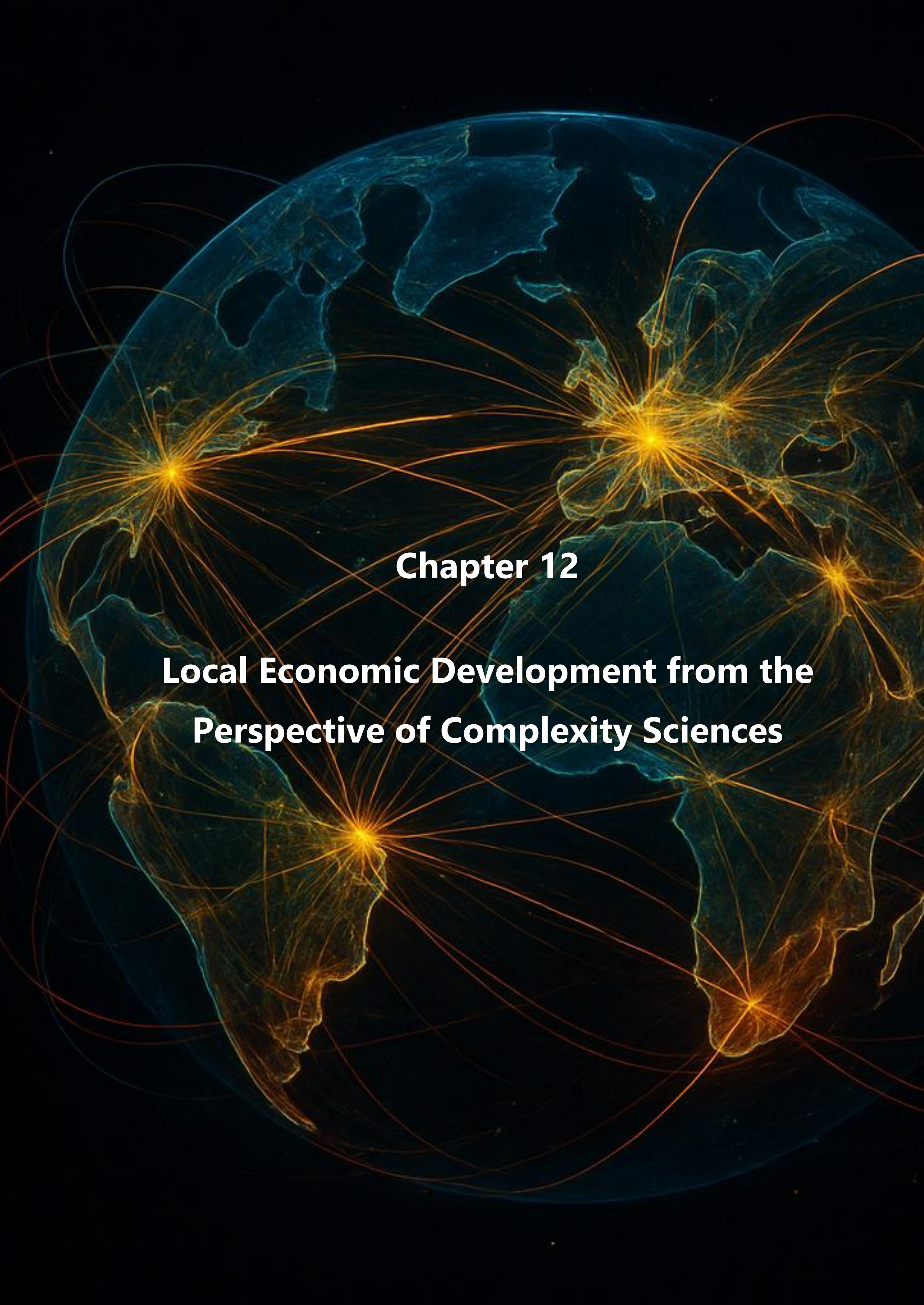


Chapter 12

Local Economic Development from the Perspective of Complexity Sciences

Local Economic Development from the Perspective of Complexity Sciences

In recent decades, Local Economic Development (LED) has been predominantly approached through linear frameworks that prioritize Gross Domestic Product (GDP) growth, the attraction of foreign direct investment, and the creation of formal employment as central objectives. This perspective, rooted in neoclassical economics, has prevailed in public policy, multilateral institutions, and territorial competitiveness strategies. Its reductionism reveals severe limitations when facing challenges such as the ecological crisis, structural inequality, social fragmentation, and accelerated technological transitions. Within this context, Complex Thinking (Morin, 2007) and complexity sciences (Holland, 1995) emerge as alternative epistemological frameworks that enable a rethinking of development as a nonlinear, adaptive, emergent, situated, and profoundly relational process.

The objective of this text is to critically reconstruct the foundations of LED in light of complexity sciences, proposing a shift from mechanistic and universal approaches toward contextualized, co-evolutionary, and participatory strategies. To this end, the main theories of local development are reviewed, articulated with the ideas of Morin and Holland, and the practical implications of conceiving the territory as a complex adaptive system are explored.

The field of local development has been historically shaped by theoretical currents that, while valuable, remain partial. A complex reading avoids dismissing them and instead reconnects them, revealing their hidden complementarities.

- Comparative Advantage (Ricardo, 1817). Argues that territories should specialize in goods and services with lower relative costs, fostering trade to maximize aggregate efficiency. Its weakness lies in conceiving territories as passive and homogeneous units, overlooking learning processes, and assuming the existence of perfect markets.

- Endogenous Growth (Romer, 1990; Lucas, 1988). Introduces the idea that the accumulation of human capital, innovation, and endogenous knowledge constitute internal drivers of development. It contributes the notion of increasing returns derived from collective knowledge, although it tends to underestimate power asymmetries and structural barriers that condition the appropriation of these benefits.

- Industrial Districts (Marshall, 1920; Becattini, 1991). Emphasize the importance of territorial networks of small and medium-sized enterprises connected through trust, shared norms, and social capital. These local productive systems demonstrate that geographic proximity facilitates the circulation of tacit knowledge, flexibility, and incremental innovation.

- Territorial Development (Boisier, 2005; Vázquez Barquero, 2009). Conceives the territory as a social construct resulting from the interaction among actors, institutions, and endogenous resources. It emphasizes participatory governance and the co-creation of collective future-oriented projects, paving the way for development strategies grounded in identity and multiscalar cooperation.

- Social and Solidarity Economy (Coraggio, 2011; Laville, 2013). Proposes an economy guided by principles of equity, reciprocity, and sustainability. It acknowledges the centrality of life reproduction beyond capital accumulation and introduces political subjectivities that are essential for territorial cohesion.

- Complex Adaptive Systems (Holland, 1995; Arthur, 2015). Argue that territories are configured as open systems composed of heterogeneous agents who interact, learn, and adapt. Development emerges as a pattern arising from nonlinear interactions and both positive and negative feedback loops.

The articulation of these currents reveals that local development depends on the synergistic combination of tangible resources, such as infrastructure and financing, and intangible resources, such as knowledge, values, and identities. For example, Medellín's software cluster was strengthened through tax incentives and the sustained interaction among universities, start-ups, social capital networks, and a collective narrative of post-industrial transformation. These experiences confirm that complexity demands systemic observation capacities, adaptive governance, and an ethics of co-responsibility. Comparative advantage is no longer grounded exclusively in natural endowments but redefined by the capacity to articulate distributed knowledge ecosystems capable of generating sustained social and technological innovation (Cooke, 2013).

Foundations of Complex Thinking and Complexity

In 2007, Edgar Morin asserted that reality is simultaneously organized through interdependent orders and disorders. Complex thought, far from being an ornamental methodology, constitutes a reform of understanding that requires contextualization, articulation, and the embrace of uncertainty.

Morin introduces the principles of self-eco-organization, organizational recursion, and the dialogical part–whole loop, encouraging a rethinking of economics beyond the paradigm of simplicity. In 1995, Holland and the Santa Fe Institute extended this sensitivity to quantifiable domains through cellular automata models, genetic algorithms, and network theory.

In complex adaptive systems, global patterns emerge from simple local rules, and emergent properties feed back into agent behavior, generating a dynamic of permanent coevolution. This framework deepens the understanding of complexity.

Morin's dialogical principle invites us to simultaneously hold seemingly antagonistic notions: competition and cooperation, efficiency and equity, tradition and innovation. This mode of thinking enables institutional designs that reconcile divergent interests through hybrid arrangements, such as science and technology parks operated by public–private–community partnerships. Methodologically, complexity privileges experimental modeling, agent-based simulation, and multi-sited ethnography to capture the multiscalar nature of development processes.

- Positive and Negative Feedback. Feedback loops shape divergent trajectories: successful policies amplify their effects through interactive learning, while late-detected failures may lead to technological lock-ins. Continuous evaluation becomes an inherent part of the development process.

- Multiple Temporalities. Short-, medium-, and long-term rhythms coexist: incremental innovation, investment cycles, cultural change, and ecosystem regeneration. Strategies consider differentiated temporal horizons to avoid myopias that undermine sustainability.

The convergence between the principles of complexity and the objectives of sustainable development drives transitions toward circular economies, clean energy matrices, and territorialized food systems. Territories that have adopted multilevel governance arrangements such as Basel, Curitiba, and Costa Rica demonstrate greater climate resilience and stronger capacity for local value capture (Intergovernmental Panel on Climate Change, 2023). In sum, a complex approach to local economic development affirms the primacy of life over accumulation and fosters innovative solidarities for collective territorial resilience.

From the perspective of complex thought, public policy design concerning local economic development moves away from the universalist, normative, and technocratic frameworks that have historically defined it. Policies are conceived as processes of social co-construction, rooted in situated knowledge and the capacity for collective learning. This approach recognizes territorial complexity as a dynamic web of relationships, knowledges, and practices in continuous transformation. Consequently, a public policy inspired by complexity adheres to the following guiding principles:

- Radical contextualization. Each territory requires specific interventions based on the analysis of its local histories, development trajectories, organizational cultures, and particular ecologies. This entails replacing homogeneous frameworks with participatory diagnostics that are attuned to the singularities of each place.

- Multisectoral and intercultural participation. Policy formulation incorporates a plurality of actors governments, communities, the private sector, universities, and civil society organizations alongside traditional, technical, and popular knowledges. The active inclusion of Indigenous peoples, peasant collectives, urban youth, and marginalized groups strengthens the legitimacy and effectiveness of public action.

- Institutional innovation and adaptive learning. Territorial innovation ecosystems are consolidated to foster experimentation, constructive error, and the ongoing adjustment of strategies. Policies operate as living prototypes, subject to dialogical evaluation and constant reformulation based on their actual impacts.

- Evaluation systems with dynamic logic. Instead of static metrics focused on quantitative indicators, formative and qualitative evaluations are prioritized, assessing transformation trajectories, organizational learning, capacity building, and the generation of social trust.

- Adaptive capacity and institutional resilience. Policies are designed with flexibility to respond to health crises, socio-political conflicts, climate change, or technological disruptions. This adaptability requires a state apparatus capable of reading the environment, interpreting emergent signals, and articulating agile and collaborative responses.

Public policy design from a complexity-based approach avoids suppressing uncertainty and instead proposes to navigate it collectively. This approach replaces the logic of control with an ethics of territorial care, grounded in active listening, ongoing negotiation, and shared co-responsibility.

Territorial Governance from the Perspective of Complexity

Territorial governance, viewed through the lens of complexity, departs from the hierarchical and vertical models characteristic of classical planning. Rather than imposing directives from a central authority, it entails articulating an ecosystem of actors with diverse capacities, interests, and languages. In this conception, governance is understood as a polycentric, distributed, and adaptive process, where decisions are constructed relationally and contextually.

Authors such as Jessop (2002) and Ostrom (2009) demonstrated that the most resilient institutional arrangements are those that promote ongoing deliberation, shared learning, and the collaborative management of resources. The state, far from monopolizing public action, becomes a facilitator of collective processes, capable of building bridges, generating trust, and enabling the emergence of collaborative intelligences. This perspective demands profound transformations in institutional capacities.

- Contextual intelligence is required. Beyond technical efficiency, institutions must develop the ability to interpret territorial logics, understand complex configurations, and anticipate scenarios. This requires multidisciplinary teams, flexible information systems, and continuous feedback mechanisms.

- It is also essential to build porous institutional frameworks. This means that the boundaries between the state, civil society, and the private sector become permeable, fostering the circulation of knowledge, the co-production of public goods, and the negotiation of diverse objectives without imposing a single rationality.

- Multilevel coordination becomes indispensable. Governance must operate across different scales local, regional, national, and international. This requires building synergies grounded in respect for local autonomy and territorial specificity, while avoiding the homogenization of decisions.

- Participatory monitoring mechanisms are essential. To prevent the technocratization of policy, it is crucial to establish dialogical evaluation processes, in which citizens and stakeholders assess outcomes, identify bottlenecks, and propose strategic adjustments. This monitoring is oriented toward institutional learning and promotes continuous improvement. From this perspective, territory is understood as a political and epistemic subject, capable of shaping its own future based on its memory, diversity, and collective agency.

Complex Thinking and complexity sciences propose an epistemological rupture by rethinking the concept of territory. Rather than conceiving it as a bounded geographic space or a manageable administrative unit, it is understood as a complex adaptive system, as articulated by Holland (1995) and Morin (2005). This system constitutes a dynamic web of relationships, in which heterogeneous actors such as institutions, enterprises, social organizations, communities, ancestral knowledges, and ecosystems interact. These interactions generate learning, transformations, and emergent phenomena.

This vision displaces the notion of linear and controlled intervention. Policy actions generate unforeseen effects, local actors' decisions may be amplified or transformed depending on the context, and equilibria remain in constant flux. Territory behaves as a living organism endowed with capacities for self-regulation, resilience, and meaning-making. Key features of this approach include:

- Emergence. The properties of a territory transcend the sum of its components. They arise from the complex interactions among actors, processes, and structures. Territorial identity emerges from the symbolic relationship between place, history, culture, and its inhabitants.

- Feedback. Every public action generates effects that reconfigure the system and transform its underlying conditions. This circularity demands continuously evaluated and adjusted strategies, fostering ongoing learning.

- Self-organization. Local communities possess the capacity to generate order, cooperation, and innovation without relying on centralized direction. This principle is evident in active citizen networks responding to crises, regenerative agroecological systems, and experiences of urban self-management.

- Nonlinearity. Small interventions can produce large-scale systemic effects. This sensitivity to initial conditions requires caution, constant monitoring, and flexible responsiveness.

- Co-evolution. Territorial actors transform their environment and are simultaneously transformed by it. This mutual dynamic requires policies that accompany and strengthen local processes, supporting the collective construction of development trajectories.

Under this conception, territory acts as a collective, creative, and resilient subject. Its understanding requires an integrative approach that combines systemic analysis, cultural sensitivity, political ecology, and strategic foresight.

Territorial planning is understood as the art of navigation in uncertain contexts, where the compass is guided by ethical orientation, the map is constructed dynamically, and the course is defined alongside the community.

Visualizing territory as a complex adaptive system transforms both the conceptual perspective and the concrete strategies of management. Rather than relying on rigid plans, fixed goals, or replicable models, territorial management adopts experimental, iterative, and deliberative approaches. This implies an institutional praxis that is process-oriented, grounded in active listening, and committed to the collective construction of meaning. The following are key strategies for complexity-inspired territorial management:

- Relational cartographies. Planning emerges from living maps that integrate physical resources, infrastructure, social relationships, latent conflicts, community knowledge, and invisible flows. These cartographies include symbolic, emotional, and cultural dimensions essential for understanding lived territoriality.

- Territorial innovation laboratories. Hybrid spaces where diverse actors communities, governments, universities, entrepreneurs, and artists converge to experiment with local solutions. These laboratories allow for idea testing, learning through failure, scaling validated innovations, and feeding public policy from practice.

- Adaptive planning. Replacing closed plans with flexible roadmaps that can be revised based on contextual indicators, civic narratives, and participatory diagnostics. This approach strengthens responsiveness to unforeseen events and reinforces local strategic autonomy.

- Weaving collaborative networks. Promoting horizontal coordination platforms that integrate diverse sectors. These networks serve as spaces for trust-building, ethical deliberation, and the generation of collective intelligence.

- Distributed knowledge management. Building systems for documenting, systematizing, and sharing the knowledge generated within territories. Institutional and community memory constitutes a strategic asset for strengthening resilience, avoiding unnecessary repetition, and consolidating local knowledge.

These strategies operate according to a logic that runs counter to that of many public policies: rather than imposing external models, they begin with what the territory already practices its latent capacities and emerging dynamics. The task of public management is to make these living forces visible, connect them, and amplify their potential.

A complex approach to Local Economic Development is intrinsically linked to an ethical dimension. If territories are understood as living systems and public policies are part of them, then development is conceived as a situated practice of caring for life in all its forms. This perspective establishes normative boundaries against the instrumental use of territory as a mere space for extraction or economic growth.

In this sense, territorial development is understood as a collective construction oriented toward ecological sustainability, social equity, and human dignity. It entails caring for both productive capacities and conditions of existence, integrating visible economies with care economies, and valuing both the use and symbolic meaning of common goods. Several ethical principles emerge from this perspective:

- Intergenerational responsibility. Every development action must consider its impacts on future generations, particularly regarding natural, cultural, and symbolic commons.

- Territorial justice. Equitable access to the benefits of development requires mechanisms that prevent the reproduction of exclusion, concentration, or dispossession. This implies redistribution, recognition, and historical reparation.

- Recognition of diversity. The cultural, productive, and ecological heterogeneity of territory is understood as a source of resilience, creativity, and collective meaning. Policies must protect and nurture this diversity, avoiding its homogenization.

- Care for social ties. Development aims to strengthen community bonds, relationships of trust, and networks of solidarity. Social fragmentation reflects a form of territorial degradation as severe as unemployment or poverty.

- This ethical paradigm transforms intervention logics. Development is no longer defined solely by growth rates or investment levels, but by its capacity to sustain life under conditions of dignity, equity, and fulfillment.

Complex Thinking and complexity sciences offer a robust epistemological framework for rethinking Local Economic Development, moving beyond reductionist economicism and technocratic planning logics. Conceiving territories as complex adaptive systems displaces notions of control, predictability, and efficiency in favor of interdependence, emergence, resilience, learning, and care.

This paradigmatic shift entails profound transformations in policy design, institutional configuration, and management practices. It means embracing the idea of living, intelligent, and ethical territories capable of generating their own meanings of development based on their singularity, history, and collective vocation.

The challenge is twofold: to decolonize development knowledge and to repoliticize territorial governance. The first acknowledges that hegemonic models emerge from positions of power that render invisible other ways of living and producing. The second recognizes that development is a political matter: it defines which lives are valued, which futures are imagined as possible, and who participates in their construction.

To embrace a complex approach to local economic development is to affirm that every territory holds the potential to reinvent itself as an active subject of its own transformation. Within the living web of relationships, conflicts, learning processes, and affections, lies the possibility of building diverse and dignified futures.

In these systems, the heterogeneity of agents is understood as a fundamental resource for resilience. Local governments, agricultural cooperatives, universities, non-governmental organizations, businesses, informal networks, cultural actors, and ancestral communities constitute nodes within a relational fabric that is built through constant interaction, where each contributes distinct interpretive frameworks, knowledges, and resources. Adaptive learning, understood as the capacity of actors to modify their behavior in response to their environment and accumulated experience, constitutes one of the central properties of the territorial system (Folke, 2006).

This learning manifests at the individual and institutional levels, as well as at the systemic level, through feedback processes that allow for the correction, adjustment, or transformation of territorial dynamics. The introduction of a public policy may generate unexpected effects, which requires collective responses to redefine it. These cycles of trial and error where error is embraced as a constitutive part of the learning process depart from rationalist frameworks that envision perfect and definitive planning. Adopting the perspective of territory as a complex adaptive system entails a profound shift in intervention strategies:

- Designing public policies that are flexible, experimental, and capable of learning from practice.

- Creating governance platforms that foster dialogue among knowledges, the recognition of cultural diversity, and the co-production of knowledge.

- Moving beyond static indicators and working with dynamic modeling tools, scenario simulations, actor mapping, and social network analysis.

- Incorporating uncertainty as a structural feature, promoting anticipatory and resilience-building capacities rather than pursuing illusory certainties.

Understanding territory as a complex adaptive system enables a move beyond technocratic and functionalist visions, allowing development to be conceived through a processual, relational, and interdependent logic. It involves viewing territories as social, economic, and cultural ecosystems in constant mutation, where planning becomes an exercise in active listening, multiple interaction, and collective co-evolution.

Understanding local economic development through the lens of Complex Thinking implies an epistemological shift that rejects analytical fragmentation. Rather than dissociating economy, society, politics, and ecology, it proposes an integrative perspective in which territories are configured as open, dynamic, and interdependent systems, in continuous interaction with their environment and with themselves. From this standpoint, development emerges from the articulation of tangible and intangible, structural and cultural, material and symbolic dimensions an interaction that is both emergent and recursive.

Toward a Complex Methodology for Territorial Development

Understanding local economic development as a complex process demands more than a conceptual framework it requires practical methodological tools. Instead of relying on replicable models or universal formulas, the complexity approach proposes situated methodologies that are context-sensitive, integrating multiple levels of analysis and diverse sources of knowledge. The following presents a methodological pathway inspired by complex thought, aimed at diagnosing, planning, and intervening in territories through an adaptive, participatory, and integrative logic.

- Mapping actors and knowledges. The starting point for any complex territorial diagnosis is the plural identification of actors, including those often rendered invisible, such as rural women, ethnic communities, youth collectives, and informal networks. This diversity must be complemented by recognizing the range of knowledges present: technical, empirical, ancestral, organizational, and artistic.

This relational mapping helps to understand the ecology of interactions that sustains the territory its tensions, silences, and synergistic potentials. It includes power nodes and symbolic, material, and communicative flows. Tools such as collective mind maps, social network analysis, participatory workshops, and affective mapping enable the construction of this integrated picture.

- Systemic and historical diagnosis. A critical phase involves building a systemic view of the territory by analyzing economic, ecological, sociocultural, institutional, and symbolic dynamics. This includes studying interrelationships, feedback loops, structural asymmetries, and interterritorial flows.

This diagnosis requires a historical dimension to understand long-term processes that have shaped current conditions. What trajectories has the territory followed? What continuities and ruptures have marked its development cycles? What collective memories serve as references or obstacles? Complex Thinking is grounded in acknowledging lived history and its multiple interpretations.

- Identification of emergent patterns and leverage points. One of the most valuable contributions of a complexity perspective is its capacity to detect emergent patterns recurring behaviors that arise from system interactions. Identifying these patterns allows for the visualization of latent dynamics, hidden opportunities, and underestimated risks. The growth of barter networks, peasant markets, and neighborhood organizations in peripheral areas are examples of emergent processes worth strengthening.

Alongside these patterns, it is essential to identify leverage points strategic nodes where small interventions can produce significant effects. These may include community leadership, bridging institutions, symbolic resources, or key infrastructure. Acting on these points requires attentive listening and co-design processes that strengthen endogenous transformations.

- Co-design of scenarios and adaptive strategies. Local development strategies must be built through multiple scenarios and adaptive strategies that allow for experimentation, learning, and course adjustment. Scenarios function as plausible narratives collectively constructed to explore alternative futures and prepare flexible responses.

Strategies combine levels of action, time scales, and types of intervention. It is essential that they emerge from dialogue with local actors, integrating diverse visions, interests, and capacities.

Tools such as territorial innovation laboratories, simulations, collective intelligence platforms, and participatory budgeting facilitate these processes. The core aim is to foster a culture of planning that is alive, flexible, dialogical, and open to uncertainty.

- Reflective evaluation and institutional learning. The complexity approach calls for rethinking evaluation. Rather than measuring predefined goals, it involves accompanying processes, identifying learning moments, correcting trajectories, and strengthening collective capacities. Evaluation becomes a continuous, participatory, and reflective process, focused on the path taken and the emerging insights.

Mixed indicators are needed context-sensitive, relevant to stakeholders, and adaptable over time. Mechanisms for institutional learning are also necessary: spaces where organizations can critically review their actions, reformulate strategies, and systematize lessons. From this perspective, error is embraced as a source of learning. The essential task is to learn to navigate complexity with humility, creativity, and shared responsibility.

To advance a model of local economic development inspired by complexity, it is necessary to move beyond one-dimensional interventions and promote governance involving multiple levels and actors. This perspective understands development as requiring dense and dynamic articulations across territorial scales (local, regional, national, global) and between public, private, community, and academic actors.

From the lens of complex thought, territory is conceived as a node embedded in multiple networks a space where interdependent systems with diverse logics and asymmetric rhythms interact. This vision encourages mechanisms of flexible coordination, intercultural dialogue, and creative institutional arrangements to prevent bureaucratic gridlock and fragmented governance.

Functional polyarchy offers a way to envision horizontal coordination among institutions such as ministries, municipalities, organizations, chambers of commerce, universities, and cooperatives. The goal is to synchronize without imposing uniformity. This requires flexible structures, mediation spaces, clear deliberation rules, and an organizational culture that values cooperation.

Instruments for Complex Management

Accompanying processes from the perspective of complexity requires management tools aligned with this logic. Key elements include:

- Adaptive monitoring systems, which allow strategies to be adjusted in real time, detect early signals, and respond to changing environments.

- Actor maps and shared agendas, useful for identifying interests, conflicts, and potential synergies, as well as for defining common objectives.

- Mixed indicator systems, integrating objective variables such as production or income and subjective variables such as perceived well-being, collective self-esteem, or trust in institutions.

- Participatory evaluations, based on active listening, intercultural dialogue, and shared review of results to support joint decision-making.

These tools demand technical capacities and an ethical attitude rooted in transparency, co-responsibility, and commitment to the common good.

Knowledge Economy and Territorial Innovation Ecosystems

The transition toward a knowledge-based economy presents new challenges for local development. Beyond competing through costs or location, territories must build cognitive and relational advantages: learning, innovating, and connecting diverse knowledges. An innovation ecosystem represents a dense network of interactions among heterogeneous actors who produce, exchange, and apply knowledge.

This ecosystem integrates technical expertise, traditional wisdom, practical experience, and cultural values. Understood this way, knowledge emerges from social interaction and is distributed throughout the territory. Hence the relevance of education, applied research, collaborative platforms, and civic laboratories as pillars of development.

From a complexity perspective, innovation is understood as an emergent process resulting from multiple interactions and ongoing transformations. Innovation policies must create spaces for experimentation, cooperation among actors, and the social appropriation of knowledge.

The challenge lies in balancing the need to generate economic impact with the urgency of addressing social and environmental problems. The knowledge economy must improve living conditions, regenerate ecosystems, and strengthen the social fabric. Achieving this requires redefining success criteria to include equity, sustainability, and collective well-being.

- Indicators and reflective evaluation. One of the main challenges in applying complexity to territorial development is building appropriate indicators. Traditional indicators, focused on GDP or foreign investment, capture only partial dimensions. Evaluation systems are needed that account for multidimensionality, nonlinearity, and emergent processes.

Authors such as Midgley and Espinosa have proposed systemic evaluations that integrate qualitative variables, subjective indicators, and collective deliberation. These methodologies value triangulation, real-time evaluation, and the capacity to adjust policies based on learning.

Tools such as social cartographies, network analysis, territorial resilience matrices, and shared value maps help visualize key interactions, strategic nodes, and zones of vulnerability. These instruments allow us to understand how and why a process functions, avoiding the replication of models without contextual consideration.

The challenge is to build a common language among practitioners, communities, and academics one that translates complexity into practical decisions. This requires openness to learning, acknowledgment of uncertainty, and willingness to adapt to ambiguity.

- Risks and conditions for meaningful application. While powerful, Complex Thinking carries certain risks. One is the superficial use of terms like "emergence" or "resilience" without translating them into concrete practices. Another is the elitization of the discourse, which may alienate local actors. Avoiding this requires translating concepts into clear strategies, pedagogical tools, and accessible narratives.

Applying complexity demands institutions capable of sustaining long-term, coherent processes backed by political will, support structures, and well-prepared teams. Without these elements, complexity may remain a well-intentioned but ultimately ineffective discourse.

Institutional Transformations and Territorial Learning

Consolidating local economic development through the lens of Complex Thinking requires transforming institutions. Conceived as living systems of formal and informal rules that guide collective action, institutions evolve through interaction with their environment. From this perspective, local institutions must learn, adapt, and evolve alongside territorial dynamics, moving beyond centralized frameworks and pre-designed policies.

This learning involves moving away from bureaucratic approaches based on rigid targets and embracing reflective governance one that incorporates continuous review, error management, and ongoing adaptation. A local development agency implements policies, monitors their effects, learns from outcomes, incorporates community feedback, and redesigns interventions through participatory means.

The key lies in activating cycles of organizational learning. Governments, businesses, universities, and social organizations share visions, develop joint diagnostics, and experiment using scenario-based approaches. This process recognizes uncertainty as a natural aspect of transformation. Institutions become collective intelligences that guide territorial processes through active listening, informed deliberation, and strategic flexibility.

Institutional learning is strengthened by territorial pedagogies that promote the collective appropriation of territory as a space for constructing the future. This is reflected in participatory planning, civic laboratories, deliberative assemblies, and social innovation projects, where scientific, technical, and community knowledge are integrated horizontally.

From a complexity perspective, territory is defined by its relational fabric. Territorial capital understood as the sum of tangible and intangible resources includes social trust, intersectoral cooperation, associative networks, cultural memory, and shared values. This capital emerges from historical processes of interaction, conflict, and collaboration.

Local economic development requires strengthening networks of trust, reciprocity, and strategic coordination. These networks function as invisible infrastructures that sustain the economy. The absence of trust, cooperation, and collective projects leads to fragile and unequal growth. Research shows that dense and horizontal social ties foster innovation, efficiency, and equity.

Public policies take on the strengthening of social capital as a strategic goal. This involves promoting local supplier and consumer networks, creating collaborative digital platforms, and recognizing diverse associative forms such as cooperatives and care networks. Social capital is the product of deliberate political construction, which requires institutional support and encouragement.

Network analysis enables the mapping of key actors, identification of bottlenecks, visualization of knowledge communities, and design of multiscale strategies. This approach helps to understand the interdependent dynamics that sustain territorial development.

Resilience is expressed as the capacity for reorganization, learning, and transformation in the face of deep disruptions. Rather than merely resisting, it entails creating new structures and relationships to confront challenges. Territorial resilience involves identifying key socio-economic systems such as food, energy, and employment and designing strategies that ensure continuity while fostering transformation. It requires governance capable of detecting early signals, activating coordinated responses, and stimulating institutional innovation.

Resilience is grounded in principles of social justice. The aim is to build distributed resiliences, where historically marginalized groups participate with voice, resources, and the capacity to define their futures. Systemic transitions are understood as political processes. The goal is not simply to improve existing models, but to imagine and construct alternative futures. This involves activating pilot experiences, experimenting with new forms of production, and reconfiguring the relationships between economy, ecology, and culture. These transitions emerge through contestation, learning, and alliances.

Complex Thinking is conceived as an attitude that acknowledges uncertainty, ambiguity, and interdependence as constitutive features of social life. Applied to local economic development, it involves recognizing territories as living systems with their own histories, latent conflicts, emergent capacities, and diverse potentialities.

This perspective challenges traditional planning frameworks that fragment reality and measure success using decontextualized indicators. Complexity proposes planning as learning, public action as collective construction, and evaluation as a space for dialogue.

Complex Thinking redefines local economic development as a situated, participatory practice open to transformation. This demands flexible institutions, active citizenship, shared knowledge, and genuine political will. In this way, development becomes a concrete experience of transformation and territorial dignity.

Articulation with Theories of Local Economic Development

Complex Thinking integrates and enriches previous theories of local economic development by offering a more situated, critical, and layered perspective. Its main contribution is epistemological: it challenges linear assumptions, rigid dichotomies, and closed causal logics inherent in conventional planning. It proposes a transdisciplinary metatheory open to uncertainty, plurality, and coevolution.

The endogenous development approach, advanced by Vázquez Barquero, emphasizes territorial innovation, human capital, and cultural identity as drivers of development. This perspective values internal capacities and rooted participation. From a complexity standpoint, it is complemented by a relational and multiscalar view that acknowledges the hybrid, contested, and situated construction of each territory shaped by multiple scales and tensions among competing rationalities. Endogenous development is strengthened when internal capacities and external linkages are considered together, including their tensions and transformative potential.

Multilevel governance seeks to coordinate different levels of government and actors in public policy. The complex vision expands this notion by incorporating social self-organization. Many processes emerge from informal networks, spontaneous alliances, and distributed learning. Polycentric governance distributes authority based on legitimacy, experience, and the ability to articulate shared agendas.

Emerging practices such as multi-actor cooperatives, citizen observatories, territorial pacts, and participatory budgeting reflect a relational and evolving form of democracy. Governance is understood as a living process grounded in ongoing adjustments, deliberation, and collective learning.

The social and solidarity economy offers fertile ground for complexity. Rooted in cooperation, equity, sustainability, and self-management, it prioritizes people over profit. From the complexity perspective, it is interpreted as a social resilience infrastructure. Instruments such as local currencies, short supply chains, community banks, and care networks create collaborative fabrics that mitigate crises and enhance adaptive capacity. The social and solidarity economy is understood as both an emergent phenomenon and a legitimate form of social innovation. In contexts of structural exclusion, these practices open transformative pathways and require supportive development policies.

Complex Thinking critically revisits classical theories. Comparative advantage, centered on specialization and free trade, is reinterpreted in light of vulnerabilities exposed by global interdependence. The pandemic revealed territorial fragilities and breakdowns in supply chains. Within this framework, concepts such as productive redundancy, solidaristic interdependence, and adaptive systems gain relevance.

Models such as growth poles or unbalanced regional development acquire new meanings when institutional coevolution, multiscalar interactions, and feedback loops are taken into account. Complexity reinterprets these theories through a dynamic and contemporary lens. Complex Thinking engages with heterodox perspectives without diluting them. Ecological economics contributes the principle of biophysical limits. Decolonial thought offers critiques of Eurocentric epistemologies. Dependency theory provides a structural view of global power. These perspectives are articulated as part of an ecology of complementary knowledges. This positioning supports a critical horizon that integrates diverse rationalities into territorial projects aimed at justice and sustainability.

Complexity invites movement toward a situated metatheory. Each territory builds its own cartography by articulating objective dimensions such as infrastructure, productivity, and employment with subjective ones like identity, memory, and meaning. Theories serve as tools for thought, functioning as flexible frameworks. The design of territorial strategies is grounded in co-construction, experimentation, and continuous validation. Planning becomes a situated practice of learning and shared transformation.

Challenges and Opportunities

Approaching local economic development through the lens of complexity entails abandoning preconfigured solutions, univocal matrices, and linear intervention frameworks. Territories function as complex adaptive systems where uncertainty, diversity, conflict, and emergence shape unpredictable dynamics. The greatest challenge is methodological: to build flexible, context-sensitive frameworks capable of articulating qualitative and quantitative, rational and intuitive, technical and cultural dimensions.

One of the main challenges lies in strengthening adaptive capacities within local governments and social organizations. Operating with rigid planning frameworks proves insufficient. Institutions must learn how to learn. This requires developing dynamic capabilities that allow for detecting change, processing complex information, and reconfiguring resources and narratives. Territories must be cultivated as living organisms whose resilience depends on their capacity for conscious adaptation.

This institutional learning process demands internal feedback systems, a reflective culture, distributed leadership, and structures that promote interdisciplinary and cross-sectoral dialogue. Evaluation must function as a device for collective reflection aimed at revisiting assumptions, exploring alternatives, and facilitating course corrections.

A key condition for adaptability is the creation of safe spaces for experimentation. These environments enable testing of new practices, models, or technologies without irreversible consequences. Valuing error-driven learning as a driver of innovation requires documenting and analyzing failures as inputs for continuous improvement.

The design of territorial innovation laboratories is effective for promoting such dynamics. In these spaces, actors such as producers, academics, public officials, and citizens co-create policy prototypes, validate solutions, and generate situated knowledge. This experimental logic breaks away from imposed policies and paves the way for participatory and evolutionary models of governance. The complexity approach requires formative evaluation methods that accompany processes and value dimensions that are difficult to quantify, such as trust, agency, relational quality, creativity, and local ownership. Evaluation must consider outcomes, processes, trajectories, and critical turning points.

Instruments must be designed with flexibility, epistemic plurality, and contextual sensitivity. Methods such as qualitative participatory evaluation, actor mapping, narrative indicators, and socio-spatial cartographies offer rich insights into local dynamics and conditions for future transformation. System modeling tools such as system dynamics and simulations help identify strategic nodes and visualize scenarios. The complexity approach creates space for ontological and epistemic diversity. Development integrates a plurality of ways of life, forms of knowledge, and ways of inhabiting territory. This diversity enhances both resilience and innovation. Including Indigenous, peasant, Afro-descendant, and peripheral urban perspectives expands the repertoire of strategies and prevents technocratic reductionism.

From the perspective of political ecology, many territorial conflicts arise from value-based incompatibilities and differing conceptions of buen vivir. Complex planning brings these tensions to light, facilitates translation across worlds, and enables intercultural and transdisciplinary agreements.

Recognizing ecological diversity means overcoming the utilitarian view of resources. Ecosystems act as territorial actors: they co-produce well-being, shape economic dynamics, influence cultural identity, and affect future viability. Integrating this logic fosters a socio-ecological approach.

Examples of Territorial Implementation from the Perspective of Complexity

- Territorial Innovation Laboratories in Medellín, Colombia. The city of Medellín transformed from a locus of structural violence into an international reference for urban social innovation through the creation of complex innovation ecosystems. Notable examples include Ruta N and the Teacher Innovation Center (MOVA), where universities, businesses, government, and citizens engage in co-creation dynamics.

These laboratories operate as adaptive systems. Solutions are developed through iterative prototypes, with community participation and formative evaluation. Key areas of focus include sustainable mobility, teacher training, violence prevention, and the transformation of public spaces driven by collective learning and controlled experimentation (Alcaldía de Medellín, 2018).

- Resilient Governance Strategy in the Paraná Delta, Argentina. In this region, known for high biodiversity and climate vulnerability, a socio-ecological participatory planning initiative is underway. A multi-actor network composed of peasant organizations, island communities, scientists, and local governments has developed an early warning and participatory hydrological monitoring system.

The project integrates local and institutional knowledge through simple technologies and ancestral understandings of the river's cycles. This experience demonstrates how a watershed can be governed through distributed governance, attuned to emergent dynamics and adaptive in the face of disruptions (López Cerezo et al., 2019).

- Agroecological Networks in Oaxaca, Mexico. In Zapotec communities of Oaxaca, organizations promote endogenous development strategies based on agroecology, fair trade, and cultural strengthening. Relational capital is fostered through peasant networks for seed exchange, knowledge sharing, and product distribution, with a high degree of autonomy.

Methodologies include social cartography, deliberative assemblies, and community diagnostics. In the face of climate uncertainty, these communities demonstrate resilience by combining traditional practices with ecological innovations (Toledo & Barrera-Bassols, 2009). Biocultural diversity is embraced as both an asset and a source of strength.

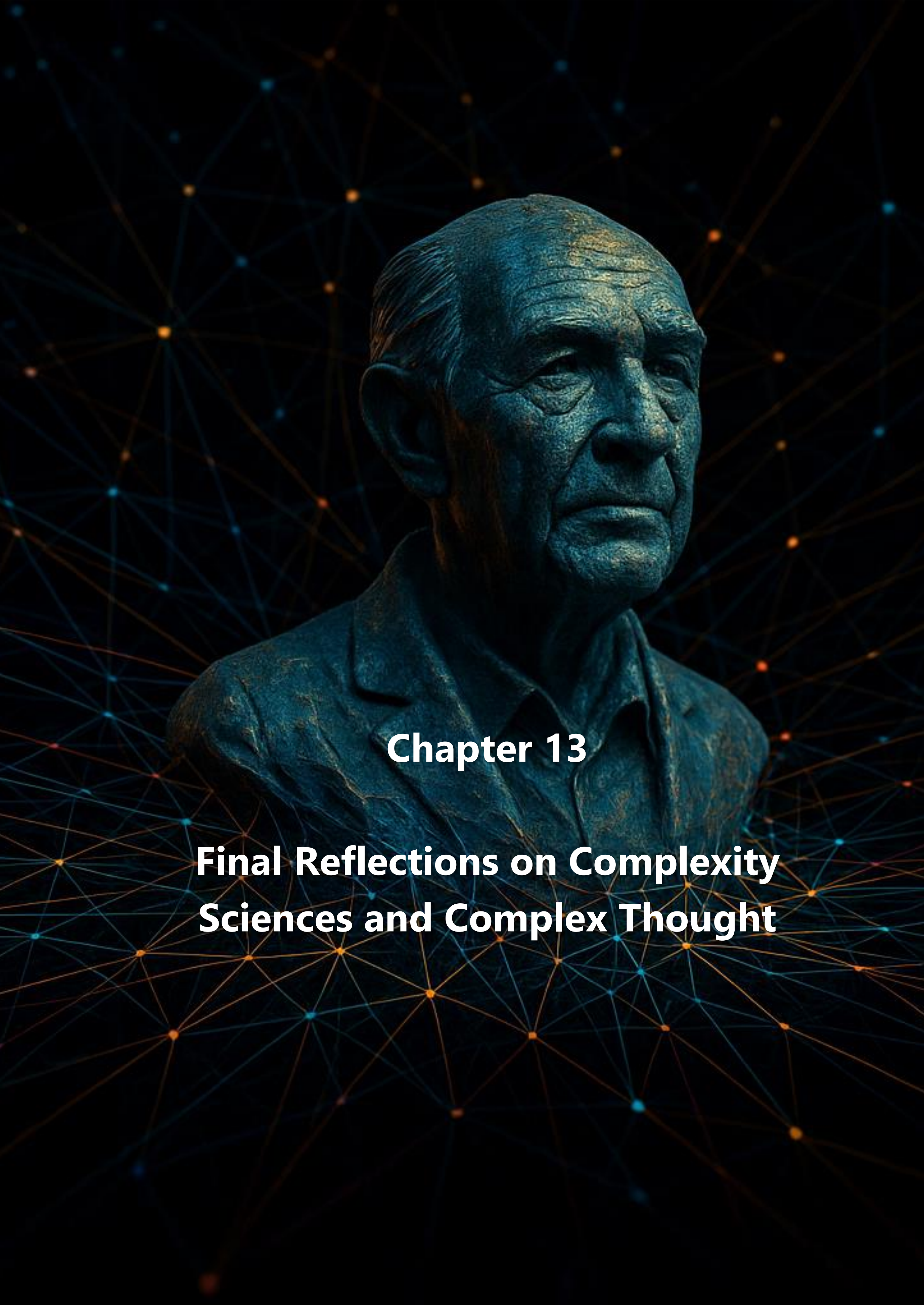
- Adaptive Participatory Budgeting in Porto Alegre, Brazil. In Porto Alegre, participatory budgeting was refined through annual adjustments based on citizen feedback and the actual performance of public projects.

District-level feedback and deliberation enabled the redefinition of priorities, adjustment of timelines, redistribution of funds, and reinforcement of community agency. This practice became an example of a self-organized system with distributed governance, where bureaucracy was replaced by territorial collective intelligence (Avritzer, 2009).

- Mapping Local Food Systems in Catalonia, Spain. The Catalonia Food Systems Observatory is developing a participatory cartography of producers, short marketing channels, seed banks, municipal policies, and social economy actors. The aim is to reveal hidden interconnections within the food system and to support informed and collaborative decision-making.

The initiative is grounded in recognizing the emergent and nonlinear nature of the agri-food system. Methodologies such as network analysis, ethnographic interviews, and multiscalar approaches help design integrated policies, promote alternative circuits, and strengthen ecological and economic resilience tied to communities (Vivas & Padilla, 2022).

These cases demonstrate that Complex Thinking operates as an applied grammar to guide public, community, and academic interventions. Each experience reflects principles such as collective learning, distributed governance, epistemological diversity, self-organization, and adaptability.



Chapter 13

Final Reflections on Complexity Sciences and Complex Thought

Final Reflections on Complexity Sciences and Complex Thinking

1. General Reflections

This book presents a transdisciplinary journey that weaves together knowledges, practices, and epistemic tensions to understand reality through the lens of complexity. From the origins of modern science to contemporary debates on agriculture, economics, globalization, governance, and sustainability, it explores how Complex Thinking helps question reductionist worldviews and imagine new ontological and political possibilities. Understanding the world emerges as an ethical necessity that challenges our ways of knowing, acting, and coexisting within interdependent and dynamic systems.

Far from being associated with chaos or disorder, complexity is understood as the web of interactions, feedback loops, emergent properties, and self-organizing processes that shape social, ecological, technological, and cognitive systems. This approach recognizes that controlling systems from the outside is unfeasible, as we inhabit them and act as interdependent subjects. Such an understanding calls for an open disposition toward uncertainty and the capacity to embrace paradoxes, contradictions, and the multiple dimensions of knowledge.

Complexity is conceived as a way of thinking that displaces the notions of neutral objectivity, technical control, and linear causality. Rather than offering closed answers, it invites us to sustain deep questions, read contexts with situated attention, and evolve alongside the problems. The so-called "dance of complexity" represents an epistemic practice that requires contextual sensitivity, cognitive flexibility, and an ethic grounded in the acceptance of uncertainty.

This pedagogy of wonder reminds us that all knowledge is partial, and every intervention generates unforeseen effects. The ethics of Complex Thinking rests on ontological humility and the recognition of the impossibility of absolute knowledge. Accordingly, this work opens toward new questions that emerge as challenges for thinking, action, and coexistence in times of systemic crises:

- How can we educate for complexity without falling into paralysis?
- How can we design public policies that integrate uncertainty, diversity, and interdependence?
- How can we build organizations capable of learning and transforming themselves?
- How can we activate collective processes that allow us to imagine futures centered on regeneration, justice, and care?

These questions invite collective processes of meaning-making. In a world marked by deep interdependencies and multiple accelerations, thinking through complexity emerges as a civilizational imperative. Each reader is invited to join this dance with humility, creativity, and ethical commitment.

2. Reflections on the Frontiers of Knowledge

In recent decades, Complex Thinking and complexity sciences have significantly expanded their horizons by integrating contributions from biology, quantum physics, computer science, neuroscience, network theory, and systemic sustainability studies. This epistemological convergence emerges from the need to rethink knowledge structures in the face of phenomena characterized by disrupted linearity, emergence, and dynamic instability.

Complex thought, inspired by the work of Morin, has evolved from a critique of disciplinary fragmentation into a proposal for a reform of thought grounded in the articulation of knowledges, self-reflexivity, and the integration of uncertainty as a central epistemological category (Morin, 2007). This perspective has been adopted and reinterpreted in fields such as transformative education, adaptive governance, decolonial epistemologies, and critical pedagogies (Leff, 2020; Capra & Luisi, 2014).

An emerging trend is the connection between Complex Thinking and socio-ecological networks, which model interactions between human and natural systems without reducing them to simplified causal relations. These approaches require rigorous methodological refinement to avoid superficial uses of the concept of complexity or its reduction to a decorative category.

In the educational domain, new frameworks have been developed to promote competencies for complexity such as systems thinking, critical thinking, and ethical reasoning with the aim of preparing individuals to act in contexts of high uncertainty and interdependence. These proposals demand a profound curricular redesign that transforms traditional pedagogical logics through a relational epistemology.

Within complexity sciences, recent advances include the intensive use of computational modeling to explore emergent behaviors in adaptive systems. In evolutionary biology, for example, a new explanation has been proposed for the transition from prokaryotic to eukaryotic cells, based on structural constraints on protein size and intron-mediated genetic regulation suggesting an abrupt evolutionary reorganization event (Lane, 2021).

In structural biology, the 2024 Nobel Prize in Chemistry awarded to the creators of artificial intelligence tools for protein structure prediction, such as AlphaFold, marked a turning point. These tools, capable of accurately inferring the three-dimensional conformation of a protein from its amino acid sequence, accelerate scientific discovery, drug design, and the understanding of complex diseases (Senior et al., 2020).

In neuroscience, creativity has been reinterpreted through the study of the Default Mode Network, which is involved in imagination, divergent thinking, and the generation of disruptive ideas. Inhibition of this network is associated with diminished creative capacity, allowing creativity to be understood as an emergent property of distributed and dynamic neural systems (Beaty et al., 2016). These findings open new perspectives on the relationship between brain complexity, mental states, and cultural production, challenging reductionist models based on fixed functional localizations.

Quantum computing emerges as a novel frontier for complexity. The redefinition of traditional complexity classes through categories such as BQP and QMA has expanded the limits of computability, enabling the tackling of problems intractable for classical algorithms. These advances have implications for fields such as cryptography, ecosystem simulation, logistics network optimization, and complex market modeling (Preskill, 2018). However, these developments demand continuous critical vigilance. Technological fascination must be balanced with rigorous philosophical and political reflection to avoid forms of exclusion disguised as technical sophistication.

3. Traditional Science and the Complexity Paradigm

The contrast between traditional science and the complexity paradigm should be understood as a productive epistemological tension that reveals different ways of approaching reality. Traditional science, heir to Cartesian modernity and the mechanistic paradigm, has been defined by its analytical vocation, its pursuit of universal laws, its emphasis on predictability, and its tendency toward disciplinary fragmentation. This approach has proven remarkably effective in technological development, knowledge systematization, and the resolution of well-defined problems. However, its explanatory capacity is limited when faced with dynamic, open, adaptive, and nonlinear phenomena such as ecosystems, social bodies, cognitive processes, and global economic systems.

The complexity paradigm, far from proposing a total rupture with scientific tradition, seeks to enrich and complexify it by acknowledging the limits of reductive simplification. As Morin (2007) argues, thinking in complexity means learning to unite without confounding, to distinguish without dissociating, and to integrate without reducing. This epistemological logic embraces a relational lens, conceiving phenomena as emergent configurations generated by multiple interactions among heterogeneous components. Emergence, self-organization, feedback, nonlinearity, randomness, and uncertainty become essential properties to understand and cultivate.

From this standpoint, Complex Thinking challenges the absolutization of science. It values analytical precision while demanding its contextualization within broader systems. It recognizes the importance of method but decenters it as the sole legitimate pathway to knowledge. It integrates reason within a cognitive ecology that also includes intuition, emotion, ethics, and aesthetics. This epistemological expansion enables a deeper, more critical, and situated understanding of reality one that maintains rigor while embracing its unfinished and contingent nature.

A compelling example of this articulation is the analysis of climate change. While traditional science contributes quantitative models on the behavior of greenhouse gases, the complexity paradigm allows for the integration of political, social, cultural, and economic dimensions that interact with biophysical processes in nonlinear and often unpredictable ways.

This approach has been adopted by institutions such as the IPCC, which now incorporates integrated methodologies and adaptive scenarios to address the structural uncertainty of the global climate system (IPCC, 2022). Knowledge thus becomes a plural construction, one that admits bifurcations, critical thresholds, and unexpected developments.

Another key case is the study of pandemics. The global crisis triggered by COVID-19 exposed the limitations of classical epidemiological models based on fixed parameters and assumptions of population homogeneity. In response, complexity-based approaches emerged, incorporating variables such as urban mobility, social networks, risk perception, institutional responses, misinformation, and structural inequalities. Although these models were less precise in numerical terms, they provided more faithful representations of reality and enabled the design of public policies that were more responsive to context and emergent dynamics (Barabási, 2021).

This epistemological transition entails a profound transformation in how knowledge is produced and validated. It involves reshaping the questions we ask, the frameworks through which we observe, the methodologies we apply, and the values that guide our investigative practice. As Nicolescu (2008) warns, such a transformation demands a new contract between science, philosophy, and society one in which knowledge is conceived as a transdisciplinary, open, situated, and ethically oriented process.

From this standpoint, the complementarity between traditional science and Complex Thinking becomes fertile. It is about integrating the strengths of each to build a more robust, reflexive, and socially committed science. Science ceases to be an ivory tower and instead becomes an ecological, political, and coevolutionary practice one that acknowledges its entanglement within the very systems it studies and acts responsibly within them.

This shift also calls for a reconfiguration of scientific education. Teaching for complexity means promoting an ecology of thought that cultivates the ability to connect knowledges, detect patterns, manage uncertainty, think across multiple temporal and spatial scales, and critically reflect on the role of knowledge in transforming the world. The goal is to form epistemic agents capable of acting amid uncertainty, dialoguing with diversity, and imagining alternatives.

Within this framework, Complex Thinking emerges as a powerful tool for decision-making under high ambiguity. Its orientation is to learn how to navigate uncertainty. By expanding the field of vision, it enables more inclusive deliberative processes, more integral diagnoses, and more sustainable solutions. It fosters modes of problematization that invite thinking in terms of interactions, feedback loops, and unintended consequences.

Its application in education enables the design of more holistic learning processes that enhance analytical capacity, creativity, ethical sensitivity, and dialogic disposition. Education grounded in complexity seeks to form subjects capable of engaging with problems reflectively, cooperatively, and transformatively.

This orientation resonates with critical education, the pedagogy of the question, and participatory methodologies that articulate academic knowledge with community experiences and subaltern knowledges (Freire, 1970; De Sousa Santos, 2009).

In this sense, Complex Thinking constitutes an epistemological necessity in a world marked by radical uncertainty, accelerated change, deepening interdependencies, and intensifying socioecological crises. Its alliance with the sciences of complexity understood as analytical and computational tools for modeling complex systems offers a potent synergy between reflection and technique, between qualitative understanding and quantitative simulation, between philosophical insight and operational capability.

While the sciences of complexity offer means to analyze the dynamics of adaptive systems, Complex Thinking provides an epistemological and methodological lens to interpret those results, resist reductionism, and remain critically attuned to the limits of all modeling. By integrating these approaches, a deeper, more situated, and transformative understanding of reality becomes possible one that orients both explanation and ethical action.

Such integration is crucial in a historical moment where the challenges we face from climate collapse to crises of meaning demand nonlinear, transdisciplinary, and ethically grounded logics. What is required is a science that understands, dialogues, and assumes responsibility. Complexity represents an opportunity for science to renew itself, to expand its horizons, and to respond to the demands of the present.

4. Contemporary Advances in Complex Thinking and Complexity Sciences

The development of Complex Thinking and the sciences of complexity in the twenty-first century has been marked by increasing institutionalization, transdisciplinary expansion, and a turn toward cutting-edge methodologies. Institutions such as the Santa Fe Institute, the Center for Complex Systems Research, the Instituto de Sistemas Complejos de Valparaíso, and the Multiversidad Mundo Real Foundation have served as key nodes in the articulation of academic networks linking mathematics, biology, sociology, ecology, philosophy, artificial intelligence, and education.

One of the most significant advances has been the development of complex network analysis tools applied to social phenomena. Recent studies have employed multilayer network techniques to investigate processes of innovation, knowledge diffusion, scientific collaboration, and polycentric governance. For instance, analysis of the global scientific collaboration network on COVID-19 vaccines revealed patterns of centrality, power asymmetries, and coevolutionary dynamics among institutional actors patterns that would remain invisible through a linear perspective (Chen et al., 2021).

In the field of sustainability, socioecological systems models have emerged that integrate ecological, economic, cultural, and institutional variables. These models enable the simulation of governance, resilience, and collapse scenarios, offering tools for decision-making under conditions of high uncertainty. The work of Elinor Ostrom and her followers has demonstrated how complex systems can be self-governed through adaptive rules, community-based monitoring, and localized sanctioning mechanisms, thereby challenging the dichotomy between state and market (Ostrom, 2009).

In the educational sphere, the pedagogy of complexity has been taken up by movements such as ecosocial education, the ecology of knowledges (Santos, 2010), transformative learning, and systemic design. These approaches promote dialogical, contextualized, multisensory, and action-oriented learning forms. Methodologies such as citizen laboratories, flipped classrooms, systemic mapping, and transmedia narratives have been developed to activate students' systemic imagination and their ethical engagement with the world.

A critical current has also emerged within the field of complexity itself, warning against its co-optation by technocratic discourses, its conceptual dilution, and its use as an empty signifier in public policy. Authors such as Cilliers (2005) and Urry (2016) have emphasized the need for a critical complexity one that acknowledges its limits, interrogates its assumptions, and confronts the power relations embedded in knowledge production. This reflexive turn is essential for complexity to become a plural, open, and transformative epistemology.

5. Complexity Science and Complex Thought: Convergences and Distinctions

Although often used interchangeably, complexity science and Complex Thinking stem from different genealogies and offer complementary approaches. Complexity science, as developed in institutions such as the Santa Fe Institute and in the work of Mitchell (2009) and Holland (1995), focuses on the mathematical and computational modeling of nonlinear systems, adaptive networks, and emergent phenomena. Its orientation is formal, empirical, and aimed at simulation and prediction.

Complex thought, chiefly articulated by Edgar Morin (2007), represents a critical epistemology that challenges the fragmentation of modern knowledge and proposes an integrative, dialogical, and contextual rationality. While complexity science builds algorithms and models to represent systems, Complex Thinking offers a philosophical, ethical, and educational framework for engaging with uncertainty, contradiction, and plurality.

The two perspectives converge in their critique of reductionism, their affirmation of emergence, and their acknowledgment of nonlinear interactions. They diverge in epistemological status: complexity science seeks to describe and explain dynamics, whereas Complex Thinking aims to understand and transform realities. The former is expressed in quantitative language and computational diagrams, the latter in reflective narratives and philosophical arguments.

This divergence is also a source of complementarity. Complex Thinking requires complexity science to avoid remaining at the level of intuition or metaphor. Complexity science benefits from Complex Thinking to prevent absolutizing its models and to recognize the ethical, political, and cultural dimensions of knowledge. In contexts such as territorial planning, public health, or environmental governance, this articulation becomes vital, as it necessitates both the simulation of scenarios through computational modeling and an understanding of the subjectivities, values, and power relations that shape decision-making.

For example, designing resilient food systems demands the modeling of nutrient flows, consumption patterns, and logistical networks while also requiring insight into cultural imaginaries of food, structures of exclusion, and peasant knowledges. The integration of both perspectives enables more sensitive, just, and adaptive planning.

6. Open Science, Situated Knowledge, and the Epistemology of Complexity

One of the most significant contributions of contemporary Complex Thinking lies in its critical interrogation of truth regimes and knowledge politics. Rather than conceiving science as a universal and neutral process, the epistemology of complexity acknowledges the situated, relational, and conditioned nature of knowledge. This epistemic shift draws on perspectives such as the post-normal science proposed by Funtowicz and Ravetz, Haraway’s feminist epistemology, and the decolonial studies articulated by Mignolo. From this standpoint, knowledge is understood as a social construction shaped by interests, values, power asymmetries, and historical contexts. Complexity is not simply a property of systems but a constitutive condition of knowledge itself. This approach entails an ethical commitment to epistemic plurality, the inclusion of subaltern voices, and the recognition of alternative ways of knowing.

Within this framework, the notion of open science acquires renewed significance. It refers to an epistemic openness that fosters the co-production of knowledge with diverse actors such as local communities, social movements, Indigenous peoples, artists, children, and elders. This openness calls for abandoning the arrogance of expertise and embracing a dialogical, horizontal, and reflexive stance.

A notable example is the participatory action research methodology, which aims to produce knowledge, empower subjects, transform realities, and democratize science. In fields such as watershed management, the recovery of ancestral knowledges, or social innovation, this methodology emerges as a powerful tool to operationalize the epistemology of complexity through concrete practices.

The concept of situated knowledge, advanced by Haraway, has been taken up by complexity thinkers such as Morin to challenge the illusion of absolute objectivity and to propose a more embodied, affective, and accountable science. Acknowledging that all knowledge arises from a specific place, body, and history invites the adoption of an epistemology of humility one that values incompleteness and fosters a genuine dialogue among knowledges.

7. Education, Complexity, and Transdisciplinarity

Education stands out as one of the most fertile grounds for applying the epistemology of complexity. Modern schooling has historically been structured around the paradigm of simplification: separation of disciplines, fragmentation of knowledge, quantitative assessment, teacher-centered hierarchy, and the exclusion of affective, embodied, and ethical dimensions. While this model proved effective for an industrial society, it has become obsolete in the face of twenty-first-century challenges.

Complex Thinking calls for a profound reform of the educational system. It seeks to reconfigure the way learning, teaching, and knowledge itself are conceived. As Morin emphasizes, it is essential to teach the human condition, uncertainty, the ethics of dialogue, mutual understanding, and planetary responsibility. Education must nurture subjects capable of critical thinking, ethical action, and sensitive engagement with the world.

This transformation requires a pedagogy of transdisciplinarity, in which real-world problems such as climate change, inequality, or artificial intelligence are addressed through multiple perspectives and with the active involvement of students. The school becomes a laboratory for citizenship, a learning community, and a platform for imagining desirable futures. The logic of the correct answer is replaced by creative inquiry, and single-solution thinking gives way to collective exploration.

Methodologically, this complex education draws on strategies such as project-based learning, systems thinking, emergent narratives, pedagogical theater, speculative design, concept mapping, and citizen laboratories. These methodologies foster relational thinking, emotional intelligence, adaptive capacity, and ecosocial awareness.

At the institutional level, this proposal entails profound changes: flexible curricula, transdisciplinary teacher training, formative assessment, adaptive school architecture, and public policies attuned to diversity. Education ceases to function as a factory for individual competencies aimed at a global market and instead becomes an ecosystem of care, creativity, and transformation.

8. The Ethics of Complexity and Civilizational Challenges

Complex Thinking is more than an epistemological or pedagogical proposal. Above all, it constitutes an ethics for uncertain times. In a world defined by interdependence, technological acceleration, ecological crisis, and social fragmentation, it becomes imperative to rethink the ways we act, decide, and inhabit the Earth. Edgar Morin has emphasized that knowledge without ethics can lead to disaster, and that complexity offers a path to reconfiguring our responsibility as a species.

This ethics of complexity goes beyond a set of norms. It demands a fundamental attitude: the recognition of the other, openness to dialogue, acceptance of uncertainty, and a willingness to transform our own certainties. It calls for an ethics of care one that weaves together the cognitive and the affective, the personal and the planetary, the local and the global.

Within this framework, today's civilizational challenges require a departure from the logic of control and technocratic management. Crises such as climate breakdown, forced migration, food insecurity, and the mental health emergency demand responses that grasp their systemic and multidimensional nature. The ethics of complexity calls for abandoning the illusion of simple solutions to complex problems and embracing deliberative, adaptive, and collaborative processes.

This ethical perspective carries concrete implications across multiple fields. In economics, it urges a transition toward regenerative models that value commons, equity, and sustainability. In politics, it promotes forms of governance based on co-creation, collective intelligence, and active listening. In science, it supports a reflexive, humble, and life-affirming practice. In everyday life, it encourages compassion, attentive listening, and a sense of wonder before the world's complexity.

9. Complexity and the Future: Scenarios, Imagination, and Transformative Action

Thinking through the lens of complexity also entails reimagining the future. In contrast to technological determinism or visions of inevitable collapse, the complexity paradigm affirms openness, possibility, and emergence. It seeks to prepare us for multiple potential futures, to design scenarios, to learn how to navigate uncertainty, and to build more just, livable, and meaningful worlds through collective action.

This perspective aligns with futures studies and critical foresight, which combine trend analysis with social imagination. Unlike linear projections, complexity offers an evolutionary and reflexive approach in which scenarios are constructed as open hypotheses that guide action. As Ramos suggests, the task is to connect desirable futures with emergent strategies that can adapt to changing contexts.

Within this process, imagination plays a central role. Envisioning futures becomes a political act, a form of resistance, and a way to open up new possibilities. Utopia understood as an ethical-pragmatic orientation counters present-day paralysis and mobilizes collective will toward transformation. Complex Thinking proposes a practice of futurity that integrates intuition and analysis, art and science, emotion and reason. It calls for new complex narratives that weave together diverse voices, values, and knowledges. It also demands institutional and community spaces where such narratives can be translated into decisions, experiments, and shared learning.

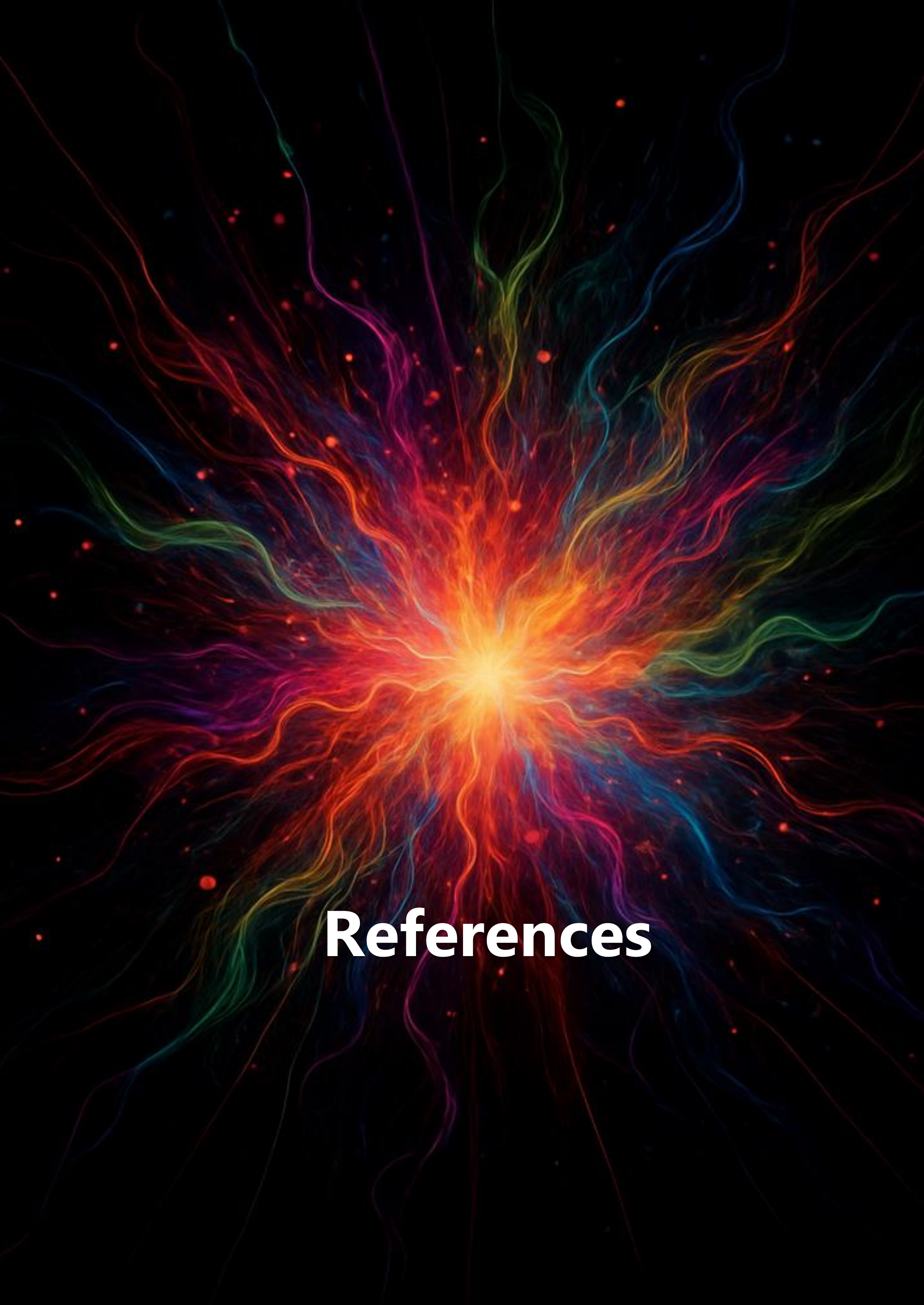
10. A Call to Inhabit Complexity

The journey through Complex Thinking and the sciences of complexity is an invitation to reconfigure how we think, know, feel, and act. It calls us to move beyond the comfort of certainty, to challenge the compartmentalization of knowledge, to embrace uncertainty as a condition of life, and to build, alongside others, more caring, creative, and just ways of inhabiting the world.

To inhabit complexity is to acknowledge the interdependence of all phenomena, to assume responsibility for our decisions, and to accept that many paths emerge through interaction, dialogue, and experimentation. It means committing to an inclusive rationality, a politics of listening, an economy of care, a science with conscience, and an education for life.

This paradigm is indispensable for facing the challenges of the twenty-first century with integrity, clarity, and hope. As Morin suggests, we need a metamorphosis a civilizational transformation. Complexity arises as a possibility built through each act, each relationship, each decision. In a time when knowledge is fragmented, politics is polarized, and the planet is exhausted, Complex Thinking offers an ethical and epistemological compass for reconnecting with life, with others, and with ourselves. To comprehend complexity is far more than to understand the world: it is to begin transforming it from within.

Teófilo Cuesta Borja



References

References

Abbagnano, N. (1963). Diccionario de filosofía. Fondo de Cultura Económica.

Arthur, W. B. (1995). Increasing returns and path dependence in the economy. University of Michigan Press.

Bateson, G. (1972). Steps to an ecology of mind. Chandler Publishing.

Bertalanffy, L. von. (1968). General system theory: Foundations, development, applications. George Braziller.

Capra, F., & Luisi, P. L. (2014). The systems view of life: A unifying vision. Cambridge University Press.

Cohen, I. B. (1971). Introduction to Newton's "Principia". Harvard University Press.

Cohen, I. B., & Koyré, A. (1972). Isaac Newton's "Principia": The mathematical principles of natural philosophy. University of California Press.

De Rosnay, J. (1996). El macroscopio: Un enfoque sistémico de la humanidad. Gedisa.

Descartes, R. (1977). Meditaciones metafísicas (Original work published 1641). Ediciones Orbis.

Feyerabend, P. (1993). Against method (3rd ed.). Verso.

Ferrater Mora, J. (1988). Diccionario de filosofía (Vols. 1–4). Alianza Editorial.

Ferrer, J. (1998). Ciencias y sistemas: Una introducción al pensamiento sistémico. Gedisa.

Gell-Mann, M. (1994). The quark and the jaguar: Adventures in the simple and the complex. W. H. Freeman.

Hartmanis, J., & Stearns, R. E. (1965). On the computational complexity of algorithms. Transactions of the American Mathematical Society, 117, 285–306.

Heisenberg, W. (1927). Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik. Zeitschrift für Physik, 43, 172–198.

Holland, J. H. (1995). Hidden order: How adaptation builds complexity. Basic Books.

Kauffman, S. A. (1995). At home in the universe: The search for laws of self-organization and complexity. Oxford University Press.

Kuhn, T. S. (1962). The structure of scientific revolutions. University of Chicago Press.

Kuhn, T. S. (1971). La estructura de las revoluciones científicas (Spanish version). Fondo de Cultura Económica.

Laplace, P. S. (1814). Essai philosophique sur les probabilités. Courcier.

Lorenz, E. N. (1963). Deterministic nonperiodic flow. Journal of the Atmospheric Sciences, 20(2), 130–141.

Mandelbrot, B. B. (1975). Les objets fractals: forme, hasard et dimension. Flammarion.

Maturana, H., & Varela, F. J. (1994). El árbol del conocimiento: Las bases biológicas del entendimiento humano. Editorial Universitaria.

Morin, E. (1990). Introducción al pensamiento complejo. Gedisa.

Morin, E. (1992). El método 1: La naturaleza de la naturaleza. Cátedra.

Morin, E. (1995). El método 2: La vida de la vida. Cátedra.

Morin, E. (1999). Los siete saberes necesarios para la educación del futuro. UNESCO.

Morin, E. (2000). El método 3: El conocimiento del conocimiento. Cátedra.

Morin, E. (2002a). El método 4: Las ideas: su hábitat, su vida, sus costumbres, su organización. Cátedra.

Morin, E. (2004). La vía: Para el futuro de la humanidad. Paidós.

Morin, E. (2008). On complexity. Hampton Press.

Nicolescu, B. (2008). Transdisciplinarity: Theory and practice. Hampton Press.

Nicolescu, B. (2020). La transdisciplinariedad: Manifiesto. Anthropos Editorial.

Popper, K. R. (1994). The myth of the framework: In defence of science and rationality. Routledge.

Prigogine, I. (1980). From being to becoming: Time and complexity in the physical sciences. W. H. Freeman.

Prigogine, I., & Stengers, I. (1984). Order out of chaos: Man's new dialogue with nature. Bantam Books.

Salcedo, J. (2010). Determinismo y causalidad: Una aproximación epistemológica. Editorial Académica Española.

Simmons, G. F. (1996). Calculus gems: Brief lives and memorable mathematics. McGraw-Hill.

Spinoza, B. (2008). Ética demostrada según el orden geométrico (Original work published 1677). Alianza Editorial.

Stewart, I. (2001). Does God play dice? The new mathematics of chaos. Blackwell.

Von Foerster, H. (1981). Observing systems. Intersystems Publications.

Woodward, W. W. (1891). Napoleon and the scientists: The story of Napoleon's interest in science and scientists. Harper & Brothers.