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THE EVOLUTIONARY NATURE OF SCIENCE AND MECHANISMS OF FORMING SCIENTIFIC KNOWLEDGE

The paper presents a comprehensive analysis of the evolutionary nature of science, treating scientific knowledge not as a static set of theories but as a dynamic process unfolding through cognitive, social, informational, and cybernetic mechanisms. The emergence of new scientific fields and disciplines results from multi-level evolutionary processes in which changes in methods of cognition, formalization, and scientific organization follow regular patterns. The aim is to explain mechanisms of scientific knowledge formation. Methods: historical-epistemological analysis and conceptual phase modeling. The work clarifies the epistemological and methodological foundations of scientific development, revealing the historical and epistemological logic of transitions from natural philosophical forms through differentiated sciences to integrative and transdisciplinary paradigms.

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A multi-phase evolutionary model is proposed that describes science's development through successive stages: empirical articulation, conceptual-theoretical initiation, formal constructivization, disciplinary structuring, institutional stabilization, transdisciplinary convergence, and industrial knowledge implementation. Science is interpreted as an evolutionary adaptive and information-cybernetic system, where variation manifests through generation of alternative hypotheses, selection occurs through theory competition, and inheritance operates via educational institutions and scientific schools. An information-algorithmic approach reveals theories as data-compression mechanisms and scientific development as an optimization process in an entropic landscape of possible explanations. The work identifies social, technological, and infrastructural factors determining scientific evolution trajectories. The significance of knowledge industrialization — the complete cycle of transforming fundamental theories into technologies and social practices — is emphasized. Based on this integration of results, the feasibility of establishing Evolutionary Cybernetics as a new scientific field is substantiated as a metatheoretical framework combining evolutionary, informational, and cybernetic mechanisms of scientific development.

Keywords: *evolutionary nature of science, epistemological mechanisms, disciplinary formation, transdisciplinarity, evolutionary cybernetics, knowledge industrialization, scientific knowledge formation, knowledge evolution, scientific paradigms.*

Introduction. The emergence of science throughout human history has been accompanied by a constant expansion of the boundaries of cognition, shifts in intellectual paradigms, and the appearance of new ways of representing reality. In modern conditions, these processes gain special intensity: science ceases to be a set of stable disciplines and turns into a dynamic system in which theories, methods, and research practices exist in a state of continuous transformation. This creates a need for a theoretical approach capable of explaining by what regularities new scientific fields arise, how they integrate into already existing structures of knowledge, and why some forms of scientific thinking become dominant.

During the 20th and 21st centuries, the issue of the “evolution of science” acquired an interdisciplinary meaning: it can no longer be reduced to historical observations or descriptive models of scientific revolutions. Modern conditions, associated with the growing complexity of objects of study, the convergence of technologies, and global cognitive challenge, require a more universal framework that combines epistemology, systems analysis, information theory, and the methodology of complex systems. It is precisely here that a key research question arises: how do new disciplines emerge, and what mechanisms determine their trajectory of development?

Traditional models of the development of science — from cumulative to revolutionary — capture individual aspects of scientific change, but they do not allow one to describe the multiphase process of transformation from a local scientific problem to the formation of new disciplinary and transdisciplinary systems. A more comprehensive model is needed — one capable of integrating the cognitive mechanisms of concept formation, procedures of formalization, institutional mechanisms of knowledge consolidation, as well as information-algorithmic factors that determine the stability and productivity of scientific structures.

This work proposes to consider science as an evolutionary process unfolding in a multidimensional space: from the empirical articulation of phenomena to the formation of theories; from the formal constructivization of theory to disciplinary differentiation; from institutional consolidation to transdisciplinary convergence and the industrialization of knowledge. Such a model makes it possible to explain the emergence of new scientific directions not as isolated historical events, but as lawful stages in the development of a complex adaptive system.

Looking ahead, this logic of evolutionary transitions creates the groundwork for forming a new direction — Evolutionary Cybernetics — which generalizes cybernetic, evolutionary, and informational mechanisms of the science development [1—2]. Evolutionary cybernetics can provide a methodological basis for modeling the emergence of new disciplines, analyzing the selection of scientific theories, and forecasting structural changes in the scientific landscape.

Review of research and publications. The problem of how science develops and how scientific fields are transformed has been addressed within several influential philosophical and methodological traditions. K. Popper grounded the critical-rationalist view of science, according to which the growth of knowledge is driven by the proposal of bold hypotheses and their systematic refutation through empirical tests [3]. T. Kuhn proposed a historical concept of paradigms and paradigm shifts, emphasizing the alternation of periods of “normal science” with scientific revolutions that reconfigure conceptual frameworks and standards of explanation [4]. I. Lakatos developed the idea of scientific research programs consisting of a hard core of fundamental assumptions surrounded by a protective belt of auxiliary hypotheses, whose progressive or degenerative character determines the vitality of a program [5]. S. Toulmin interpreted the evolution of human understanding as a gradual modification of conceptual structures and rational procedures within historical contexts [6].

In parallel, the development of cybernetics and information theory opened new possibilities for interpreting science as a special case of information processing and control. C. Shannon’s information theory [7—8] laid the foundations for quantitative descriptions of information and communication, while W. Ashby’s cybernetics [9] and N. Wiener’s work on feedback systems [10] formulated universal principles of regulation and adaptation. H. Simon’s studies of artificial systems [11] further contributed to understanding complex adaptive structures and the role of bounded rationality. These approaches converge in treating scientific activity as an organized, self-correcting, and information-processing system.

Recent developments have enriched the understanding of scientific evolution through multiple interconnected perspectives. Contemporary research in transdisciplinarity has demonstrated that knowledge integration across disciplinary boundaries follows identifiable patterns and mechanisms. Scholz, Zscheischler, and colleagues [12] have developed frameworks identifying seven types of transdisciplinary integration processes, including the evolution of representational codes and value systems, which aligns with the view of scientific development as multi-level transformation. This perspective has been operationalized through educational models for developing transdisciplinary competencies [13]. The role of formalization in scientific evolution has been further illuminated by Baldwin [14], whose analysis of model theory reveals how formalization processes shape disciplinary development through local structural foundations rather than global axiomatic systems, supporting the view that formal constructivization constitutes a distinct evolutionary phase. From a complexity-theoretic perspective, Fuentes [15] has advanced quantitative approaches to theory evolution, treating theory-change as shifts in parametric model complexity and proposing measures of emergent properties in scientific structures — an approach resonant with information-algorithmic interpretations of scientific development. In the Ukrainian context, recent work has examined the transformation of scientific systems under contemporary challenges [16], transdisciplinary research structures [17], and the societal impact assessment of scientific research [18]. These contributions support the conception of science as a multi-phase evolutionary system integrating cognitive, formal, institutional, and informational dimensions, and provide empirical grounding for analyzing scientific development through evolutionary-cybernetic frameworks.

At the same time, many existing models focus either on epistemological norms, on historical description of scientific change, or on institutional and sociological dimensions. Less attention has been given to integrated frameworks that simultaneously incorporate cognitive mechanisms, formalization procedures, institutional dynamics, and information-algorithmic aspects. The present work develops such an integrated perspective by proposing a multiphase evolutionary model of scientific development and by interpreting science as an evolutionary adaptive information-cybernetic system. In doing so, it builds on classical results while aiming to unify them within a broader conceptual architecture.

Novelty of the problem statement. The specificity of the present problem statement lies in the attempt to combine several usually separate lines of analysis into a single conceptual framework. Instead of considering the evolution of science solely through historical narratives or isolated methodological criteria, the article formulates an explicitly evolutionary approach that treats scientific development as a sequence of qualitatively distinct but structurally connected phases. Each phase is characterized by its own cognitive, formal, institutional, and technological configuration, and transitions between phases are interpreted as evolutionary shifts in the structure of scientific activity.

A further element of novelty is the systematic use of information-cybernetic and algorithmic notions to describe how scientific theories behave and how disciplines emerge. Scientific theories are interpreted not only as explanatory constructs, but also as mechanisms for compressing and organizing information about the world; their competition and selection are analyzed in terms of efficiency, robustness, and informational optimality in a complex entropic landscape. This creates preconditions for constructing more formal models of the growth and restructuring of knowledge.

In addition, the problem is posed in such a way that transdisciplinary integration and the industrialization of knowledge are not viewed as external "applications" of science, but as integral stages of the same evolutionary process. The concept of Evolutionary Cybernetics is introduced precisely as a metatheoretical framework capable of capturing this full cycle — from the initial empirical articulation of phenomena to the formation of transdisciplinary clusters and to the transformation of theories into technologies and social practices.

The aim of the article is to present and substantiate an integrated evolutionary model of scientific development that explains how scientific knowledge is formed, structured, and transformed, and to demonstrate how this model can serve as a conceptual basis for establishing Evolutionary Cybernetics as a new scientific field. Within this aim, the article seeks to (i) describe the main historical-epistemological stages and structural levels of scientific knowledge formation; (ii) identify key evolutionary mechanisms (variation, selection, and inheritance) and information-cybernetic principles underlying scientific development; (iii) reveal how transdisciplinary convergence and knowledge industrialization emerge as natural phases of scientific evolution.

Methods of research and source base. The methodological basis of the study is formed by historical-epistemological analysis and conceptual phase modeling. Historical-epistemological analysis is used to reconstruct the sequence of stages through which scientific knowledge has passed, to uncover how methods of cognition, conceptual schemes, and institutional forms have changed, and to relate these changes to broader transformations of the scientific worldview. Conceptual phase modeling is employed to formalize the idea of science as an evolutionary process that unfolds through a series of relatively stable phases separated by transitions in which new disciplines and paradigms arise.

These approaches are complemented by systems analysis and information-theoretic and cybernetic perspectives, which provide tools for interpreting science as an adaptive system of information processing and control. The source base of the research includes classical works in the philosophy and methodology of science (Popper [3], Kuhn [4], Lakatos [5], Toulmin [6]), foundational texts in cybernetics and information theory (Shannon [7], Ashby [9], Wiener [10]) and studies of artificial and complex systems (Simon [11]), as well as contemporary research on transdisciplinary knowledge integration [12—13], complexity-theoretic approaches to theory evolution [14—15], and recent analyses of scientific system transformations in the Ukrainian context [16—18].

Presentation and discussion of results. The development of scientific knowledge can be viewed as a sequence of historical-epistemological stages within which methods of cognition, ways of conceptualization, and organizational forms of science changed. The first foundational stage is natural philosophy, which formed general ideas about nature and introduced primary ways of rationalizing the experience. Already within the medieval philosophical tradition, a key proposition appears, formulated by Nicholas of Cusa: science begins with measurement, that is, with the ability to compare parameters, establish relationships between quantities, and form quantitative models of phenomena. This idea became a fundamental prerequisite for the subsequent mathematization of natural science.

The second stage is differentiation, within which separate scientific disciplines form with their own objects of study, methodologies, and terminological systems. The development of experimental instruments, mathematical methods, and specialized theoretical apparatuses contributed to structuring science into autonomous fields — physics, chemistry, biology, mathematics, logic, and technical sciences. This process significantly increased the precision of descriptions, but at the same time led to fragmentation of knowledge.

The third stage is the integration of scientific disciplines, associated with the creation of interdisciplinary institutions, research centers, and complex scientific programs. Integrative processes in the 20th century contributed to the emergence of such fields as systems analysis, cybernetics, cognitive sciences, biophysics, and informatics. They combined the theoretical apparatuses of different disciplines and initiated the development of universal models of complex systems.

The fourth stage is transdisciplinarity, which goes beyond integration and forms new conceptual spaces that cannot be reduced to any single science. In this context, such modern directions as data science, evolutionary cybernetics, synthetic biology, complex systems, and intelligent technologies arise. Transdisciplinarity ensures the formation of metatheoretical structures capable of describing multilevel, nonlinear, and emergent phenomena that cannot be studied within isolated disciplines.

Thus, the development of general scientific knowledge occurs through a gradual transition from philosophical reflection and elementary forms of measurement to differentiated sciences, their integration, and the formation of transdisciplinary paradigms. Such a historical-epistemological perspective makes it possible to more deeply understand the logic of the formation of modern science and its movement toward all-encompassing models of complex systems.

The emergence of science as a special way of cognition is based on a set of epistemological prerequisites that determine methods, criteria, and forms of constructing knowledge. First and foremost, science appears as the result of the development of rational thinking oriented toward logical order, causality, and reproducibility. The transition from mythological and intuitive forms of explaining the world to structured models led to the emergence of procedures of formalization, abstraction, and systematic observation, which provide the possibility of independent verification of statements.

A key epistemological foundation is the formation of logical structures that make it possible to build coherent theories, determine their internal consistency, and justify conclusions on the basis of axioms, empirical data, or deductive rules. The standardization of verification and falsification procedures became an important element of the scientific method, embodied in the approach of K. Popper [3], who put forward the principle of testability as a criterion of scientific status.

T. Kuhn emphasized the historical evolution of science through paradigm shifts [4], within which normal scientific activity, the accumulation of anomalies, and subsequent scientific revolutions occur. I. Lakatos supplemented this picture with the concept of scientific research programs characterized by a core of immutable assumptions and a protective belt of auxiliary hypotheses [5].

Modern cognitive models consider science as an institutionalized form of collective cognition, where thinking appears as the result of integrating cognitive strategies, heuristics, and formal procedures. In this context, science is formed as a system that combines logical rigor, empirical testability, and cognitive adaptability, providing the most effective mechanism for building reliable knowledge.

The appearance of a new scientific field is the result of the interaction of epistemological, methodological, and technological factors that change the structure of scientific problem domains and form new ways of describing phenomena. One of the key mechanisms is the accumulation of anomalies within an established theory: when the existing paradigm cannot explain critical observations or contradictory data, there arises a need for conceptual expansion or a radical restructuring of the theoretical framework. In this context, a scientific revolution, according to T. Kuhn, appears as a transition to an alternative paradigm that offers a new interpretation of facts and new criteria of scientific validity.

A significant role is played by technological innovations, in particular the emergence of new tools for observation, experimentation, and modeling. The development of measurement methods, computing platforms, sensor systems, or algorithmic technologies often reveals phenomena previously inaccessible, thereby creating conditions for the emergence of a separate scientific discipline. No less significant are interdisciplinary discontinuities: the integration of concepts and methods from different fields leads to the emergence of new conceptual spaces in which classical scientific divisions lose rigidity.

Changes in scientific questions also drive the formation of new fields. The emergence of socially significant problems, complex systems, or multidimensional data stimulates the development of methods that go beyond traditional disciplinary tools. Finally, discoveries — empirical or theoretical — can trigger the self-organization of the scientific community around a new topic, institutionalizing it through scientific journals, conferences, and research programs. Thus, the emergence of a new field is a complex process combining conceptual changes, methodological innovations, and transformation of the intellectual landscape of science.

The institutionalization of science is a multilevel process within which a new field of knowledge takes the form of a stable social institution with its own norms, structures, and mechanisms for knowledge reproduction. At the initial stage, scientific communities form that unite researchers around a shared problem-field, methods, and conceptual frameworks. Such communities create communication channels, initiate discussions, and define collective criteria of scientific quality.

One of the key mechanisms of institutionalization is the creation of specialized scientific journals, conferences, and research centers that ensure a formalized circulation of knowledge. In parallel, terminology is standardized, methodological protocols are developed, and formal criteria for verifying results are created. Clearly defined procedures for peer review and publication create a mechanism of legitimation — a process that grants a new discipline academic and intellectual authority.

An important role is played by scientific schools, which form traditions, teaching methods, and conceptual continuity. It is through schools that research strategies are transmitted, specific modes of thinking develop, and benchmarks of scientific behavior are formed. Institutionalization is supplemented by the creation of curricula and the inclusion of the discipline in university courses, which ensures training of new generations of researchers and the expansion of the personnel base.

At the final stage, the discipline integrates into the broader scientific landscape, gains recognition in adjacent fields, and forms its own problem-, method-, and tool-oriented infrastructure. Thus, the institutionalization of science is a process that combines social, cognitive, and organizational mechanisms, ensuring the stability and self-reproduction of scientific activity.

The development of science from the first ideas to an established discipline can be described as a sequence of stages that determine the formation of the theoretical, methodological, and organizational foundation of a scientific field. The first stage is conceptual innovation, which appears as a new idea, hypothesis, or model that offers an alternative explanation of phenomena or solves a problem inaccessible to previous theories. At this level, basic principles are defined, the boundaries of the problem field are outlined, and a primary intellectual core is formed.

The second stage — formation of terminology — ensures the linguistic and logical ordering of the field. The creation of clear definitions, classifications, and conceptual schemes makes it possible to standardize communication among researchers and avoid ambiguities. This forms a basis for building formal theories and achieving methodological coherence.

The third stage is methodological stabilization. It includes the development of research tools, the formation of experimental and mathematical methods, and criteria of evidential strength and reproducibility. At this level, science gains structural rigor that ensures the testability of results.

The fourth stage is organizational institutionalization. The discipline forms scientific communities, journals, educational programs, peer-review systems, and research standards. As a result, science turns into a stable social institution with its own norms and infrastructure.

The final stage is integration into the scientific picture of the world. The discipline enters the system of interconnected sciences, influences their development, and contributes to the formation of generalized models of nature, society, or technical systems. Thus, the life cycle of a science is an evolutionary sequence within which a new idea becomes a mature, stable, and influential discipline.

The transdisciplinary paradigm requires the development of a special theory and methodology of interdisciplinary interaction, because complex scientific projects cannot be implemented within isolated disciplines. A certain contribution to solving this task is the use of methods and a universal language of ontological engineering, which ensure the alignment of terminology, the formalization of subject domains, and the construction of shared conceptual models. Thanks to this, transdisciplinary research gains clearer structural organization and becomes manageable under conditions of high complexity.

Transdisciplinarity plays a key role in the emergence of new scientific fields because it ensures the integration of models, methods, and principles that traditionally belong to different domains of knowledge. Unlike interdisciplinarity, which combines tools of several disciplines without changing their internal structures, transdisciplinarity forms a new conceptual field within which fundamentally different ways of describing complex multilevel phenomena arise. This process is aimed at overcoming disciplinary barriers and building coherent models capable of reflecting systemic interactions, the heterogeneity of processes, and the emergent nature of structures.

Since classical cybernetics, information theory gradually became a universal instrument for describing processes of organization and control across different sciences, which significantly contributed to the formation of a transdisciplinary optic. The main stimulus of transdisciplinary development of science is the aspiration to obtain a synergistic effect that arises in productive convergence clusters, where different disciplines, methods, and technologies interact within a single research space. It is in these clusters that a qualitative strengthening of scientific results occurs — something impossible to achieve within the framework of a single discipline. In addition, TD clusters provide optimization and scaling of the complex process of organizing scientific research, creating conditions for efficient distribution of resources, integration of infrastructures, and acceleration of the knowledge-creation cycle. Thus, synergy and institutional convergence act as key driving forces of transdisciplinary scientific dynamics.

The interaction of different fields creates conditions for forming new theoretical frameworks in which problems are viewed through the lens of universal mechanisms — information flows, self-organization, evolutionary processes, or the dynamics of complex systems. It was precisely the transdisciplinary approach that enabled the emergence of domains such as cybernetics, systems analysis, cognitive sciences, bioinformatics, and data science. In these fields, the integration of mathematical, technical, biological, and social models created new research paradigms.

Transdisciplinarity also contributes to the emergence of new research methods: hybrid models, multiscale simulations, multi-agent systems, and algorithmic approaches to natural and social phenomena. As a result, concepts that cannot be obtained within a single discipline are formed. Moreover, the alignment of different theoretical languages and structures makes it possible to form more complete and robust models that reflect the real complexity of the systems being studied.

Thus, transdisciplinarity is a powerful mechanism of innovation that contributes to the emergence of new scientific fields through the creation of coherent conceptual spaces suitable for analyzing complex phenomena that go beyond the traditional disciplinary division.

Transdisciplinary approaches significantly change the modern scientific worldview because they ensure the integration of knowledge from physics, biology, informatics, cybernetics, cognitive sciences, and social disciplines into single coherent models. This integration makes it possible to overcome the fragmentation of traditional science, in which different fields describe separate aspects of reality in isolation. Instead, transdisciplinarity creates a basis for constructing universal principles — such as the dynamics of self-organization, informational processes, evolutionary mechanisms, and nonlinear interaction of complex systems.

The combination of physical regularities, biological principles, and informational models contributes to a deeper understanding of multilevel natural and social phenomena. For example, evolutionary mechanisms that arose in biology are used to model adaptive artificial systems; information theory from physics is introduced into cognitive sciences; concepts of self-organization and complexity are integrated into economics, sociology, and control theory. This forms a metatheoretical level of description at which different sciences are united through shared structural principles.

Transdisciplinarity also stimulates the emergence of hybrid models capable of describing interactions among system components of different natures: technical, biological, cognitive, and social. In such models, informational and evolutionary processes act as a single language that makes it possible to formulate universal laws for complex systems. As a result, the scientific worldview shifts from a static set of disciplines to a dynamic network structure in which general principles of organization and information processing dominate.

Thus, transdisciplinary approaches ensure the conceptual integration of science, contributing to the formation of a new paradigm in which the world appears as a multilevel, evolutionarily interconnected system.

The formation of new scientific concepts is the result of a complex interaction of cognitive mechanisms that ensure the construction of generalized, internally coherent, and formalized conceptual structures. One of the key mechanisms is abstraction, which makes it possible to separate essential properties of phenomena from nonessential details. Through abstraction, models are created that can generalize a wide range of empirical situations, providing their theoretical explanation.

The second fundamental mechanism is generalization — the process of constructing concepts that unite diverse objects and phenomena on the basis of shared regularities. Generalization determines the structure of scientific theories, allowing the formulation of rules, laws, and principles relevant to different scales or domains of research.

Analogy plays an important role: it provides a cognitive transfer of knowledge structures between different domains. Thanks to analogies, numerous interdisciplinary concepts arose — from informational processes in biology to energy models in social systems. Analogical mapping makes it possible to reveal structural isomorphisms and create new theoretical frameworks.

In the process of scientific knowledge development, a regular problem arises: the transition from metaphysical or analogy-based formulations of new concepts to their constructive definition. In the early stages of the formation of disciplines, new concepts are often introduced through metaphor, figurative comparison, or an intuitive transfer of structures between domains, which provides primary cognitive orientation. However, for the further development of science, it becomes necessary to endow these concepts with formal precision — through precise definitions, mathematical idealization, or operational criteria of application.

Mathematical idealization complements this process by simplifying real systems into formal models that preserve key dynamic or structural properties. Idealization performs the function of a cognitive “filter” that ensures accuracy and rigor of scientific description, making axiomatic constructions and quantitative predictions possible.

In interaction, these mechanisms create conditions for constructing new definitions, concepts, and theoretical structures. They make it possible to systematize knowledge, expand empirical domains, and form the foundations for the emergence of new scientific fields.

In parallel with the constructive development of concepts, a need arises for their unification in order to ensure ontological clarity. In transdisciplinary research, concepts often migrate between different fields, acquiring different semantic interpretations. Therefore, it is extremely important to develop coordinated systems of definitions that guarantee shared meaning structures, the avoidance of terminological conflicts, and the correct integration of knowledge within a single methodological framework. Such unification is what ensures the coherence of transdisciplinary models and the stability of scientific discourse.

The theory of definitions plays a central role in the formation of scientific disciplines, because it is through a system of clear, logically coherent definitions that the concepts boundaries are established, terminology is structured, and the internal coherence of theories is ensured. One fundamental type is so-called nominal definitions, which fix the linguistic designation of a concept and set its basic meaning. Although they do not reveal the full nature of a phenomenon, nominal definitions create a basis for further theoretical refinement.

Real definitions describe the essential properties of objects and processes, reproducing their nature or mechanisms. It is they that allow one to form scientific models, identify regularities, and build causal explanations. Real definitions ensure theoretical depth and reproducibility of knowledge.

In the exact sciences, axiomatic definitions play a special role: they introduce concepts through a system of axioms or formal rules. Such definitions guarantee rigor, consistency, and the possibility of deductively deriving complex structures from a minimal set of initial assumptions. They are key to building mathematical, logical, and formal theories.

Operational definitions tie a concept to specific measurement procedures or experimental operations, ensuring empirical testability. This type of definition is critically important in physics, psychology, biology, and applied sciences, where the correctness of concepts depends on the possibility of their practical application.

For the stable development of science, definitions must meet the criteria of precision, minimality, consistency, and operational usefulness. A clear system of definitions structures the theoretical space, ensures terminological coherence, and makes it possible to integrate new knowledge without destroying existing models. Thus, the theory of definitions is a fundamental element of the epistemological architecture of science.

Formalization is one of the key mechanisms of the emergence of a new scientific discipline, because it ensures the transition from intuitive, descriptive models to a rigorous and reproducible theoretical structure. A central aspect of formalization is mathematization, which makes it possible to precisely describe regularities, introduce variables and parameters, analyze systems in a generalized form, and make quantitative predictions. Thanks to mathematization, science obtains an apparatus for testing hypotheses, comparing alternative models, and building coherent theoretical frameworks.

The construction of formal models plays an important role, as it abstracts essential properties of phenomena and frees the theory from excessive details. Formal models ensure the unification of heterogeneous processes, allow comparison of systems of different nature, and reveal common structural regularities. In this context, formalization performs a function of cognitive optimization, reducing the complexity of description and increasing analytical precision.

Axiomatization is no less significant: it introduces concepts and relations through a system of axioms, ensuring rigor, internal consistency, and logical completeness of a theory. The axiomatic approach creates the possibility of deductive development of a discipline, when complex structures are derived from a minimal set of basic assumptions. This makes it possible to expand a theory without losing its integrity.

Formalization is also critically important for the reproducibility and extensibility of scientific results. Clear formal rules ensure the possibility of independent verification, the integration of new methods, and embedding a theory into a broader scientific context. As a result, formalization not only strengthens the rigor of science, but also contributes to its evolutionary stability, robustness, and capacity for interdisciplinary integration.

The development of science is largely shaped by the interaction of social and technological factors that determine both the conditions of inquiry and the structure of research priorities. One of the most important drivers are technological revolutions, that open up new instrumental possibilities for investigation. The emergence of telescopes, microscopes, computing machines, large-scale scientific facilities, and modern algorithmic platforms has radically transformed the range of scientific problems and created prerequisites for new disciplines — from molecular biology to data science.

Information platforms and digital infrastructures influence the speed of knowledge circulation, the scale of collective collaboration, and access to data. Cloud computing, open databases, networked research communities, and automated analysis systems enable new research methods, strengthen replicability, and make multi-level modeling possible — modeling that was previously unattainable.

A major social factor is societal demand, which shapes research fields and determines their practical relevance. The needs of medicine, energy, security, communications, and ecology stimulate the growth of corresponding scientific fields and concentrate resources on solving urgent problems. This is closely connected to funding systems, which set research priorities, support innovation, and ensure long-term stability of scientific programs.

Equally important is the role of infrastructural change — creating research centers, laboratories, interdisciplinary platforms, and global projects. Such structures foster knowledge integration, expand communication capacity, and accelerate the formation of new research areas.

Thus, social and technological factors form a dynamic context in which science evolves, defining its pace, its evolutionary direction, and its ability to renew itself through innovation.

Universal scientific laws rely on a set of metaprinciples that express fundamental properties of natural, technical, and social systems. One key principle is invariance — the idea that regularities remain unchanged under transformations of the environment or the system itself. Invariance provides stability to laws of nature and allows models to remain valid across different scales and contexts.

Symmetry is closely related to invariance, which describes structural properties of systems that remain unaffected by certain transformations. In physics, symmetries determine conservation laws; in mathematical models they shape the structure of equations; and in biology and the social sciences, they influence types of organization and evolutionary patterns. Symmetries act as a conceptual “frame” that limits the set of possible models and gives them universality.

An important metaprinciple is minimization: according to which systems tend to implement dynamics that optimize certain functionalities — energy, action, entropy, or risk. This principle underlies variational methods, optimal control models, and evolutionary algorithms, acting as a universal mechanism of organization.

The meta-concept of causality ensures the logical order of scientific theories, setting directions of influence and enabling prediction. It is the basis for models of dynamics, regression structures, network interactions, and evolutionary processes.

A special place belongs to the principle of informationality, which treats nature as a system of information exchange, preservation, and transformation. Many modern sciences converge on the idea that fundamental laws can be expressed through informational constraints, entropic principles, and structural complexity.

The coordination of these metaprinciples supports the concept of a "single law of nature," where different phenomena are described through universal mechanisms of symmetry, causality, optimization, and informational organization.

The question of whether a single universal law of nature exists is among the deepest problems in contemporary science and philosophy. In physics, the drive toward unification appears in attempts to reconcile general relativity and quantum mechanics within quantum gravity theory, as well as in Grand Unification models and string theory. These approaches assume that the diversity of physical phenomena can be derived from a few fundamental principles of symmetry and geometric structure. However, the lack of experimental confirmation and the mathematical complexity of these programs leave them unfinished.

Outside physics, the idea of a universal law takes a different form. Complex systems theory and cybernetics suggest viewing nature as a set of self-organization processes, evolution, and informational dynamics. Here, universality is not a single equation but general principles — information preservation, entropic constraints, invariance, and optimization mechanisms. This perspective makes it possible to build models relevant not only for physical, but also for biological, cognitive, and social systems.

A philosophical view emphasizes that the search for unified explanatory law is, on the one hand, a projection of the desire for a simple and elegant worldview, and on the other hand, a way to reveal structural unity across diverse manifestations of reality. Yet there is a critical point: complex systems exhibit emergent properties that do not reduce neatly to micro-level rules, casting doubt on the possibility of fully reducing everything to one principle.

Thus, a single law of nature may exist only as a metaprinciple — a fundamental structure manifesting through symmetries, informational processes, or evolutionary mechanisms, rather than as a single formula or theory.

The scientific worldview forms as a multi-level system of coherent representations integrating empirical data, theoretical models, and philosophical foundations of explanation. At the lowest level lies the empirical layer: observations, experimental data, and measurements. It provides the factual basis of science but does not by itself create a coherent description of reality.

The second level consists of theoretical models that generalize empirical material, describing regularities and mechanisms in formalized or mathematical form. Theories introduce concepts that do not always have direct empirical analogues, yet they enable prediction of new phenomena, simulation, and identification of systemic relationships.

A higher level is formed by metatheories — structures that unify separate theories by setting shared principles, validity criteria, and methodological frameworks. Metatheories reflect generalized models of world organization such as the evolutionary paradigm, information theory, systemic approach or cybernetic interpretations of processes.

Above them is the philosophical-methodological level, defining fundamental principles of knowledge: causality, invariance, symmetry, informationality, rationality, and observer limitations. This level forms the "metalanguage" of science, setting truth criteria, methodological norms, and conceptual boundaries.

The scientific worldview serves not only explanatory and methodological functions, but also plays an important socio-cognitive role, contributing to the formation of a planetary consciousness. By integrating knowledge about the origin of matter, the evolution of life, the nature of information, and the dynamics of complex systems, it supports a global perspective beyond local cultural, political, or technological contexts. This perspective provides shared reference points for collective decision-making, responsible technology use, and awareness of the interdependence between humanity and the biosphere.

The scientific worldview emerges through coordinated interaction of several structural levels: empirical data correct theories, theories stimulate metatheories, and philosophical-methodological principles define the limits of possible explanations. As a result, science appears as a dynamic system of conceptual models capable of evolving alongside cognitive tools and technological possibilities. A separate aspect of forming a scientific picture of the world is the construction of linguistic-ontological structures that determine the way objects and their relationships are categorized.

Scientific language serves not only as a means of description but also as a mechanism of constructing reality, defining the boundaries of interpretation. In this sense, the linguistic-ontological worldview is a foundational level ensuring unambiguous concepts, coherent definitions, and structural integrity of scientific discourse — especially under transdisciplinary interaction.

The transition from early forms of knowledge — often labeled "proto-science" — to a full-fledged scientific field is determined by a number of clear demarcation criteria. One fundamental criterion is falsifiability: claims must be formulated in a way that allows them to be refuted by empirical data. Proto-science often relies on hypotheses that do not permit operational testing or are expressed in overly broad terms.

A second key criterion is reproducibility: different researchers must be able to repeat experiments, measurements, or computations and obtain consistent results. No scientific field can exist without a stable experimental or computational base that supports its claims independently of context.

Formalization is also decisive. It requires mathematical models, logical structures, or clearly described procedures that ensure precision, unambiguity, and verifiability of concepts. Proto-science often operates with descriptive or metaphorical notions without formal criteria.

Equally important is the emergence of a communicative infrastructure: journals, conferences, research centers, peer review mechanisms, and scientific schools. In proto-science, knowledge spreads fragmentarily and without formal channels of validation.

Evidence standards play a special role, determining the level of argumentation, requirements for empirical support, and the logical structure of research. Science strives for rigor, while proto-science is often based on intuitive interpretations.

Therefore, a scientific field differs from proto-science through the presence of formal models, testable claims, institutional support, and standardized methods of inquiry that ensure stability and development.

Stability and continuity of scientific traditions are ensured by a set of institutional, cognitive, and social mechanisms that maintain uninterrupted scientific development and preserve its methodological foundation. Central roles are played by scientific institutions — universities, academies of science, and research centers — that create organizational conditions for transferring knowledge between generations. Such structures form the infrastructure within which learning, research, exchange of results, and the formation of professional standards take place.

Scientific journals and peer review provide a formal quality-control mechanism. Peer review checks not only correctness of results but also preserves methodological continuity, since reviewers act as carriers of a school's traditions. Journals fix the intellectual capital of a discipline, codify it, and make it accessible for future generations.

An important element is scientific schools, which function as environments for intellectual socialization. They transmit methodology, research strategies, ethical norms, and conceptual frameworks. Schools shape cognitive continuity, as students imitate the thinking styles of their mentors, adapting them to new contexts.

An equally important mechanism is the reconstruction of knowledge over time. Science regularly revises theories, refines concepts, corrects errors, and builds metatheoretical structures that maintain coherence across different developmental stages. Historical-scientific analysis plays a key role here, integrating previous results into contemporary theoretical models.

The stability of traditions is also supported by methodological unification — shared research standards, accepted protocols, widely recognized analysis methods, and evidence criteria. Thanks to these mechanisms, science retains integrity, adaptability, and the capacity to evolve without losing structural foundations.

The formation of new scientific directions, disciplines, and conceptual structures is not accidental or linear. Scientific development has an evolutionary character and unfolds as a multi-level dynamic, where the ways of describing reality, forms of knowledge representation, institutional mechanisms, and technological means of cognition change. Science functions as a complex adaptive system responding to empirical challenges, internal logical contradictions, technological innovations, and social demands — producing new models, theories, disciplines, and transdisciplinary knowledge clusters.

The evolutionary character of scientific development lies in the gradual transformation of knowledge: from local empirical facts that require explanation to formalized theoretical frameworks; from established disciplines to their differentiation into specialized subfields; from disciplinary plurality to integrative and transdisciplinary forms of scientific space organization. Each stage is accompanied by the emergence of new epistemological mechanisms, methodological principles, and forms of the social organization of science.

In modern terms, scientific evolution is not limited to moving from one theory to another. It includes formal constructivization of concepts, the establishment of institutional structures, the development of universal languages and ontologies, and the industrialization of knowledge — its transformation into technological and practical forms. For this reason, describing scientific evolution requires a multi-phase model that captures cognitive, social, informational, and cybernetic mechanisms of development.

This section proposes a generalized model of scientific evolution consisting of a sequence of phases: from the empirical articulation of a scientific problem to transdisciplinary convergence and industrial implementation of knowledge. Such a model makes it possible not only to systematize the mechanisms through which new disciplines are formed, but also to reveal the internal logic of scientific transformations inherent in complex adaptive systems.

Within this model, we distinguish seven interrelated phases:

1. *Phase of empirical articulation and problematization.* The initial driving force for the evolution of science is empirical facts, anomalies, or persistent observations that do not fit into existing explanatory schemes. What occurs is not merely the accumulation of data, but their problematization: a fact is transformed into a scientific problem that requires theoretical explanation. It is precisely at this stage that an initial “demand for theory” is formed.

2. *Phase of conceptual-theoretical initiation.* The next step is the construction of initial models and concepts that set the foundation for a future theory. Relevant variables are selected, basic concepts are introduced, and hypotheses and principles are formulated. This phase has the character of conceptual initiation: the subject domain is clarified, the limits of applicability are outlined, and the primary structure of the explanatory framework is established.

3. *Phase of formal constructivization*. A theory moves from intuitive and metaphorical formulations to formally defined structures. Definitions are refined, axiomatic systems are built, mathematization takes place, and formal models capable of quantitative predictions are created. At this stage, knowledge acquires a constructive character, which ensures reproducibility, logical transparency, and the possibility of algorithmic implementation.

4. *Phase of disciplinary structuring and differentiation*. As the theoretical apparatus deepens and the range of tasks expands, relatively autonomous subfields and subdisciplines are emerging. Specific methods, parameter scales, and subclasses of models are formed (for example, the division of mathematics into algebra, geometry, analysis, applied mathematics). Disciplinary structuring reduces cognitive load, but at the same time intensifies the fragmentation of the scientific space.

5. *Phase of institutional stabilization*. The established disciplinary structure is reinforced through institutions: scientific schools, journals, conferences, professional associations, and educational programs. Stable standards of evidence, research protocols, peer-review models, and mechanisms of reproducibility emerge. Science acquires the features of a self-regulating social system with its own norms and mechanisms for legitimizing knowledge.

6. *Phase of transdisciplinary convergence*. Further complication of research objects and the growing role of informational, evolutionary, and systemic concepts lead to the formation of new clusters of knowledge that go beyond individual disciplines. NBIC convergence, cognitive science, contemporary cybernetics, and artificial intelligence are examples of such transdisciplinary formations. At this stage, universal languages of description (informational, ontological, systemic) and models of complex adaptive systems play the key role.

7. *Phase of industrial implementation of knowledge*. The final phase of the model describes the transformation of scientific results into technologies, economic systems, and management practices. A complete cycle of the industrialization of knowledge takes place: from fundamental theories to applied methods, engineering solutions, innovative products, and the social institutions that support them. The effectiveness of this phase depends on the ability of the scientific system to provide a constructive representation of knowledge, its algorithmic exploitation, and its economic valuation.

The proposed evolutionary model is not a rigid chronological scale; rather, it is a structural scheme that describes typical trajectories of transition from empirical problematization to transdisciplinary clusters and industrial forms of knowledge. It creates a methodological foundation for the evolutionary cybernetics of science, allowing scientific disciplines to be analyzed as dynamic systems moving within a landscape of possible theoretical configurations.

The formulated phase structure of scientific development demonstrates the presence of stable evolutionary mechanisms that determine the emergence of new theories, disciplines, and transdisciplinary clusters. In this context, the need naturally arises to form a new integrative field — Evolutionary Cybernetics — which studies the general principles of the evolution of scientific systems, their dynamics, selection mechanisms, and informational processes. Evolutionary cybernetics can serve as a methodological framework that combines philosophical, cognitive, systemic, and informational approaches to the analysis of scientific development.

Viewing science as an evolutionary system opens the possibility of analyzing its development not only in terms of historical descriptions or social transformations, but as a dynamic process of the self-organization of knowledge that obeys general regularities of complex adaptive systems. Within this paradigm, science appears as a set of interacting theories, methods, conceptual structures, and research traditions that evolve under the influence of variation and selection mechanisms. The evolution of scientific knowledge is the result of continuous processes of generating new hypotheses, their competition, selection, and stabilization within disciplinary paradigms.

Variation in science arises through the introduction of new concepts, models, measurement tools, computational technologies, or interpretive frameworks that expand the space of possible explanations. This corresponds to the emergence of new states in a dynamical system or shifts within a landscape of possible theoretical configurations. Such variations are not random: they are driven both by the internal logic of theoretical structures and by external perturbations — technological innovations, changes in social demand, the appearance of new types of data, or cognitive shifts within the scientific community.

In this perspective, the formation of the field of Evolutionary Cybernetics becomes relevant, combining principles of the theory of complex adaptive systems, second-order cybernetics, and contemporary informational concepts. Evolutionary Cybernetics makes it possible to describe science as a population of competing and interacting theories that evolve under the influence of internal cognitive factors and external technological conditions.

Selection manifests itself through competition among theories for empirical grounding, explanatory power, predictability, formal economy, and computational efficiency. In this context, scientific theories can be considered informational structures competing for survival under conditions of limited cognitive and resource capacities. Selection mechanisms include peer review, experimental verification, modeling, critical discussion, complexity assessment, and comparative analysis of alternative models. Theories that do not withstand these tests are displaced from the scientific space, whereas more robust structures occupy stable positions and move into the phase of normal science [6].

Inheritance ensures the transmission of methodological standards, definitions, tools, and conceptual frameworks through mechanisms of learning, scientific schools, and educational programs. This process forms attractors — stable regions in the space of theoretical configurations toward which research practice gravitates. Attractors ensure the structural stability of science by reducing the entropy of possible variants and ordering evolutionary movement.

The evolutionary dynamics of science also includes mutation mechanisms — radical or incremental changes in the theoretical apparatus that can initiate new fields or cause scientific revolutions. Mutations may be triggered both by the emergence of unexpected empirical data and by breakthrough mathematical or conceptual discoveries. In the terms of Evolutionary Cybernetics, such changes correspond to bifurcations — points at which the system transitions into a new mode of operation.

Within a cybernetic approach, science appears as a system of multi-level feedback loops: cognitive mechanisms regulate processes of thinking and interpretation; social structures determine organizational forms of science; technological infrastructures influence the possibilities of experiment and modeling; informational factors regulate the speed and accuracy of knowledge dissemination. All these loops interact, forming the complex evolutionary dynamics of science.

Thus, science can be described as an evolutionary adaptive system developing within a complex landscape of hypotheses, models, and interpretations. Attractors correspond to stable paradigms, bifurcations to revolutionary changes, and selection mechanisms to competition among theories. This approach integrates all previous sections and forms a general evolutionary framework for the development of science, which is a necessary foundation for developing a conceptual model of Evolutionary Cybernetics.

Considering science as an information and cybernetic system creates a new methodological basis for analyzing its dynamics, structure, and evolutionary characteristics. In contemporary approaches, science is increasingly interpreted as a process of systematically reducing uncertainty about reality through building models with high predictive, explanatory, and adaptive capacity. Within this paradigm, each theory appears as a mechanism of data compression: it transforms large volumes of empirical information into compact, structured representations that minimize the entropy of knowledge and provide a coherent description of complex phenomena [7—8].

The informational paradigm allows the development of science to be understood as a process of filtering, transforming, and accumulating information. The entropy of knowledge serves as a measure of uncertainty regarding the states of objects, processes, or systems, and scientific explanation as a means of its purposeful reduction. The dynamics of scientific progress, therefore, can be described as movement toward increasingly efficient models capable of integrating new data without a significant increase in complexity. Scientific revolutions, in this context, correspond to leaps in the structure of the informational landscape, when radically new forms of data compression emerge that change the organization of knowledge at all levels.

A cybernetic perspective makes it possible to specify the mechanisms of regulation and feedback that ensure the stability and development of scientific systems [7—8]. Peer-review mechanisms, standards of evidence, reproducibility procedures, and ethical norms perform the role of informational filters that control the quality of knowledge and prevent the accumulation of noise. They ensure the maintenance of low entropy in the theoretical space and contribute to the formation of coherent conceptual structures. Feedback between empiricism and theory plays a special role: empirical data correct models, and models set the structure of expectations and the direction of research, forming an adaptive learning cycle of science as a system [9].

An information-algorithmic interpretation of science makes it possible to model its evolution as an optimization process in a complex, multidimensional space of theoretical constructions. In this model, competition among theories resembles a search process in an energy or entropic landscape, where local minima correspond to stable paradigms and global minima to potentially universal explanatory structures. New theories function as "mutations" or innovations that change the form of informational compression and allow reaching lower values of energy functionals associated with accuracy, simplicity, or computational efficiency.

This approach naturally combines with Evolutionary Cybernetics, which considers science as a system capable not only of adapting to external conditions, but also of modifying its own regulatory mechanisms, transforming the structure of selection and variation processes. In this context, the evolution of science is a multi-level process that integrates individuals' cognitive strategies, the social structures of scientific communities, technological platforms for obtaining and analyzing data, and epistemological limitations of human cognition.

From the standpoint of contemporary evolutionary methodology, a key aspect of the development of science is ensuring the process of the industrialization of knowledge — a full cycle of its transformation from fundamental theories to innovative technologies and products [10]. This process includes the creation of applied methods, prototypes, technical solutions, as well as organizational and managerial mechanisms necessary for implementing scientific results in socio-economic practice. The industrialization of knowledge is not automatic; it requires institutional support, coordination of research clusters, and formalized procedures for transferring knowledge between levels of the scientific system. In this context, tasks of constructive representation of knowledge gain particular weight, including the formalization of models, the description of algorithms for their practical use, the definition of verification procedures, and the economic evaluation of knowledge as a component of a final innovative product. The effectiveness of this process largely depends on the development of metaknowledge — science studies — which analyzes the structure of science, the mechanisms of its evolution, and the conditions for transforming scientific results into technological, managerial, or social solutions.

The information-and-cybernetic approach, thus, forms a foundation for developing a full-fledged metatheory of the evolutionary dynamics of science. It ensures the integration of cognitive, social, technological, and logical-mathematical factors into a single analytical framework capable of explaining both the gradual accumulation of knowledge and radical transformations of scientific paradigms. In perspective, this opens the possibility of constructing formal models of scientific development suitable for forecasting, optimization, and managing evolutionary processes in the sphere of science.

Conclusion. The work provides a holistic analysis of the evolutionary nature of science, within which scientific knowledge is considered not as a static set of theories, but as a dynamic process unfolding in a space of cognitive, social, informational, and cybernetic mechanisms. It is shown that the emergence of new scientific fields and disciplines is the result of multi-level evolutionary processes in which changes in the methods of cognition, formalization, and organization of science are regular in nature.

The first block of results is the clarification of the epistemological and methodological foundations of scientific development. The historical and epistemological logic of the transition from natural philosophical forms of rationality to differentiated sciences, their integration, and transdisciplinary paradigms has been revealed. The role of logical structures, standards of verification and falsification, as well as cognitive mechanisms of abstraction, generalization, analogy, and mathematical idealization in the formation of new concepts and theories is emphasized. The concept of a linguistic-ontological picture of the world is introduced as a key level that determines the unambiguity of definitions and the structural integrity of scientific discourse.

The second fundamental result is the construction of a multi-phase evolutionary model of the development of science. It is proposed to consider the evolution of science as a sequence of phases: from the empirical articulation of a problem to conceptual-theoretical initiation, formal constructivization, disciplinary structuring, institutional stabilization, transdisciplinary convergence, and the industrial realization of knowledge. Such a model makes it possible to describe a typical mechanism of the birth of new disciplines, to capture critical transitions (bifurcations) in the development of scientific theories, and to connect them with cognitive, social, and technological conditions.

The third block of results concerns interpreting science as an evolutionary adaptive and information and cybernetic system. It is revealed that variation is realized through the generation of alternative hypotheses and models, selection through competition among theories for empirical confirmability, explanatory and predictive capacity, and inheritance through the mechanisms of educational programs, scientific schools, and institutional structures. It is shown that the information-algorithmic approach makes it possible to treat theories as data-compression mechanisms, and the development of science as an optimization process in a complex entropic landscape of possible explanations.

The fourth important result is the identification of the role of social, technological, and infrastructural factors in determining the trajectories of scientific evolution. It is shown that technological revolutions, digital platforms, global scientific infrastructures, and societal demand determine the pace, direction, and scale of the development of science, creating conditions for the formation of interdisciplinary and transdisciplinary clusters of knowledge. The significance of the industrialization of knowledge — the full cycle of transforming fundamental theories into technologies, innovative products, and social practices – is particularly emphasized.

Based on the integration of these results, the feasibility of forming a new scientific field — Evolutionary Cybernetics — is substantiated. It is considered as a metatheoretical framework that combines evolutionary, informational, and cybernetic mechanisms of scientific development, enabling the description and modeling of the emergence of new theories, disciplines, and transdisciplinary clusters. Evolutionary Cybernetics opens possibilities for quantitative analysis of the trajectories of scientific programs, the construction of models of theory selection, optimization of research organization, and forecasting structural shifts in the scientific landscape.

Thus, the work forms a conceptual and methodological foundation for further development of Evolutionary Cybernetics as a separate research field. The next steps should be to build formal models of the evolution of scientific disciplines, develop entropy-information criteria for evaluating theories, and empirically validate the proposed model using specific examples of the formation of modern scientific clusters.

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ЕВОЛЮЦІЙНА ПРИРОДА НАУКИ ТА МЕХАНІЗМИ ФОРМУВАННЯ НАУКОВОГО ЗНАННЯ

Представлено комплексний аналіз еволюційної природи науки, де наукове знання розглядається не як статичний набір теорій, а як динамічний процес, що розгортається крізь когнітивні, соціальні, інформаційні та кібернетичні механізми. Виникнення нових наукових галузей і дисциплін є результатом багаторівневих еволюційних процесів, де зміни методів пізнання, формалізації та організації науки мають закономірний характер. Метою статті є пояснення механізмів формування наукового знання. Методи: історико-епістемологічний аналіз і концептуальне моделювання фазових переходів. З'ясовано епістемологічні та методологічні засади розвитку науки, розкрито історико-епістемологічну логіку переходів від природно-філософських форм через диференційовані науки до інтегративних і трансдисциплінарних парадигм. Запропоновано багатофазну еволюційну модель розвитку науки, яка описує розвиток науки через послідовність етапів: емпіричної артикуляції, концептуально-теоретичної ініціації, формальної конструктивізації, дисциплінарного структурування, інституціональної стабілізації, трансдисциплінарної конвергенції та індустріалізації знання. Наука інтерпретується як еволюційна адаптивна та інформаційно-кібернетична система, де варіація проявляється через генерування альтернативних гіпотез, селекція відбувається через конкуренцію теорій, а спадковість функціонує через освітні інститути та наукові школи. Інформаційно-алгоритмічний підхід розкриває теорії як механізми стиснення даних, а розвиток науки — як процес оптимізації в ентропійному ландшафті можливих пояснень. Виявлено соціальні, технологічні та інфраструктурні фактори, що визначають траєкторії еволюції науки. Наголошено на значущості індустріалізації знання — повного циклу перетворення фундаментальних теорій на технології та суспільні практики. На основі інтеграції цих результатів обґрунтовано можливість становлення еволюційної кібернетики як нової наукової галузі, яка постає метатеоретичною основою, що поєднує еволюційні, інформаційні та кібернетичні механізми розвитку науки.

Ключові слова: *еволюційна природа науки, епістемологічні механізми, формування дисциплін, трансдисциплінарність, еволюційна кібернетика, індустріалізація знання, формування наукового знання, еволюція знання, наукові парадигми.*