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A BASE-REPRESENTATION-LINKAGE FRAME FOR HISTORIC–METHODOLOGICAL ANALYSIS OF FUNDAMENTAL CHEMICAL CONCEPTS

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Abstract. This study presents a novel methodological framework for analyzing the historical evolution of fundamental chemical concepts (element, compound, reaction) by transforming the Triplet Model of concepts into the Triad model. It posits that any scientific concept can be analyzed as consisting of three interconnected subsystems: (1) the Base (the domain of referential entities), (2) the Representation (symbolic and linguistic systems), and (3) the Linkage (procedural and explanatory relationships). The last has components of three types: Empirical-Technical, Explanatory-Theoretical, and Institutional-Social. **The aim** is to in-depth analyze three historical case studies, while referencing recent developments in the philosophy of chemistry. **Methods**. The paper uses comparative methods of reading and interpreting authentic texts, combined with their deconstruction. **The main result** is putting forward an innovative and thought-provoking perspective on the historical case studies in question. **Conclusions**. The study is of a historical-scientific and theoretical-cognitive nature, and the results obtained can be applied in research on the history and philosophy of science, as well as in the teaching of natural science disciplines.

Keywords. Philosophy of Chemistry, History of Chemistry, Conceptual Evolution, Triad Model, Conceptual Change, Scientific Modeling, Historical Epistemology.

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ІСТОРИКО-МЕТОДОЛОГІЧНИЙ АНАЛІЗ ФУНДАМЕНТАЛЬНИХ ХІМІЧНИХ ПОНЯТЬ У ФРЕЙМІ БАЗА – РЕПРЕЗЕНТАЦІЯ – ЗВ'ЯЗОК

Анотація. Це дослідження пропонує нову методологічну основу для аналізу історичної еволюції фундаментальних хімічних понять (елемент, сполука, реакція) шляхом перетворення Триплетної моделі понять на Тріадну модель. Вона стверджує, що будь-яке наукове поняття можна проаналізувати як складене з трьох взаємопов'язаних підсистем: (1) база (область референційних сутностей), (2) репрезентація (символічні та лінгвістичні системи) та (3) зв'язок (процедурні й пояснювальні відносини). Остання має компоненти трьох типів: емпірично-технічні, пояснювально-теоретичні та інституційно-соціальні. **Метою** є поглиблений аналіз трьох історичних тематичних досліджень, посилаючись на останні розробки у філософії хімії. У статті використовуються порівняльні **методи** читання та інтерпретації автентичних текстів у поєднанні з їх деконструкцією. **Основним результатом** є отримання інноваційного та стимулюючого до роздумів погляду на розглянуті історичні тематичні дослідження. **Висновки**. Дослідження має історико-науковий та теоретико-пізнавальний характер, а отримані результати можуть бути застосовані в дослідженнях з історії та філософії науки, а також у викладанні природничо-наукових дисциплін.

Ключові слова: філософія хімії, історія хімії, концептуальна еволюція, тріадна модель, концептуальні зміни, наукове моделювання, історична епістемологія.

1. Introduction.

The conceptual and methodological framework for studying chemical evolution. Chemistry constitutes a rich intellectual laboratory for studying the dynamics of conceptual evolution in the sciences, offering a complex historical trajectory where theoretical development intersects with technical progress and shifting cultural contexts[1]. Fundamental chemical concepts such as «element», «compound», and «reaction» represent ideal case studies for examining the mechanisms of conceptual transformation, not merely as changes in verbal definitions, but as profound restructuring of the relationships between experimental practices, theoretical representations, and explanatory frameworks.

Within the contemporary academic context, the philosophy of chemistry[2] is experiencing notable development as an independent field of knowledge, with an increasing focus on

[1] Bensaude-Vincent B., Simon J. Chemistry: The Impure Science. Imperial College Press. 2008. 280 p. https://doi.org/10.1142/9781848162266.

[2] Hendry R. F., Weisberg M., Needham P. Philosophy of chemistry / Ed. E. N. Zalta, *The Stanford Encyclopedia of Philosophy* (Winter 2016 Edition). URL: https://plato.stanford.edu/archives/win2016/entries/chemistry/(дата звернення 12.02.2026); Scerri E., McIntyre L. (Eds). Philosophy of Chemistry: Growth of a New Discipline. Dordrecht: Springer. 2015. 233 p. https://doi.org/10.1007/978–94–017–9364–3.

laboratory practices, representational systems, and the social aspects of chemical knowledge[3]. This highlights the need for new analytical frameworks capable of addressing the complexity of multicultural chemical history and the hybrid nature of chemical knowledge, which combines experiment and theory, matter and symbol.

Methodological gaps in traditional studies. Historical and philosophical studies of chemistry face several methodological challenges[4]. First, historical analysis often focuses on the chronological sequence of discoveries and theories, neglecting the internal structure of concepts and the mechanisms of their transformation[5]. Second, many historical narratives ignore the central role of material practices and technical tools in shaping chemical concepts[6]. Third, Eurocentric bias remains prevalent in many studies, disregarding the foundational contributions of non-Western chemical traditions and understating the complexity of cultural interactions in the history of chemistry[7].

The Triad Model of concepts as a holistic analytical framework. To overcome these limitations, we embellish the Triplet Model[8], originally proposed by one of the authors, into the Triad model[9]. According to the first model, the concept is analyzed as consisting of representing, basic, and linking static parts. In a sense, this view of the concept is reminiscent of Plato's view of eidos (εἶδος) as something eternal, ideal, perfect and unchanging that exists outside the sensory world and that man can only partially and approximately comprehend.

Taking into account the practice of concept uses in science, we view concepts as ever-improving (due to scientists' cognitive activity) abstract constructions that adapt to realities as their cognition deepens. We dissect the concept analytically into Base (the domain of its referential realities), Representation (symbolic and linguistic systems), and Linkage (procedural and explanatory relationships). In the last, we discern three interconnected types: the Empirical-Technical Linkage (L_1), the Explanatory-Theoretical Linkage (L_2), and the Institutional-Social Linkage (L_3). All are complex polysystems.

Thus, we understand concepts not as a priori given, but ever-modified intellectual means of ordering and understanding the realities they refer to.

In the Triad framework, one can analyze the internal structures of a scientific concept as dynamic entities, shaped by factors of different natures that are usually not taken into account in historical and philosophical studies of scientific concepts. (In literature, there

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3 Scerri E. R. The Periodic Table: Its Story and Its Significance. 2nd ed. Oxford: Oxford University Press. 2020. 504 p.; Taber K. S. Conceptual confusion in the chemistry curriculum: Exemplifying the problematic nature of representing chemical concepts as target knowledge. *Foundations of Chemistry*. 2019. Vol. 22. No. 2. P. 309–334. https://doi.org/10.1007/s10698–019–09346–3.

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9 Belkheiri N., Kuznetsov V. From the triplet to the triad model of scientific concepts: a new methodological framework for understanding conceptual evolution in science education. *Матеріали VII Міжнародної міжгалузевої науково-практичної онлайн-конференції (Культура, наука, освіта: смисложиттєві цінності в сучасних умовах).* Київ, 25–31 березня 2026 року. Київ, 2026. P. 165–174. https://doi.org/10.63437/978–617–7734–51-l-2026–1736

is another use of the derivative from the word «triad» for naming a rather formal concept model[10].)

Our central hypothesis asserts that conceptual evolution in chemistry is not a superficial and chaotic/flow of «idea», but a complex and ordered process of systematic restructuring of the triadic relationships among these components. This framework contributes to contemporary debates on the nature of scientific modeling[11], the relationship between theory and experiment[12], and the role of social and institutional contexts in shaping scientific knowledge.

2. Theoretical prolegomena: conceptual structures in scientific evolution.

Fundamental presuppositions of empirical science. Scientific investigation operates upon foundational presuppositions concerning the relationship between cognitive agents, the realities they study, and the knowledge thereby obtained. A core tenet within the natural sciences is that objects of inquiry from elementary particles to celestial bodies possess an existence independent of the investigator's consciousness and sensory engagement. These realities remain ontologically invariant throughout the investigative process, thereby guaranteeing the essential reproducibility of experimental results. From this principle, several operational corollaries follow that general features of a natural class may be inferred from studies of specific instances; that phenomena, though interconnected, can be isolated for study; and that identification proceeds through the empirical selection, measurement, and labeling of attributes. This entire cognitive enterprise is mediated by material instruments, both natural senses and constructed devices, and its outcomes are articulated using the available technical, linguistic and theoretical resources of the epoch. Crucially, this knowledge is not static; it evolves with the refinement of instruments, the development of new representational systems, and shifts within the broader social, cultural, and philosophical milieu.

To grasp these aspects of ordinary and scientific cognition, knowledge, and inquiry, one/mankind invents/constructs/develops a form of thought, such as a concept. That is why it attracts many researchers as a proper and important object of study.

Philosophers analyze this form as it has been understood in the history of philosophy[13]. Different philosophers meant different things by it. The terms are the same, but their references vary. However, as we know, historians of philosophy do not consider how, within the framework of a certain understanding of concepts, the evolution of some scientific concepts can be analyzed.

Psychologists and cognitive scientists consider a concept a mental entity with which the human mind, primarily though unconsciously, organizes external and internal information. It should be noted that new information is processed within the framework of the old. Some cognitivists develop experimental methods to support their hypotheses about what such a mental entity is and how it is used during categorizing and recognizing events in the external and internal worlds[14]. Others continue to appeal to introspective notions of concept[15].

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[10] Lehmann F., Wille R. A triadic approach to formal concept analysis / Eds. G. Ellis, R. Levinson, W. Rich, J. F. Sowa. Conceptual Structures: Applications, Implementation and Theory. ICCS 1995. Lecture Notes in Computer Science. Vol 954. Berlin, Heidelberg: Springer, 1995. 363 p. https://doi.org/10.1007/3–540–60161–9_27).

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[14] Rosch E. Reclaiming concepts. *Journal of Consciousness Studies.* 1999. No. 6. P. 61–78; Rosch E., Mervis C. Family resemblance: Studies in internal structures of categories. *Cognitive Psychology*. 1975. Vol. 7. P. 573–605; Smith E., Medin D. Categories and Concepts. Cambridge, MA: Harvard University Press, 1981. 219 p.

[15] Shea N. Concepts at the Interface. Oxford: Oxford University Press, 2024. 270 p.

Logicians view a concept as the entity they can transform by their technical means. They analyze what are called the central concepts of logic, but do not explicate what, according to their views, a concept as such is[16].

It is natural that philosophers of science and education also present their views on concepts, particularly scientific ones. They propose various versions of concept development, but, in fact, without touching the internal composition of the concept[17].

Thus, if one analyses the history of science and wishes to apply a certain reconstruction of concepts for the study of their development, there is a choice between different positions. In any case, historians of science should treat the scientific concept as «fluid» and changeable, rather than as a stable entity.

The inadequacy of reductive models: singlet and duplet formulations. Prevailing analyses of conceptual structure have often relied on models that fail to capture this dynamic complexity. Moreover, almost all belong to either the singlet or the duplet class of concept models. Singlets offer a severely reductive view, identifying a concept either solely with a not differentiated principle/idea (https://dictionary.cambridge.org/dictionary/english/concept) or directly with the name of the reality it denotes[18]. Symbolically represented as $C(X) = \langle N(X) \rangle$, these models presuppose a stable, one-to-one correspondence between word and world, treating the concept as a lexical or nominative given.

Duplets, represented as $C(X) = \langle Z(X), Y(X) \rangle$, provide a bipartite structure, typically pairing a set of entities (extension) with a set of defining attributes (intension)[19] or reference and sense[20]. While an advance over singlet models, this framework still presents concepts as relatively static pairings, describable by dichotomous or fuzzy membership functions[21]. Both model types share a critical deficiency: they treat scientific concepts as pre-formed, a priori units akin to a *deus ex machina* rather than as complex constructs generated and continuously modifiкed through the empirical, theoretical, and social practices of scientific communities. As such, they are ill-equipped to analyze the processes of conceptual change, particularly the profound restructuring characteristic of scientific transformations/metamorphoses.

The Triad Model: a dynamic framework for conceptual analysis. To overcome these limitations, we use the Triad Model of scientific concepts It posits that any mature scientific concept (C) is constituted by three interconnected, yet functionally distinct components:

$$C(t) = \langle B(t), R(t), L(t) \rangle$$

- **The Base (B):** The referential domain of the concept is the set of entities or phenomena, to which it applies. This component embodies the concept's ontic commitments, defining *what* the concept is fundamentally about.
- **The Representation (R):** The system of symbolic and linguistic means used to denote, describe, and reason about the base. This includes nomenclature, terminology, mathematical formalisms, diagrams, and visual models the *language* of the concept.
- **The Linkage (L):** The complex of mechanisms that connect representations to the base. This tripartite component encompasses:

[16] Gabbay D. M., Pelletier F. J., Woods J. (Eds). Logic: A History of Its Central Concepts. Vol. 11. Handbook of the History of Logic. In eleven volumes. Amsterdam: North-Holland, 2004. 707 p.

[17] Feest U., Steinle F. (Eds). Scientific Concepts and Investigative Practice. Berlin and Boston: de Gruyter, 2012. 309 p.

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[19] Fodor J. A. Concepts. Where Cognitive Science Went Wrong. Oxford: Clarendon Press, 1998. 186 p.

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- **L_1: Empirical-technical linkage:** The physical procedures, instrumental techniques, and measurement protocols that interact with the material base.
- **L_2: explanatory-theoretical linkage:** The conceptual frameworks, theories, and inferential rules used to interpret data and explain phenomena.
- **L_3: Institutional-social linkage:** The communal practices, educational traditions, and professional norms that stabilize and transmit conceptual meaning within a scientific community.

The model's pivotal insight is that these components evolve *asynchronously*. During periods of conceptual transformation, one component (e.g., L_1 through a new instrument) may change rapidly, while others (e.g., the core ontic base, B) exhibit significant inertia. This differential rate of change allows for continuity within discontinuity: established practices and representations can persist, providing stability even as theoretical foundations are overthrown. Furthermore, the model recognizes that concepts are objectified and intersubjectively accessible primarily through *scientific texts*, making their evolution amenable to rigorous historical and philosophical analysis.

Following the presentation of the Triad Model's general theoretical framework, we now turn to its specific application in the chemical context, focusing on how it illuminates the nature of conceptual transformations in this field.

Application to the historical evolution of chemistry. This robust theoretical framework is uniquely suited to dissect the complex evolution of fundamental chemical concepts. Chemical concepts such as *element*, *compound*, and ~~*chemical*~~ *reaction* have not merely changed their definitions; they have undergone radical restructuring of their tripartite architecture. By applying the Triad Model, we can systematically analyze:

1. Transformations in the **Base** (e.g., from elements as qualitative principles to elements as classes of atoms defined by nuclear charge).
2. Evolution in the **Representation** (e.g., from alchemical symbols to Lavoisier's nomenclature to structural formulas and computational visualizations).
3. The driving role of the **Linkage** (e.g., how the introduction of precise gravimetry (L_1), the rise of oxidation theory (L_2), and the formation of chemical societies (L_3) collectively reshaped the concept of combustion).

In this study, we develop and apply this adapted Triad Model to trace the historical pathways of these core chemical ideas. Our analysis moves beyond narratives of simple discovery or replacement, offering instead a structured account of how scientific concepts persist through their own transformations via the asynchronous yet coordinated evolution of their foundational, representational, and pragmatic dimensions. This approach not only clarifies the past but also provides a methodological lens for understanding ongoing conceptual change in science.

3. Theoretical framework: developing the Triad model in light of contemporary philosophy of chemistry.

Theoretical origins and contemporary development. Building on the Triad Model, we now further develop it in light of recent developments in the philosophy of chemistry and the philosophy of science.

In our contemporary development of this model, we benefit from recent advances in the philosophy of chemistry that emphasize the importance of studying laboratory practices, multiple representational systems, and social aspects of chemical knowledge. Our model aligns with the trend toward a «philosophy of scientific practice» that focuses on how scientific knowledge is produced in laboratories and scientific communities, rather than merely analyzing abstract theoretical products.

The chemical base (B_k): a hybrid, multi-layered system. In our analysis, the chemical base cannot be reduced to a mere «set of objects» or «class of entities.» It is a composite system involving four interconnected layers:

1. **Primary target entities**: The material samples and laboratory apparatus that constitute the immediate experimental reality.

2. **Material-experimental context**: Reaction conditions, procedural protocols, and practical rules governing laboratory practice.
3. **Theoretical-interpretive framework**: Conceptual networks and theoretical models that define how chemical phenomena are understood and interpreted.
4. **Cultural-historical context**: Epistemic traditions, philosophical systems, and practical goals that shape perceptions of matter and transformation across different cultures.

This expanded definition aligns with contemporary theories in the philosophy of science that view scientific knowledge as a product of complex interactions among material, theoretical, and cultural factors.

Clarification on the ontological distinction: It is crucial to distinguish, from the outset, the «theoretical framework» as part of the Base (B_k) from the «explanatory theory» as part of the Explanatory-Theoretical Linkage (L_2). In our model, a theoretical framework is part of the Base when it defines the category or type of entities to which the concept refers (e.g., defining an «element» as a latent philosophical principle versus a chemically indecomposable substance). This constitutes the initial ontological condition or «domain of possibility.» In contrast, the Linkage (L_2) comprises the set of mechanisms and inferential principles used to interpret the behavior and relations of those pre-defined entities (e.g., using phlogiston theory versus oxidation theory to explain combustion). The former (in B) answers «What is this?»; the latter (in L_2) answers «How and why does this happen?» This distinction prevents confusion and ensures that expanding the Base to include theoretical and cultural dimensions is enriching without being functionally overlapping with linking mechanisms.

Chemical representation (R_k): plurality of media and symbolic systems. Chemical representation is characterized by an unusual diversity in media and symbolic systems that have developed historically across different cultures. This representational plurality includes:

1. **Linguistic-verbal systems**: Terminology, nomenclature, qualitative descriptions conveying chemical knowledge orally and textually.
2. **Symbolic-visual systems**: Alchemical symbols, chemical formulae, structural diagrams, and other visual representations.
3. **Mathematical-formal systems**: Chemical equations, equivalent weight calculations, complex mathematical models.
4. **Computational-digital systems**: Computer models, molecular simulations, and structural databases reliant on advanced digital technologies.

Studying the evolution of these representational systems contributes to contemporary debates on the philosophy of scientific modeling and the role of multiple representations in scientific understanding.

Chemical linkage (L_k): a precise, multi-level stratified analysis. To achieve greater analytical precision in studying the relationships between representations and the base, we propose dividing the Linkage into three interconnected yet analytically distinct types:

1. **Empirical-technical linkage (L_1)**: Encompasses the physical processes and technical procedures that link representations to immediate reality. This level includes instrument calibration, experiment execution, direct measurements, laboratory skills, and experimental techniques. It answers the question: «How do we practically move from the material sample to experimental data?»
2. **Explanatory-theoretical linkage (L_2)**: Encompasses the conceptual frameworks and theoretical models that connect experimental data to symbolic representations. It includes interpreting results, model building, theoretical inference, and hypothesis formulation. It answers the question: «How do we interpret this data within a coherent theoretical framework?».
3. **Institutional-social linkage (L_3)**: Encompasses community conventions, institutional practices, educational traditions, professional standards, and social networks that ensure the stability and communication of meaning among members of the scientific community. It answers the question: «How is the stability and communicative efficacy of meaning maintained across time and space?»

This analytical division aligns with contemporary trends in the philosophy of science that emphasize the importance of studying the social and institutional aspects of scientific knowledge.

Formal representation and structural diagram of the Triad model. The Triad Model can be formally represented to clarify its structure and the dynamic, asynchronous interactions among its components. This representation serves as a heuristic tool rather than a deterministic mathematical model.

$$\text{Concept}C_k(t) = \langle B_k(t), R_k(t), L_k(t)\rangle$$
$$\text{Where: } L_k(t)=f(L_1(t), L_2(t), L_3(t); \theta)$$

The dynamic evolution of the concept can be approximated by the differential change in its components, where the rates of change are not necessarily synchronized:

$$dC_k/dt \approx (\alpha_{B.} dB_k/dt, \alpha_{R.} dR_k/dt, \alpha_{L.} dL_k/dt)$$
$$\text{with } \alpha_B, \alpha_R, \alpha_L \in R^+ \text{ and not necessarily equal.}$$

Interpretation: This formalism captures the core idea of asynchronous evolution. The coefficients α_B, α_R, α_L represent the relative «weights» or «rates» of change for each component during a historical period. For instance, during Lavoisier's revolution, the coefficient for technical linkage (α_{L1}) might be very high due to the introduction of precise quantitative measurement, while the coefficient for the base (α_B) might be moderate (a redefinition of «element»), and that for representation (α_R) lower (as some alchemical symbols persisted temporarily).

The structural relationships are further illustrated in the following diagram:

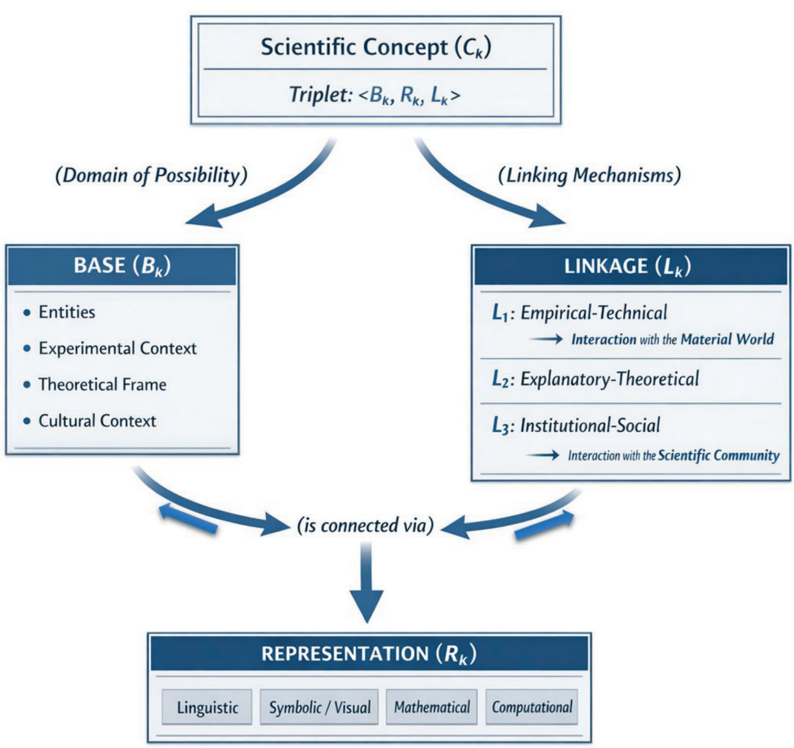

Figure 1. The Triad diagram of the scientific concept: base, representation, and linking mechanisms. (Arrows of varying thickness symbolize asynchronous change: R may change rapidly while L_2 remains stable, and vice versa)

This diagram and its accompanying formalism emphasize that the Base acts as the domain of possibility («What exists?»), while the Linkage constitutes the mechanisms of connection («How do we link it to symbols and share meaning?»). The Representation is the mutable product of this ongoing, triadic negotiation. The varying thickness of the arrows visually encodes the historical reality of non-simultaneous change across these components and linkage levels.

4. Study methodology: comparative historical-philosophical analysis.

This study is based on a comparative historical-philosophical analytical methodology that integrates several levels of analysis. At the historical level, we rely on the analysis of texts and primary sources from different periods, paying attention to the cultural and social contexts in which they were produced. At the philosophical level, we apply the Triad Model to deconstruct the internal structure of concepts and analyze their transformation mechanisms. At the comparative level, we compare the evolution of the three concepts (element, compound, reaction) to extract general patterns, as well as between different chemical traditions to understand the diversity of historical pathways.

The study adopts a multicultural perspective in reading the history of chemistry, referencing the foundational contributions of non-Western chemical traditions (Arabic, Chinese, Indian) not as «precursors» or «anticipations» of modern chemistry, but as complete epistemic systems with their own concepts, rules, representations, and linkages[22].

Conditions of comparability. The comparative methodology employed here rests on three explicit conditions of comparability that frame the selection and analysis of historical cases:

1. **Functional equivalence condition**: Concepts across traditions are compared as cognitive tools performing analogous organizational functions in understanding matter and its transformations, not as identical definitions. This permits comparing, for instance, the Chinese «Five Elements» with the Greco-Islamic «Four Elements,» despite their differing theoretical content.
2. **Structural analyzability condition**: A historical case must be sufficiently documentable to allow its reasonable decomposition into the three model components (B, R, L). This excludes periods where records are too scarce or fragmentary for a coherent structural analysis.
3. **Influence/representativeness condition**: Cases are selected either for their demonstrable influence on a subsequent historical trajectory (e.g., Arabic chemistry) or as representative of a coherent, relatively autonomous epistemic system (e.g., traditional Chinese chemistry). The aim is to trace transitions and influences or to explore conceptual alternatives.

These conditions ensure that the comparison is neither anachronistic nor superficial but is instead methodological and aimed at revealing patterns of transformation in the very structure of concepts. **5. Analysis of chemical concepts via the Triad model: a comparative Study.**

5. Comprehensive analytical table of chemical concept evolution.

Table 1 illustrates the general evolutionary patterns of the three components of chemical concepts across eras. We will now proceed to a detailed textual analysis of these transformations as they appear in primary historical sources.

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[22] Al-Khalili J. The House of Wisdom: How Arabic Science Saved Ancient Knowledge and Gave Us the Renaissance. Penguin Press, 2011. 302 p.; Sivin N., Habib S. I., Raina D. Situating the history of science: Dialogues with Joseph Needham. *The American Historical Review*. 2001. Vol. 106. No 1. P. 131. https://doi.org/10.2307/2652231.

Concept	Period / Context	Base (B)	Representation (R)	Linkage (L_1: empirical-technical)	Linkage (L_2: explanatory-theoretical)	Linkage (L_3: institutional-social)
Element	Arabic / Islamic Traditions (pre-16th c.)	Four elements as latent principles in matter manifest via chemical processes	Advanced alchemical symbolic system, precise technical terminology	Advanced distillation & calcination techniques, sophisticated lab apparatus	Philosophical-medical explanations linking properties to principles, theories of transformation	Wisdom traditions, professional training in laboratories, networks of scholars
Element	Traditional Chinese Traditions	Five elements as dynamic, interacting forces linked by cycles of generation and control	Representations based on Yin-Yang concepts, medical/chemical applications	Medicinal/ chemical preparation practices, heat treatment techniques	Theories of cosmic balance, links to medicine/ astrology, nature philosophy	Taoist/Confucian traditions guiding practice, Imperial institutions
Element	Lavoisierian Phase (late 18th c.)	Tangible substances indecomposable by available chemical means	Systematic nomenclature reflecting composition, rejection of alchemical symbols	Precise use of balances, quantitative analysis techniques, accurate measuring devices	Law of mass conservation, theories of combustion/ oxidation, scientific materialism	Unification of names/ terms, scientific academies, specialized journals
Element	Dalton's Development (early 19th c.)	Atoms as indivisible units of elements, classified by atomic weights	Atomic symbolic system (circles with letters) representing elements & compounds	Precise measurements of relative atomic weights, gas experiments	Laws of multiple proportions, atomic theory, mechanism	Publication of textbooks, teaching of atomic theory, scientific societies
Element	Mendeleev's Methodology (1869)	Elements with periodic properties linked to atomic weights	The Periodic Table as a spatial representation organizing elements by properties	Systematic measurement of physical/ chemical properties, improved accuracy	Periodic relationships, prediction of undiscovered elements' properties, systematization	International scientific community acceptance of the Periodic Table, scientific conferences
Element	Moseley Revolution (post-1913)	Redefined by atomic number (nuclear charge) instead of atomic weight	The Periodic table reorganized by atomic number, electronic notation	Precise spectroscopic techniques for wavelength measurement, X-ray tubes	Theories of atomic structure (Bohr, Schrödinger), quantum mechanics	International standards for element clas-sification, nternational scientific unions
Compound	Arabic Alchemy	Materials resulting from union of elements in varying proportions, convertible via chemical processes	Qualitative description of compounds & preparation methods, focus on properties/ transformations	Advanced distillation, crystallization, sublimation techniques, special furnaces	Theories of transformation & interaction between elements, philosophy of matter	Traditions of artisans/practical chemists, recipe books
Compound	Law of Definite Proportions (Proust, 1799)	Pure substances of constant weight composition, distinct from mixtures	Empirical formulae expressing weight ratios of constituent elements	Accurate gravimetric analysis, advanced purification techniques, sensitive balances	Law of Definite Proportions, theory of quantitative composition, mathematical precision	Standard analytical protocols, laboratories of academies/ factories
Compound	Structural Revolution (Kekulé 1858, van 't Hoff 1874)	Redefined to include spatial arrangement of atoms, importance of 3D order	Structural formulae, spatial representations, physical molecular models	Measurements of optical isomerism, stereochemical analysis techniques, angle measurements	Theories of chemical bonding, molecular geometry, atomic theory	Unification of structural symbols, specialized organic chemistry journals

Concept	Period / Context	Base (B)	Representation (R)	Linkage (L_1: empirical-technical)	Linkage (L_2: explanatory-theoretical)	Linkage (L_3: institutional-social)
Compound	Modern Era	Concept expanded to include electronic structure & quantum properties	Molecular orbitals, computational models, interactive 3D representations	Advanced techniques (spectroscopy, X-ray diffraction, microscopy), probes	Quantum chemical theories, calculation of molecular properties, molecular dynamics	International structural databases, simulation software, IUPAC standards
Reaction	Ancient Chemical Traditions	Qualitative transformation of materials, linked to observable property changes (color, smell, texture)	Verbal description of transformations, terms borrowed from medicine/ cooking	Simple practical experiments (heating, mixing, filtering), primitive furnaces	Qualitative explanations based on observable properties, theories of elements	Oral traditions, practical workshop training, books of magic/chemistry
Reaction	Calculational Age (Lavoisier, Richter)	Quantitative transformation governed by conservation laws (mass, elements)	Balanced chemical equations, mathematical representation of reactions	Accurate balances, devices for measuring volume/pressure, calorimeters	Laws of conservation, theories of quantitative reaction, stoichiometric calculations	Standard experimental protocols, research laboratories, systematic teaching
Reaction	Thermodynamics Era (Gibbs, Helmholtz)	Energetic process governed by changes in enthalpy & entropy	Thermodynamic equations, energy diagrams, state functions	Precise calorimeters, devices for measuring heat/pres-sure, and advanced equipment	Laws of thermodynamics, concept of free energy, chemical equilibrium	Unification of symbols/units, collaboration between physicists/ chemists
Reaction	Reaction Mechanism Age (20th c.)	Dynamic pathway involving transition states & reactive intermediates	Reaction coordinate diagrams, mechanistic notation (curved arrows), rate constants (k), electronic structure schemes	Kinetic techniques (stopped-flow, relaxation), flash photolysis, ESR, NMR, chromatography, isotopic labeling	Transition state theory (Eyring), molecular orbital theory, kinetic vs. thermodynamic control, computational chemistry (DFT, ab initio)	Establishment of physical organic chemistry divisions, specialized journals (J. Am. Chem. Soc., J. Org. Chem., Tetrahedron), international symposia on mechanisms, reaction databases (Reaxys, SciFinder)

Table. 1. The development of the components (base, representation, and linking mechanisms) of the chemical concept across historical contexts.

Detailed textual analysis examples. Methodological caveat. The textual examples provided here should be understood with an important methodological caveat. These are representational analyses intended to demonstrate the operation of the Triad Model on specific historical materials, not to make comprehensive historical claims or assessments of textual authenticity.

Analysis of the «Element» concept in Jabir ibn Hayyan's texts: In his major work *The Book of Properties (Kitab al-Khawass)*[23], Jabir does not merely describe the four elements (Fire, Air, Water, Earth) as abstract principles (B: Philosophical-Theoretical Framework). He links them procedurally to tangible properties and their transformability through specific chemical operations. His description of distilling sulfur and copper to extract the «spirit»

[23] Jābir Ibn Ḥayyān, Mashhad Al Allaf. The Comprehensive Book on Properties. URL: https://www.qdl.qa/%D8%A7%D9%84%D8%B9%D8%B1%D8%A8%D9%8A%D8%A9/archive/81055/vdc_100032090042.0x000001.

of the metal (L_1: Distillation Technique) is tied to his theory of metal formation from these elements in different proportions (L_2: Theoretical Explanation). His representation of these processes uses an evolving alchemical symbolic system (R), yet it is supported by a network of technical terminology transmitted through wisdom traditions and laboratory practice (L_3). Here, we see integration between a theoretical base, a symbolic representation, and a practical-explanatory-social linkage.

Analysis of «Transformation» in the Chinese framework (Daodejing): The text describes cosmic and material transformations through the interaction of Yin-Yang forces and the Five Elements (B: A Dynamic Cosmic System). The representation of these transformations is not through chemical formulae, but through natural metaphors (water flow, metal hardness) and applications in medicine and alchemy (R). The linkage between these representations and practice (e.g., in preparing elixirs) is not achieved through quantitative laws, but through the principle of balance and harmony (L_2), which is practiced and studied within Taoist and Imperial institutions (L_3). This example shows how the nature of the base (a dynamic cosmic system) determines the form of representation and the qualitative nature of the linkage. Such cultural variations in conceptual structure align with the analysis of the diversity of concept classification.

From the analytical table and the preceding textual studies, several overarching patterns can be discerned in the evolution of chemical concepts across different traditions.

Comparative analysis and general patterns. The analytical table reveals several recurring patterns in the evolution of the three chemical concepts throughout history.

First, we observe the evolution of the Base from qualitative to quantitative to structural and theoretical, where concepts transition from reliance on directly observable properties to precisely measurable concepts and then to abstract structural and theoretical concepts. This progression was not linear but zigzagging, with some qualitative aspects retained even in modern concepts.

Second, Representation evolves from verbal to symbolic-mathematical systems, with systems accumulating without complete displacement. This representational plurality where old and new representational systems often coexist aligns with contemporary theories on the cognitive benefits of multiple representations in science[24]. This means that the concept's name is a form of its activation in consciousness, suggesting the cognitive importance of representational forms.

Third, the Linkage evolves from direct-experimental to theoretical-indirect, with increasing complexity in the epistemological network connecting the world to representations. The triple division of Linkage (L_1, L_2, L_3) allows for a more precise analysis of how these relationships are established over time. This development reflects the role of definition as a method/way for introducing concepts but extends it to include not just formal definitions but the entire network of material, theoretical, and social connections

Crucially, the comparative analysis highlights that the development of the three components is often asynchronous. Significant shifts may occur in one component while others remain relatively stable. For example, in the Lavoisierian revolution, the transformation in the Empirical-Technical Linkage (L_1: introduction of precise mass measurement) was radical, while changes to the Base (B: retention of the element-as-indecomposable-substance idea) were more moderate. Conversely, during the structural revolution in compounds, the Base underwent a major transformation (the introduction of a spatial dimension), while Representation showed relative continuity (the persistence of chemical formulae with additions). This asynchronous evolution challenges models that presume simultaneous, comprehensive change across all aspects of scientific practice during conceptual revolutions.

Mutual influence between cultural traditions. A comparative analysis reveals the complex interactions among different chemical traditions throughout history. The foundational

[24] Frigg R., Nguyen J. Modelling Nature: An Opinionated Introduction to Scientific Representation. Cham: Springer, 2020. 241 p. https://doi.org/10.1007/978–3–030–45153–0.

contributions of Arabic and Islamic alchemy, as recent historical studies clarify[25], were not merely «anticipations» of modern chemistry, but a complete epistemic system that contributed to the development of concepts, tools, and techniques that formed the basis of later chemistry. Chinese traditions, in turn, developed an epistemic system built on different logic (Five Elements, Yin-Yang) linking chemistry to the cosmos and medicine within a unified theoretical framework[26].

The Triad Model helps us analyze these traditions not as «primitive» versions of modern chemistry, but as coherent systems with their own internal logic of Base-Representation-Linkage relationships. For instance, the strong Institutional-Social Linkage (L_3) in Chinese alchemy, rooted in Taoist monastic institutions and Imperial patronage, shaped both the types of problems addressed (e.g., elixirs for longevity) and the representational systems used (metaphorical rather than mathematical).

6. Discussion: philosophical implications in light of contemporary philosophy of chemistry.

Our comparative historical analysis now leads us to a broader philosophical discussion, where we will compare the Triad Model with other theoretical frameworks in the philosophy of science and explore the epistemological implications of our findings.

Comparison with contemporary theories of scientific change. The Triad Model offers a nuanced perspective on scientific change by revealing continuity beneath apparent discontinuity. While theories of scientific revolutions[27] emphasize paradigm replacement and incommensurability, the Triad Model demonstrates how certain components, particularly representations and technical practices, can exhibit remarkable stability across theoretical shifts. The persistence of symbolic systems (like chemical formulae) and basic laboratory techniques (L_1) during theoretical revolutions (L_2) illustrates this continuity.

Our model aligns with contemporary developments that emphasize gradual, multi-level change in scientific practice over sudden, comprehensive revolutions[28] The division of Linkage into three types allows for precise analysis of how technical practices (L_1), theoretical frameworks (L_2), and social conventions (L_3) can evolve at different paces and somewhat independently.

Explicit positioning: comparative analysis with foundational frameworks. To further delineate the specific contribution of the Triad Model, an explicit comparison with other influential frameworks in the philosophy and history of science is instructive. The following table contrasts key analytical dimensions of our model with those of Thomas Kuhn, Hasok Chang, and Hans-Jörg Rheinberger[29].

Analytical dimension / model	Kuhn (scientific revolutions)	Chang (progressive coherence / continuity)	Rheinberger (epistemic things / technics)	The Triad model (this study)
Primary unit of analysis	The **Paradigm** as an integrated whole of beliefs, values, and practices.	Scientific **practice**, particularly **systems of knowledge** that maintain continuity through change.	**Epistemic things** (in the lab) and **techniques** that generate new knowledge through their stability/ instability.	The **scientific concept**, structurally analyzed into three components: **Base (B), Representation (R), Linkage (L)**.

[25] Sivin N., Habib S. I., Raina D. Situating the history of science: Dialogues with Joseph Needham. *The American Historical Review*. 2001. Vol. 106. No. 1. P. 131. https://doi.org/10.2307/2652231.

[26] Ibid.

[27] Kuhn T. S. The Structure of Scientific Revolutions. 3rd ed. Chicago: University of Chicago Press. 1996. 212 p. https://doi.org/10.7208/chicago/9780226458106.001.0001.

[28] Vickers, P. Identifying Future-Proof Science. Oxford: Oxford University Press, 2022. 280 p. https://doi.org/10.1093/oso/9780192862730.001.0001.

[29] Rheinberger H.-J. Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube. Stanford: Stanford University Press, 1997. 325 p.

Analytical dimension / model	Kuhn (scientific revolutions)	Chang (progressive coherence / continuity)	Rheinberger (epistemic things / technics)	The Triad model (this study)
Nature of scientific change	**Revolutionary & non-cumulative**: Complete replacement of incommensurable paradigms.	**Largely continuous & gradual**: Development and refinement of existing systems of knowledge, allowing for accumulation.	**Branched & non-linear**: Complex laboratory interactions generating unexpected new knowledge «differences.»	**Asynchronous & multi-level**: Uneven change in depth/pace across a concept's three components (B, R, L) and linkage levels (L_1, L_2, L_3).
Role of theory & experiment	Theory precedes and shapes perception (determines «what is seen»). Experiments are «puzzle-solving» within the paradigm.	Symbiotic and interactive. **Prospective justification**: experiments test and develop integrated knowledge systems.	Knowledge arises from material interaction with «epistemic things» in the lab. Theory forms later.	Interaction is **structured via components**: Experiment/technique (L_1) is interpreted by theory (L_2) within an institutional frame (L_3) to link entities (B) to representations (R).
Role of practices & technical tools	Part of the paradigm's «normal practice,» but secondary to theoretical commitment.	**Central**. The development of tools/techniques (e.g., thermometers) is a key driver of progress.	**Fundamentally central**. Stable techniques create the material conditions for «epistemic things» and knowledge generation.	Integrated as the distinct analytical component **Empirical-technical linkage (L_1)**, necessary for establishing any B-R relationship.
Role of social/ Institutional factors	Present within the «paradigm» as a sharing scientific community, but not independently analyzed.	Implicit in traditions of practice, but primary focus is on internal knowledge systems.	Embedded in laboratory culture and its material/ social resources, but not a separate analytical level.	An **explicit and independent analytical component**: **institutional-social linkage (L_3)**, essential for conceptual meaning stability and transmission.
Theory of representation/ Modeling	Not central. Models are expressions of the paradigm.	Assumes effective representation through knowledge systems, allowing for pluralism.	Representations arise from interaction with epistemic things (as material traces or precipitates).	**Representation (R)** is a **central, mandatory component for analysis**, with all its media plurality and historical evolution.
Key distinctive contribution	A dynamic theory of revolutionary knowledge disruptions.	A theory of continuity and knowledge accumulation through the gradual refinement of practice.	A theory of knowledge generation through the material dynamics of experimental systems, focusing on the interplay between epistemic things and technical objects.	A structural and componential theory of conceptual evolution, revealing asynchronous change across Base, Representation, and triple-linkage systems, integrating epistemic, technical, and social dimensions.

Table 2. Comparative analysis of the Triad model and key analytical frameworks.

Analytical clarification: distinguishing the «Domain of Possibility» from «Linking Mechanisms». While our expanded definition of the Base (B_k) encompasses cultural context and theoretical frameworks elements that may seem to approach the domain of Explanatory-Theoretical (L_2) and Institutional-Social (L_3) Linkage the analytical distinction between them is crucial and clear in terms of epistemological function and methodological role.

The base (B_k) as a «Domain of possibility».

The Base represents the ontological field or space of possibilities with which a concept engages. It is the framework that defines what can possibly be an object of the concept. When we state that the Base includes cultural context, we refer to the conditions of possibility for specific entities to emerge as subjects of chemical inquiry within a given historical culture. For instance, the consideration of the «elixir» as a potential chemical entity in the Chinese alchemical Base results from cultural-philosophical conditions of possibility (Daoist traditions, the goal of longevity) that prefigure the field of conceivable and researchable entities. The theoretical framework within the Base defines the category or type to which entities belong (e.g., «elements» as indecomposable principles, or «metallic spirits» as active powers); it determines what we consider existing within a specific conceptual system.

Linkage L_k as «Linking mechanisms»: Linkage represents the set of actual processes and relationships that establish, execute, and sustain the connections between those entities (in the Base) and their representations (R_k). It is the *how* of connecting the world to symbols, not the definition of the world itself.

Linkage L_2 (Explanatory-theoretical): This is the mechanism by which we interpret the observation of a substance's color change (an entity in the Base) as evidence for a chemical reaction (a concept), using a theory of oxidation-reduction. The theory here is a linking tool, not a definition of the entities.

Linkage L_3 (Institutional-social): This is the mechanism that ensures the term «oxidation» is understood identically by chemists in different laboratories, via conventions, standards, and journals. It guarantees the efficacy and stability of the linking process; it does not define the nature of the entities being linked.

In summary. The Base (B) answers the question «What?» (What are the objective entities or possibilities?), while Linkage (L) answers the question «How?» (How do we link these entities to our representations and communicate their meaning?). Expanding the definition of the Base to include the cultural and theoretical conditions that constitute it does not erase this functional distinction but enriches it, demonstrating that the «domain of possibility» is not a purely natural given but is historically shaped. However, it remains analytically distinct from the «linking mechanisms» that operate within and depend upon that domain.

The role of social and institutional contexts in shaping concepts. The Triad Model, especially through the Institutional-Social Linkage component (L_3), highlights the crucial role of social and institutional factors in shaping and evolving chemical concepts. Community conventions, professional standards, educational traditions, and scientific networks are not merely a «background» to scientific knowledge, but essential components of the very structure of concepts.

This aligns with contemporary developments in the philosophy of science emphasizing the importance of studying «distributed knowledge» and «embedded knowledge» in scientific practices and institutions. The history of chemistry, as our analysis reveals, is not only a history of ideas and theories, but also a history of institutions (laboratories, universities, scientific societies), practices (experimentation, measurement, modeling), and techniques (tools, instruments, software).

Limits of the model and potential for development. We acknowledge the limits of the Triad Model, including: (1) the risk of oversimplification, as any analytical model simplifies historical complexity; (2) the challenge of application, as the triple division of Linkage requires historical sensitivity; and (3) temporal bias, as a focus on turning points may overlook important continuities. Despite these limitations, the exploratory and analytical value of the Triad Model remains significant, especially if applied with historical sensitivity and recognition of its boundaries.

The study opens avenues for developing the model, including: (1) the potential for integrating quantitative analysis of representational systems; (2) a broader comparative study of different chemical traditions; and (3) applying the model to additional chemical concepts like chemical bonding, catalysis, and crystalline structure. These developments would build on the application of the model to historical reconstructions of the concept «planet»[30] and the concept «atom»[31]..

[30] Кузнецов В. Понятие и его структуры. Методологический анализ. Киев: Институт философии им. Г. С. Сковороды Национальной академии наук Украины, 1997. 238 с. URL: https://philpapers.org/rec/KUZACA(дата звернення: 12.02.2026).

[31] Кузнєцов В. Поняття як формоутворення систем наукового знання / ред. М. Попович. *Вимір раціональності як чинник європейської інтеграції України*. Київ: Наукова думка, 2014. С. 174–235.

7. Conclusion and future directions.

Key contributions of the study. This study has presented several theoretical and methodological contributions to understanding the evolution of chemical concepts. First, it developed the Triad Model of concepts by dividing the Linkage component into three interconnected types (Empirical-Technical, Explanatory-Theoretical, Institutional-Social), providing a more precise analytical tool for studying the relationships between the world and representations. Second, it offered a comprehensive comparative analysis of the evolution of three fundamental chemical concepts across different historical periods and cultures, revealing recurring patterns of asynchronous development of the three components. Third, it contributed to contemporary debates in the philosophy of chemistry regarding the nature of scientific modeling, the role of practices and techniques, and the social dimensions of chemical knowledge.

Applications and future research directions. This study opens several future research directions. At the historical level, the Triad Model can be applied to a broader comparative study of different chemical traditions, including Indian, African, and Native American traditions. At the philosophical level, the model can be used to analyze additional chemical concepts such as chemical bonding, catalysis, photochemical reactions, and complex systems. At the pedagogical level, educational applications can be developed to enhance students' understanding of the historical nature and complex structure of chemical concepts.

Final conclusion: towards a holistic understanding of conceptual transformation. The Triad Model provides a new methodological framework for understanding the dynamics of conceptual evolution in chemistry. By analyzing the complex interaction between the Base, Representation, and the three-typed Linkage, we reveal the mechanisms that shape and evolve chemical knowledge over time. The model reminds us that scientific concepts are not merely ideas in minds, but complex material-symbolic-social entities, rooted in laboratory practices, embodied in technical tools, and circulated within scientific communities across cultures and history.

This comprehensive understanding enriches not only the history and philosophy of chemistry but also our appreciation of the complex and creative nature of scientific practice. In an era of increasing calls to move beyond Eurocentrism in the history of science and to appreciate the epistemic diversity of humanity, our model provides an analytical tool that helps us understand the complexity of cultural interactions in the history of science and respect the multiplicity of pathways that have led to the formation of scientific knowledge as we know it today. The Triad model demonstrates the possibility of a unified viewpoint on concepts that systematizes knowledge obtained in different sciences, a goal our chemical application has sought to advance.

Disclosure of Generative AI use. During the preparation of this manuscript, the authors utilized AI-assisted tools: Grammarly for grammar correction and stylistic refinement, and ChatGPT for support with English-language formulation, solely to enhance linguistic clarity. This assistance was sought because the authors' native languages are Arabic and Ukrainian.

No part of the original conceptual framework, historical analysis, theoretical development, or scientific conclusions was generated by AI. All intellectual content, including the development and application of the Triad Model, is the original work of the

authors, who accept full responsibility for its accuracy and originality.

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THE ALGORITHMIC INTERPRETANT AS A TRANSFORMATIVE FACTOR IN THE COMMUNICATIVE SPACE OF DIGITAL CULTURE

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Abstract. This article undertakes a philosophical inquiry into the transformation of communicative space in the context of digital culture. **Introduction.** In contemporary society, digital culture has become not only the dominant mode of interaction but also a decisive factor in reshaping the social, cultural and epistemological environment. Digital communication alters not merely the technical conditions of information transfer, but the very ontology of dialogue, representation and interpretation. Algorithmic mediation, the emergence of a «semiotics of surface» and the loss of context generate new challenges for the ethics of dialogue, the structure of publicity and the capacity