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Analogical and Logical Thinking
In the Context of Inter- or Trans-disciplinary Communication and Real-Life Problems

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ABSTRACT

This work investigates the commonalities and the relationships between analogical and logical importance of analogy, not being treated as a secondary or auxiliary process to logic, but as a generative foundation of cognition, communication, and knowledge creation. By integrating insights from philosophy, cognitive science, logic, science, systems theory, and interdisciplinary practice, we highlight how analogical thinking provides the creative leaps, cross-domain mappings, and heuristic inputs that seed conjectures and heuristics, while logical thinking contributes validation, rigor, and epistemological knowledge. Their recursive interaction produces hybrid modes of reasoning, integral, integrative, and integrated, that are necessary for addressing complex, real-world problems, which level of complexity requires inter-disciplinary fields, multi-disciplinary teams, and transdisciplinary communication, understood as cross-disciplinary and beyond disciplines communication. The latter is especially important in the kind of research that requires the participation of stockholders who may include lay persons.

Based on literature research, notional analysis and diagrams, and systemic reasoning, we emphasize the cybernetic loops that emerge when analogy and logic interact. These loops operate through feedback and feedforward relations, showing how analogy inspires hypotheses that logic tests, while logical structures, once established, generate new analogies, and so on. It further demonstrates that analogical reasoning, expressed through natural language, provides an indispensable medium for transdisciplinary communication, making knowledge transfer across and beyond disciplines possible.

Ultimately, we suggest that analogical and logical thinking, understood as complementary poles of cognition, form the basis of hybrid reasoning capable of tackling complex societal challenges. By reconceiving their relationship in cybernetic and systemic terms, it becomes possible to develop ***new methodologies that integrate creativity with rigor, emergence with structure, and novelty with validation***, oriented for inter- and transdisciplinary communication, research, and practice.
This short experience-based, oriented by literature research, reflection, and reflexivity (essential in Second Order Cybernetics), we try to highlight the importance of analogical thinking, its relationship to logical thinking, and the cybernetic loops that emerge when both are connected through systemic and holistic perspectives. This whole, as it is known, is more than its parts because of its potential emergent properties and synergies. The latter is very probable because all of it is being managed by the respective neural nets, whose high level of complexity increases the potentiality and the probability of cognitive emergent properties that are essential for creativity and for continuously transforming knowledge into understanding, which is itself an emergent property.

Together, these form the basis for an integral, integrative, and integrated ***Hybrid Thinking***. Such an approach may foster systemic-cybernetic and synergistic relationships that are essential for effective inter- and transdisciplinary communication. This, in turn, is required not only for addressing real-world problems, such as those encountered in case studies, consulting, and information systems analysis, synthesis, and deployment, but also for processes that involve: (1) integrating core academic activities, namely research, education, and their respective methodologies; and (2) generating communication across and beyond disciplinary boundaries.

In a few words, our objective is to provide an initial work in progress to explain the real and the potential cybernetical relationships schematized in figure 5.

1. ANALOGY AND ANALOGICAL THINKING:

Let's start here with very important brief texts, related to the notion of “Analogy” and provided by well-known authors regarding the notion of analogy [Italics, bold fonts, and initiating with capital letters have been added]

- ***"Analogy is a mental tool that everyone uses to some degree"*** (Holyoak & Thagard, 1995) (Preface);
- ***"Everything is analogy"*** (Pask G. , 1993)**.**
- ***"All meaning comes from analogies"; "Analogy is everything, or very nearly so"*** (Hofstadter, 2001)
- ***"Analogy pervades all our thinking… [including] the highest scientific achievements."*** (Polya, 1957)
- **"*Conceptual metaphor [which is based on analogy] plays a central, defining role in mathematical ideas within the cognitive unconscious."*** Lakoff and Núñez (2000)
- ***"Historians, philosophers, and psychologists of science have documented many instances of analogical thinking"*** (Holyoak & Thagard, 1995, p. 185)
- "Analogy has never been quite accepted as the legitimate child of pure thought and reason." (Haskell, 1968; p. 162)

Just as the North and South Poles form a polarity that generates the Earth's magnetic field, orienting migratory animals and allowing humans to navigate with the compass, as well as negative and positive electrical charges create the tension that drives the movement of electrons and hence electrical current. Similarly, *analogical* and *logical* thinking constitute polar opposites within the realm of human thought. Each requires the other, and together they generate the movement of consciousness, where the term "consciousness" is used in its active sense and not as a mere passive perception. This means that in this context, the term "consciousness" is understood as the dynamic, directed state of awareness or cognitive experience that arises from the interplay of analogical and logical thinking.

Logical thinking, taken in isolation, is sterile: capable of ordering and inferencing (via deduction, induction, abduction, etc.) but incapable of generating novelty. Analogical thinking, by contrast, produces creative leaps and imaginative connections, but without logical orientation or epistemological support, though it may have a potential pragmatic application. The relationships between logical and analogical thinking are not merely useful but a constitutive essence of human existence as intellectual beings, where intellect is understood as a Teleological Cybernetic Triad of Cognition, Conation (motivation), and Feeling (emotion)

In this sense, the dialectic between analogy and logic is what gives thought both direction and propulsion, adequacy and vitality, simultaneously creative and disciplined, inventive and accountable.

Actually, there are Analogical Logic and Logical Analogy:

- ***Analogical Logic*** refers to a mode of thinking grounded in analogy, where knowledge, structures, or relations from one domain are projected onto another due to perceived similarities. As a form of *ampliative reasoning*, it extends knowledge and/or understanding beyond what is explicitly given. Analogical logic is often at work, explicitly or implicitly, in *inter- and trans-disciplinary communication,* where insights from one field are mapped to another to foster integration and discovery.
- ***Logical Analogy***, by contrast, concerns the use of analogy *between logics themselves* or within logical and philosophical discourse. Here, the focus is on identifying structural similarities across different logical systems or reasoning frameworks. Examples include the analogy between Categorial Logic (rooted in natural language and Formal Predicate Logic). Another example may be the Formal Binary (Boolean) Logic, which is analogous to Propositional Logic, where the core analogies are a shared focus on *binary values and a direct correspondence between operators*. In general, formal logic, along with its different types (concerned with logical forms and inference validity) and informal logic (focused on reasoning quality and argumentation in natural language contexts), is often regarded as analogous.

1.1. Analogical Thinking and Reasoning,

An analogy compares two objects or systems by stressing perceived or conceived similarities, especially structural similarities.

Analogical reasoning is a subset, a type of analogical thinking that focuses on ***making logical inferences*** or judgments, whereas analogical thinking encompasses all mental activities based on analogy, whether or not they produce explicit conclusions or arguments. In other words, analogical reasoning is a more deliberate and inferential subset of the broader, more spontaneous domain of analogical thinking. Cognitive science research supports this distinction: analogical reasoning typically involves structural mapping and ***inference*** projection, while analogical thinking more generally includes other cognitive uses of analogy, such as creative insight and conceptual understanding. Holyoak & Thagard, for example, emphasize in (Mental Leaps, Analogy in Creative Thought, 1995) how analogical reasoning involves mapping relationships from one domain to another, and *distinguish it from* ***broader*** *analogical thinking.*

This means that analogical reasoning necessarily has the predicates of analogical thinking, but vice versa is not always correct. So, in logical terms:

- If something is analogical reasoning, it ***implies*** that it is analogical thinking, but
- If something is "analogical thinking," it does ***not necessarily imply*** **that it is** analogical reasoning.

Furthermore, analogical thinking necessarily has the predicates of Relational Thinking, but vice versa is not necessarily correct. Analogical thinking typically relies on ***relational thinking*** because forming an analogy requires recognizing relationships or correspondences between elements in different domains. In other words, to think analogically, we need to be able to identify and find the correspondence between relationships. However, not all relational thinking is analogical. From a Cognitive Science perspective, relational thinking can occur without making analogies, for example, noticing patterns, hierarchies, or correlations within a single domain, or reasoning about relationships abstractly without transferring them to another domain (Alexander, 2016). This author also describes the concepts of relational thinking and relational reasoning, explaining them in the context of human learning, and emphasizes the spontaneity of relational thinking and the more ***deliberate, effortful*** process of relational reasoning

Thus, in logical terms:

- If something is analogical thinking, it **necessarily involves** and then **i*mplies*** relational thinking, but
- If something is relational thinking, it **does not necessarily** involve or **imply** analogical thinking.

Analogical reasoning is any thought process that relies on the comparison of structural similarities. But an *analogical argument* makes this reasoning explicit, citing known similarities, including structural ones, *to suggest further ones*. These arguments usually fall under ***ampliative reasoning***, since their conclusions are not certain but vary in strength. An epistemological validation may use a logical system and provide the analogy as input to be logically processed. Here we should emphasize that this may be achieved via any kind of Logic or a combination of them. Consequently, what is usually required is paraconsistent logic.

Analogical reasoning is central to human thought (and possibly animal cognition), with a long history in problem-solving. Since antiquity, explicit analogical arguments have shaped scientific, philosophical, and legal reasoning. This discussion centers on their nature, evaluation, and justification, while also connecting to related themes such as metaphor, models in science, and legal precedent.

Analogical Cognition embraces all cognitive processes involved in discovering, constructing, generating, and using analogies. It is broader than analogical reasoning and analogical thinking.

Taken together, the perspectives that we started with in this section reveal that analogy is not an accessory to thought but one of its deepest structures. It shapes everyday reasoning, provides the scaffolding for scientific, engineering, and humanistic creativity, and informs the very ways in which meaning is constructed. Yet its long-standing ambivalent status reminds us that the generative power of analogy has often been underestimated, even though it remains central to the creation, communication, and transformation of knowledge across disciplines. Analogies typically serve as starting points and inputs for logical inference, a role that becomes especially significant in ampliative reasoning and, by extension, in epistemological knowledge construction. Briefly, analogy stands as a generative yet often undervalued foundation of human thought, essential for building bridges of understanding across domains.

Holyoak and Thagard (1995, Preface) note that *"analogy by its very nature freely oversteps the traditional boundaries between knowledge domains, making it possible to use ideas from one domain to achieve insight in another."* Consequently, analogical thinking functions as a way for inter-disciplinary knowledge transfer and as a powerful means of creative communication across disciplinary, non-disciplinary, and transdisciplinary contexts. Such transfer is essential for transdisciplinary research, which by definition requires, as a condition *sine qua non,* the involvement of diverse stakeholders, including, in many cases, laypersons, depending on the research context and its potential societal impact. So it seems evident that the pragmatic value of analogy.

1.2. Pragmatic Value of Analogical, Heuristic, and Conjecture Thinking

The notions of "analogy," "heuristic," and "conjecture" differ in denotation but may share connotations because they operate in a common holistic thinking process. Analogies often serve a heuristic role in guiding discovery and insight; heuristics act as practical strategies often supported by analogical reasoning; and both contribute to conjectures, which are provisional knowledge requiring validation. Their overlap reflects an intertwined cognitive process advancing inquiry and knowledge creation. These relations are frequently cybernetic, forming what we may call the Analogical Thinking Cybernetic-Triad. Figure 1 schematically illustrates this idea. As phenomena, these cybernetic relationships have supported human survival since the Neanderthal era[1]. The cybernetic notion and

[1] Neanderthals were highly intelligent and sophisticated humans with cognitive abilities comparable to modern humans, capable of complex tool use, art, symbolic behavior like burying their dead with care, and possibly even speech. The idea of Neanderthals as primitive brutes is a misconception based on outdated research; modern evidence shows they were **intelligent, adaptable, and culturally complex**, not a failed or inferior species.

concept are new, but as phenomena that characterize human beings.[2]

Human beings when confronted with new situations that need quick decisions and cannot wait for knowledge accumulation through a large period of time, they usually try to understand the new situation by means of previous experience and in terms of what already is known, even if such kind of connections require a "***mental leap***" based on analogies *as affirmed by* Holyoak and Thagard in (Mental Leaps, Analogy in Creative Thought, 1995). It seems evident that this has been happening since at least the Neanderthals and Homo Sapiens. Other animal species' survival depends more on instinct, while human beings are also equipped with analogical thinking.

In this context, humans differ from most other species in that while animals rely heavily on predetermined hard-wired neural nets for their instinctual survival behaviors, such as fight, flight, or freeze reactions, humans have developed more flexible cognitive systems.

These include analogical thinking and creative problem-solving, enabling them to adapt quickly to novel and complex situations by using experiences and learned knowledge rather than relying solely on innate instinctual responses. When there was no established and known knowledge, human survival depended on analogical thinking, especially in the context of the Cybernetic Triad of Analogy-Heuristic-Conjecture (figure 1). This evidently shows the pragmatic value of analogy, especially in our thinking, 1) providing input to heuristics and conjectures which, in turn, provide input to logical thinking.

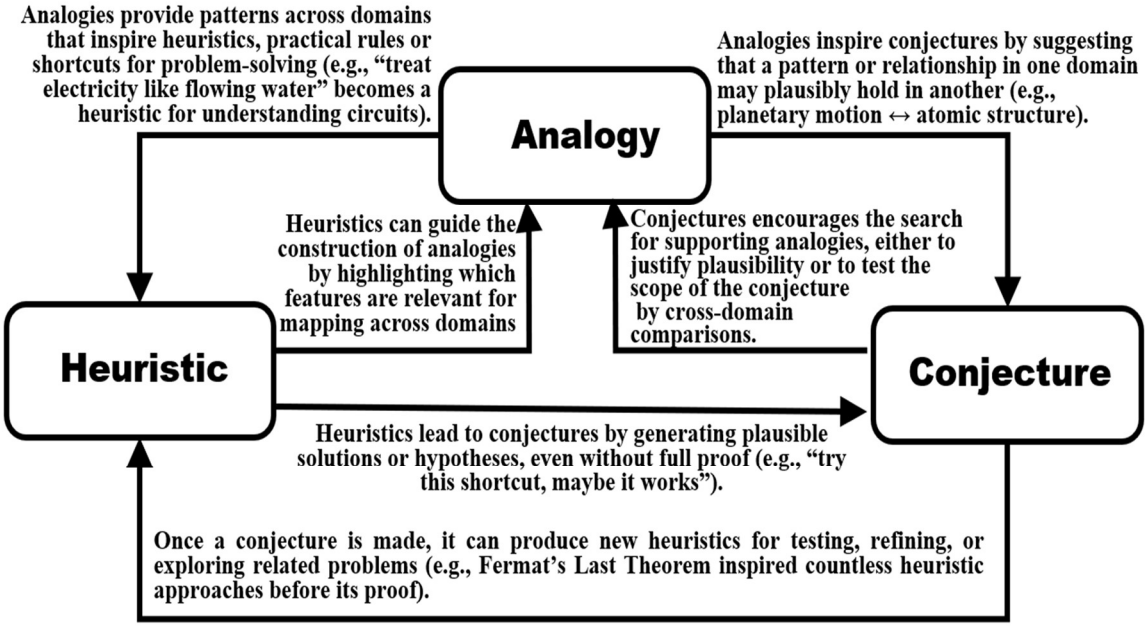

Figure 1; ***Analogical Thinking Cybernetic-Triad*** of mutual mutually reinforcing processes: analogies seed cross-domain patterns that heuristics operationalize into practical shortcuts, while heuristics in turn highlight salient features that guide the construction of more fruitful analogies; heuristics also generate conjectures by suggesting plausible yet unproven solutions, and conjectures reciprocally shape new heuristics for testing, refining, and extending inquiry; analogies inspire conjectures by proposing that a relation in one domain may plausibly apply in another, while conjectures encourage the search for supporting analogies to justify or probe their scope. In cybernetic terms, analogy is generative, heuristic is operational, and conjecture is aspirational, each providing feedback loops that correct, amplify, or redirect the others in a recursive cycle of reasoning.

[2] Probably, this may include early hominins, like *Homo habilis*, *Homo erectus*, and *Homo heidelbergensis*, leading to Neanderthals and modern humans.

Recent research in neuroscience and behavioral ecology supports that while animals show a range of mostly fixed neural nets for survival (Blanchard & Blanchard, 1989), humans possess advanced neural and cognitive architectures that combine instinct with higher-level processes such as mental simulation, metacognition, and analogical reasoning.

Gentner & Forbus, in (Computational Models of Analogy, 2011)[3] affirm that "In the past 25 years, this area [analogical reasoning] has progressed rapidly, fueled by strong collaboration between psychologists and Artificial Intelligence (AI) scientists, with contributions from linguists and philosophers as well."

(Penn, Holyoak, & Povinelli, 2008) highlights that although animals and humans share many continuities of mind, humans exhibit a unique capacity for higher-order, systemic, and relational cognition, required for analogical thinking, showing an important discontinuity between species. This distinction, aligned with Newell's concept of a physical symbol system, lies in the human ability to manipulate structured, relational representations rather than relying solely on perception or simple associations. Analogy exemplifies this capacity, as it requires perceiving structural similarities across different contexts beyond surface features. While the abstract does not explicitly mention analogy, its reference to "systematic, relational capabilities" clearly encompasses analogical thinking, which cognitive scientists like Dedre Gentner identify as the paradigmatic form of relational cognition. (Penn, Holyoak, & Povinelli, 2008).

1.3. Origin of Analogy

Relating different articles on "analogy" and those including the notion of "analogy", we noticed an important issue, related to a controversy regarding the origin of analogies, i.e., perceptual Vs. Linguistic analogies. Mitchell & Hofstadter, in (Analogy-Making as Perception: A Computer Model, 1996), provide an example of those who conceive analogy as based on perceptions. Aristotle also had this perspective. Paul Bartha in (Analogy and Analogical Reasoning, 2024). Aristotle drew parallels between the faculties of perception and thought, emphasizing that analogical thinking is fundamentally a process akin to perceiving relational patterns (Corkum, Attention, Perception and Thought in Aristotle, 2010)

On the other hand, some authors affirm that analogy started with language. Ernst Cassirer (1965) and W.V.O. Quine (1960) have proposed that analogy is fundamentally linked to language development, with some arguing that analogy, in a broad sense, is an essential prerequisite for language itself (***and vice versa***). In this view, analogy is not just a figure of speech but a core cognitive process that enables learning, comprehension, understanding, and evolution of language.

Ernst Cassirer (1965) in The Philosophy of Symbolic Forms, Volume 1, thinks that **analogy is intrinsic to language as a symbolic form,** facilitating the transformation of raw perception into shared meaning and cultural knowledge, which is basic and necessary to human cognition. Relating "language with analogy," we may paraphrase him as follows: "Language is not simply a system of signs; it is a symbolic form that shapes human experience. It functions through analogical and metaphorical processes to create meaning. Through language, what is immediate and perceptual is transformed into a stable, shared conceptual world. This process of symbolic mediation allows humans to relate different experiences by recognizing analogical relationships, enabling abstraction and the formulation of universal concepts. Language thus emerges from and extends earlier symbolic activities, such as mythical thought, by organizing experience via analogy.

He affirms that

> "Analogical expression, unlike mimetic [caused by perception], no longer attempts to reproduce a given perception but seeks to establish a relation of similarity. Yet this relation remains bound to perception, whereas symbolic expression introduces a new dimension: here the *connection of sign and meaning becomes independent of immediate perceptual likeness."* (Cassirer, 1965, pp. 34-35)
>
> "*In language, analogy plays a decisive part*: words often arise not by direct designation but through extension from an already given name to a new case by similarity of function or form." (Cassirer, 1965, p. 37)
>
> "The analogical function forms the indispensable bridge between mere perceptual resemblance and the conceptual relations fixed in linguistic symbolism." (Cassirer, 1965, p. 40)

Willard Van Orman Quine, in (Word and Object, 1960), thinks that analogy is embedded at the heart of language, both in acquiring meaning from experience and in the flexible, creative adaptation of language to new contexts.

[3] Dedre Gentner and Kenneth Forbus (2011) review the development and contributions of computational models to understanding analogical cognition. They describe how models, largely based on Gentner's structure-mapping theory, have enhanced our understanding of analogy's core subprocesses: retrieval, mapping, abstraction, and re-representation. *The review highlights the importance of structural alignment in identifying correspondences and the challenges in modeling* ***flexible cognition***.

His philosophy makes *analogy foundational for the structure, learning, and extension of linguistic behavior. For example,* language users use language structures like "The ---- is red" and ***extend them*** *to new domains by analogy*. These very simple kinds of examples are among those that support the idea of how ***analogical thinking arises as a consequence of language***, which is Quine's perspective on language as the base of analogies and analogical thinking.

We may propose a mediation in this controversy by suggesting that there is no reason to reduce the origin of analogies to a single source. Analogical thinking may stem from two or more origins (perception, language, etc.) since it is grounded in human cognition. In this sense, we can even conceive a cybernetic relationship between the two sides of the debate. Both perspectives are not necessarily contradictory; rather, they may complement each other, or, like polar opposites, even require one another. Consider, for instance: (1) the North and South Poles, which generate the electromagnetic fields guiding the movement of animal species and orienting humans via the compass; and (2) positive and negative electrical charges, whose tension allows electron flow and, consequently, electrical current. In a similar way, perceptual and linguistic perspectives on the origins of analogy may complement one another, driving cognition precisely through their opposition. Opposition, after all, does not imply contradiction. On the contrary, it may reveal a cybernetic relationship, a possibility we will further suggest below.

At this point, an important insertion is needed for what follows regarding the origin of analogy, which lies at the center of the controversy. We must briefly recall its historical origin, as well as its manifestation in individual human beings. This dual reference will provide an analogical parallel and a necessary foundation for the reasoning that will follow, thereby strengthening our case: namely, that the two perspectives represent opposing, but not contradictory, views that are cybernetically related.

1.3.1. Analogies Between Historical and Individual Origins: The two sides of the controversy may be related ***cybernetically***, especially if we adopt a well-known heuristic: the analogy between *ontogeny*[4] *and phylogeny*[5], as expressed in the *"recapitulation theory,"*[6] i.e., *ontogeny recapitulates phylogeny*. It is important to note that here I deliberately use the notion and the word ***'analogy'***, and not *'isomorphism,'* as some interpretations have implicitly suggested, let alone *"law,"* as Ernst Haeckel (1876)[7] himself described it when formulating what became known as the (Haeckel-Serres) or the (Merkel-Serres) Law[8]. The distinction we just made matters: analogy refers to a comparison based on certain similarities between objects, processes, or systems, whereas isomorphism implies a strict one-to-one correspondence in which all structural relations are preserved. The latter is not what Haeckel and Serres intended to communicate. They explicitly described a ***"rapid and rough" recapitulation*** of evolutionary stages, ***not an exact reproduction***. This is why we prefer to speak of an '***analogy'***, while other authors have referred to it as a ***"useful heuristic."*** From a ***systemic perspective***, however, any of the three terms: analogy, heuristic, or conjecture (Figure 1) may be used, especially since they ***mutually influence one another*** and their connotations intersect each other. *Analogy can be considered the most general of the three and potentially the* ***most holistic and systemic****.* This broader functionality may explain why we interpret Haeckel's formulation as an *analogy*: it better accommodates diverse purposes and aligns with a ***pragmatic–teleological conception of truth*** within the Systems Approach. In this context, analogy becomes the most systemic notion, consistent with the Systemic Truth and coherent with the general perspective and purpose of this article.

[4] Ontogeny means Development of an individual organism.

[5] Phylogeny means evolutionary history of a species.

[6] Recapitulation theory asserts ontogeny mirrors phylogeny. The original phrase was "ontogeny recapitulates phylogeny", hence the name of "recapitulation Theory"

[7] Ernst Haeckel (The Evolution of Man: A Popular Exposition of the Principal Points of Human Ontogeny and Phylogeny, 1866; English ed. 1876) is a prominent 19th-century German biologist and a ***major champion of Darwin's theory in Europe,*** attempted to create a unified theory of evolution but did not have in his time heredity Mendelian genetics. But, he has the needed insight and the analogical thinking effectiveness to approach a subject to offer a very detailed conjecture about what later was called "Modern Synthesis of evolutionary theory" thanks Mendel's hereditary findings. This essential missing piece was later provided by discoveries in genetics, which became a cornerstone of the Modern Synthesis decades after Haeckel's death in 1919.

[8] This was named Law because then, the meaning of the word "law" included the sense of conception or concept related to the description of observed phenomena. Two designation were used for this law: (Haeckel-Serres) or (Merkel-Serres) Law. The reason is the following: Johann Friedrich Meckel and Antoine Étienne Serres independently developed the core ideas behind the "Meckel-Serres law" in the early 19th century. Though they did not collaborate, their work on comparative embryology and malformations was later synthesized by other scientists. The law is a version of recapitulation theory, divulgates by Haeckel and which proposes that higher organisms' embryos pass through successive developmental stages that resemble the adult forms of lower organisms

In a few words, Ernst Haeckel's 19th-century biogenetic law stated that the development of an individual organism (ontogeny) repeats or summarizes the evolutionary history of its species (phylogeny). While the idea has initially and largely been considered an oversimplification (because, let us reiterate, it was misinterpreted as isomorphism and not as analogy), it actually pointed to a fundamental connection: the early stages of vertebrate embryos do share characteristics with ancestral forms. This is an effective example of analogies and analogical reasoning. Actually, modern evolutionary biology acknowledges that developmental pathways can provide insights into evolutionary history, but ***it's not a literal replay of ancestral adult forms***. Ernst Haeckel's analogy is a very effective example of "analogy" and "analogical thinning" as providing efficacious input to heuristics and conjectures (Figure 1) and hence, providing input to Logical Thinking for their respective validation.

The above misinterpretation we referred to has been discredited, Haeckel's analogy has been rehabilitated because of two main reasons, both in the field of biology:

1. From the perspective of the Systems Approach (also born in the field of Biology), the reasoning provided to discredit the "**Recapitulation theory" has, in turn, been discredited, because Biology presented a new perspective of organic systems as *systemic rather than systematic*. This helped *save the truth kernel* of** Haeckel's perspective and co-supported the expansion of the Evo-Devo[9] (evolution-development) movement in Biology to an intellectual movement.
2. In Biology, the Evo-Devo is considered a new paradigm that challenges and expands upon the traditional Modern Synthesis of evolutionary theory[10].[i] By integrating developmental biology with evolutionary biology, Evo-Devo has broadened scientific perspectives on how biological form originates and changes over time. This new paradigm is, in Biology, among other things, with discovering and understanding the role of changes in developmental mechanisms in the evolutionary origin of aspects of the phenotype[11]. This field connects a single organism's developmental processes to the evolutionary changes that occur across generations by uncovering how alterations in the timing[12] or location[13] of developmental events. By studying the relationships between genes and environment, Evo-Devo aims to explain the origin of biological diversity through the fundamental process of development itself.

The Evo-Devo Biological and Intellectual movement has been influential in developmental biology and psychology, *not as a validated law but as a heuristic* that highlights parallels between individual development (ontogeny) and species evolution (phylogeny). In cognition, it supports the analogical thinking needed to understand how early perceptual analogies in infancy form the basis for later linguistic analogies, mirroring (via analogy and not via isomorphism) within an individual the evolutionary progression of human analogical reasoning. In this way, both author and reader are invited to exercise analogical thinking as a means to approach what is still epistemologically[14] unknown.

Let us recall that axioms are not knowledge in the sense of justified or verified belief; rather, they offer the conceptual grounding from which knowledge can be generated, namely, the theorems that can be deduced from them. Accepting such theorems rests on our ***understanding*** of axioms that, while not proven, remain intelligible and provide the starting point for linear logical thinking.

A well-known heuristic in this regard is the mentioned analogy between ontogeny and phylogeny, presented in the recapitulation theory, i.e., "ontogeny recapitulates phylogeny." Although its strict biological form has not been validated, it continues to be valuable as a heuristic, one that both nurtures and is nurtured by analogy and conjecture (see Figure 1).

At a macro level, the following would be the sequence, relating perception with linguistic analogies, which make them complementary with each other instead of being contradictory, which has been the seed for the present controversy regarding the origin of analogies.

[9] "Evo-Devo" means evolution from development: it is the scientific field that study of how changes in development lead to changes in evolution

[10] The Modern Synthesis is the fusion of Darwinian evolution and Mendelian genetics. It combined natural selection with new discoveries about heredity, population genetics, and mutations to create a unified theory of how evolution occurs. This is what Ernst Haeckel tried to do but he did not have, in his time, the new discoveries about heredity

[11] The term "phenotype" refers to *the observable physical properties* of an organism; these include the organism's appearance, development, and behavior.

[12] Alterations in the timing are called "heterochrony", i.e. alterations in the timing of developmental events during evolution, leading to changes in the shape or size of an organism.

[13] Alterations in the spatial positioning of a structure or developmental process during evolution because of different locations is also called "heterotopy".

[14] Epistemological knowledge is a "justified belief" via at least one logical process. This is an example, here, of analogical thinking providing input to logical thinking. The latter would provide the required justification to transform the analogy in an epistemological knowledge,

1. *Perceptual Analogies:* (prelinguistic) characterize the pre-language history of human beings (e.g., "This object moves like that one"), prelinguistic infants, as well as some animal species, for example, chimpanzees and dolphins (Tomonaga, Uwano, & Saito, 2014)[15].

2. Examples: "This object moves like that one"; Direct, embodied, sensory-based, etc. Output: Immediate adaptation or reaction only.

3. *Prelinguistic Analogies*: Emerging words as handles for *relations, hence, transfer across contexts becomes possible.* Examples: Emerging words as handles for relations; "Big vs. small," "above vs. below"; Transfer across contexts becomes possible

4. *Fully Linguistic Analogies:* Structure-mapping across abstract domains; Metaphors & models", e.g., Atom ~ Solar System"; enables science, law, philosophy, cultural myths by being input to logical thinking; and analogies become transmissible & cumulative for knowledge construction.

5. *Meta-Analogies*: Analogy applied to analogy (recursive insight)
   - Cybernetics, systems theory, philosophy
   - "Reasoning is like computation."
   - Feedback loops create knowledge paradigms.

6. ***In all the above steps, there are Feedback Regulation and/or Amplification***

Figure 2 shows a diagrammatic sketch of what we are trying to convey. As it may be noticed in this diagrammatic visualization, it is not evident what THE origin of Analogy is, because it depends on what kind of analogy we are referring to. Perception is based on analogy as well as language analogy and the intermediate analogies, described above and visualized in the Diagram of Figure 2. The intention of this diagram is also to visualize the cybernetic relations that exist between the different kinds of analogies, and especially the highlighted ones between Perception and Language, which are at the center of the controversy. How may we refer to any origin in the context of cybernetic relationships?

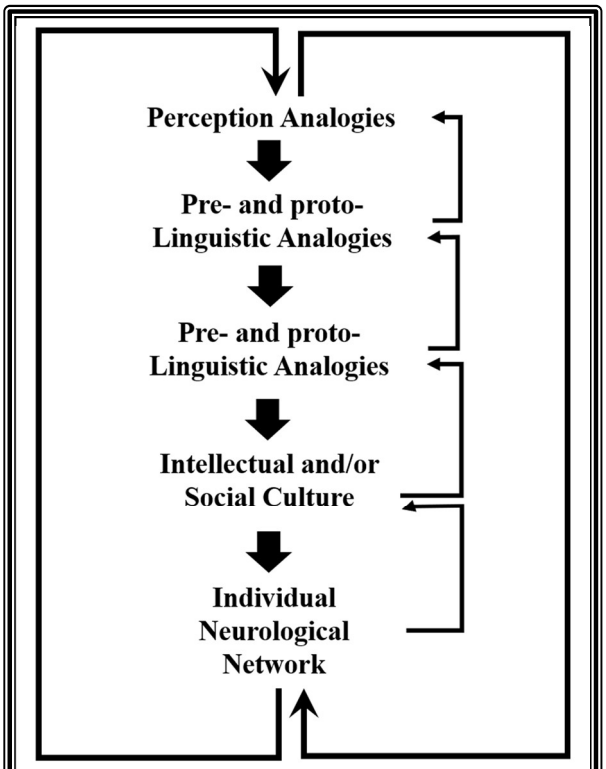

Figure 2. Cybernetic relationships between Perception and Language, as well as between each two of the intermediate phases as observed in ontogenetic (individual human beings) and phylogenetic (Human History)

Let us now focus on a more holistic cybernetic relationship between "Perception Analogy" and 'Linguistic Analogy', which would solve the existing controversy. In a few words, we may conclude that "Perception Analogy" has a biological origin that relates the exterior with the interior of a neurological network, while the neurological system is the fundamental generator of both: perceptual and

linguistic analogy and mediating between them as it is the case of our neurological systems, differentiated among individuals by their previous experiences, includes justified and not justified believes. It relates the ***internal***

[15] The authors affirms having "tested dolphins on a visual-matching task using two-dimensional geometric forms including various features. Based on error patterns, we used multidimensional scaling to analyze perceptual similarities among stimuli. In addition to dolphins, we conducted comparable tests with terrestrial species: chimpanzees were tested on a computer-controlled matching task and humans were tested on a rating task. The overall perceptual similarities among stimuli in dolphins were similar to those in the two species of primates. These results clearly indicate that ***the visual world is perceived similarly by the three species of mammals, even though each has adapted to a different environment and has differing degrees of dependence on vision***." [Italics and bold added]

and external worlds, while also relating just the internal world via neurological processing during thinking, be it analogical or logical.

1.3.2. The Dual Connotation of the Word "origin": Hermann von Helmholtz (*Selected Writings of Hermann von Helmholtz*, 1971) and Richard Gregory (*Knowledge in Perception and Illusion*, 1997) both proposed theories of perception as an *inferential process*: for Helmholtz, as *unconscious inference*, and for Gregory, as *hypothesis testing*. These belong to the family of constructive or inferential theories of perception, which hold that the brain actively constructs perceptions by applying prior knowledge and experience to interpret ambiguous sensory data. In both cases, inference and hypothesis formation rely fundamentally on analogies. Using recent terms, it is the ***evoked set*** what sense data what generate from our memory. This term and notion have been coined by Howard & Sheth (1969), and C. West Churchman divulged this notion and phrase in the Systems Approach intellectual movement by at least three of his books (1968), (1984), and (1971). In the context of the systems approach perception's "evoked set" is by the sense data as dynamic, context-dependent subset of options or elements cognitively or systemically activated by the respective sense data; i.e., from the vast amount of sensory input, a perceptual system or mind selectively activates a manageable subset of relevant elements or possibilities (the evoked set) based on the current context and cognitive processes. This activation may allow for different interpretations in different persons or even in the same individual in different objective situations and/or subjective contexts.

This perspective illustrates a ***Developmental Dynamics or a temporal sense*** of the phrase or notion "***perception origin****"*. On the other side of the above-mentioned controversy (regarding the origin of Analogy), the word "*origin"* is understood in a ***structural or logical sense***, i.e., as a foundational principle rather than a chronological process. This contrast offers a clear example of the difference between **chronological (temporal)** and **logical (atemporal)** interpretations of the n notion of "origin". The ambiguity of this term, thus, exemplifies a broader pattern: many controversies in philosophy and science arise, or may arise, from shifting or conflated senses, denotations, or connotations of fundamental words.

Seen in this light, the debate over whether analogy originates in perception or in language reflects less a substantive intellectual contrast or divergence than a difference in what sense of *origin* is being invoked. i.e., a developmental precedence versus a structural foundation. ***This duality mirrors the cybernetic nature of the brain itself: temporal feedback loops operate <u>dynamically</u> in perception and cognition, while the neurological network provides the <u>structural</u> and compartmentalized foundation that supports and constrains those processes.***

From this perspective, a way forward is to propose a ***layered conceptual structure*** (Figure 2) modeled on the brain: the structural layers of the neural network provide the enduring foundation, while ***reiterative cybernetic loops***, temporal by definition, generate and refine cognition through feedback and adaptation. ***Integrating these two dimensions, structural layering and temporal looping (Figure 2) offers a more coherent framework for resolving the ambiguity of "origin" and for understanding analogy as both rooted in structure and dynamically emergent over time.***

So, it seems highly plausible that analogical thinking and reasoning allowed humans to optimize survival beyond instinct alone and respond adaptively to environmental and social complexities.

The younger human beings are the more frequently they need to make these mental leaps, because they face more novel situations with a smaller pool of known situations. Similar situations may be associated with the initiation process of Homo sapiens.

The younger human beings are, as individuals and as a species, the more they need to know about new situations by means of what they already know, and the more active they are in constructing their world. *A similar situation might happen with new knowledge domains or disciplines. The younger a knowledge domain, or a discipline, the more it might be nurtured from previous knowledge domains, or older disciplines*. ***Since non-disciplinary knowledge usually precedes disciplinary knowledge,*** analogies based on non-disciplinary knowledge might be very effective for generating conjecture[16] production, hypothesis formulation, or even for theory creation in the context of disciplinary knowledge. Conjectures are critical in both everyday and scientific reasoning, where insight and analogy guide the search for knowledge before certainty is reached. Analogies may be considered as a kind of ***epistemologically incomplete knowledge***. The Mathematician George Polya affirms in (How to Solve it, 1957) that "analogy" is "an important source of conjectures. In mathematics, as in natural and physical sciences, discovery often starts from observation, ***analogy***, and Induction." [Italics and bold added]

[16] A **conjecture is a guess (based usually on analogies or insight) without proof or a supposition based on incomplete evidence. So, conjectures are analogies that provide input to logical thinking, be it inductive, deductive, abductive, mean-ends, etc. logics.**

2. EPISTEMOLOGICAL KNOWLEDGE GENERATION VIA ANALOGY, HEURISTIC, CONJECTURE (HYPOTHESIS)

In this section, we will brief description of the usual process that starts with analogy for the generation of epistemological knowledge, i.e., justified or verified knowledge.

As we showed, with some details above, an analogy, an incomplete epistemological knowledge, provides logic of the required input to start a logical process, mainly via heuristic and conjectures or hypotheses (Figure 1), which may generate epistemological knowledge, i.e., justified or validated knowledge, via Deductive, Inductive, Abductive, Para-Consistent, Means-Ends, etc. Logics.

2.1. Epistemological Knowledge Generation

The process of epistemological knowledge generation usually begins with an analogy, based on incomplete information that is used as a heuristic or mental shortcut to provide an initial logical framework for forming hypotheses or conjectures.

This process starts with an analogy that uses a *familiar situation, called the "source" domain, to reason about a less familiar "target" domain.* The analogy allows for inferences about unknown properties based on similarities to known properties, but relies on incomplete knowledge since it highlights only some similarities without guaranteeing the truth of the conclusion.

The analogy then acts as a heuristic, offering rules of thumb or mental shortcuts that suggest a plausible course of research, investigation, or thinking, and enable a logical process to begin without having a complete understanding. Based on the heuristic, specific testable propositions or hypotheses are generated (also by analogical processes), positing that *because two things share some similarities, they might also resemble each other in another way.*

The logical process then moves to testing and refining these hypotheses, where initial conjectures are subjected to rigorous validation, modifying or discarding them if results are inconsistent with the analogy. When hypotheses withstand scrutiny, they become validated or justified knowledge with confidence strengthened by the relevance and degree of similarity between the domains considered, including their differences.

An illustrative example is the discovery of the synthetic compound meperidine (Demerol), where a 1934 pharmacologist noted its chemical similarity to morphine, forming a potentially incomplete analogy. The heuristic "rule of thumb" was that similar compounds often have similar effects led to the hypothesis that meperidine could mimic morphine's narcotic effects. Testing on animals showed specific reactions consistent with morphine's effects, strengthening the hypothesis and ultimately leading to validated knowledge that meperidine is an effective painkiller in both animals and humans. This example showcases how an initial analogy can serve as a heuristic starting point that generates a hypothesis or conjecture for the logical process that leads to the generation of new epistemologically justified knowledge: "analogy", "Hypothesis" or "Conjecture", and "Heuristic" are different.

The meanings of 'analogy' and 'conjecture' differ but intersect. Analogy primarily refers to a relational structure of comparison, where similarities between two domains are identified, while conjecture is a provisional epistemic claim, representing a potential or tentative epistemological knowledge statement. Their intersection lies in the concept of analogical conjectures, i.e., conjectures based on perceived structural similarities. This indicates that the meaning of analogy overlaps with, but does not reduce to, the meaning of conjecture, and vice versa. A comparable relationship exists between 'analogy' and 'heuristic': analogy is the product of an analogical thinking process (where similarities are identified), while heuristic refers to the use of this analogy as input within reasoning or thinking processes that may generate hypotheses or conjectures. Thus, these three concepts (analogy, conjecture, and heuristic) are cybernetically related processes and products (Figure 1). Analogy provides the comparative structure, heuristics utilize this structure to guide thinking and discovery, and conjectures represent provisional knowledge claims emerging from that reasoning guided by analogy. This reflects a deeper epistemological interplay where analogy acts as the foundation for hypothesis formation, heuristics direct the investigative process, and conjectures embody the tentative claims that may eventually become justified knowledge.

Let us now integrate a summary of the most important articles, on which the above and the below texts are based. This integration intends to combine a bottom-up approach with a top-down presentation.

2.2. Integration of, Potentially, the Most Important Perspectives

The ***Stanford Encyclopedia of Philosophy*** entry on analogical reasoning underscores that this mode of thought involves the mapping of relational structures from a familiar source domain to a less familiar target domain, in order to establish plausibility or warrant for conjectures (Bartha, 2024) Unlike logical reasoning, which guarantees conclusions, analogy is potentially *ampliative*: it extends knowledge by proposing possible inferences that go beyond what is strictly contained in the uncertain premises of the process This ampliative character explains importance of analogical thinking in science, philosophy, engineering, law, etc. The encyclopedia stresses that analogical reasoning can support either probabilistic or

modal conclusions[17], and that criteria such as ***causal relevance***[18], the richness of shared structure, and the ***absence of critical "disanalogies"*** (differences undermining the mapping) are central in assessing the strength of an analogy. Cognitive studies by Dedre Gentner[19] elaborates this point through ***structure-mapping theory***, which frames analogy as a process of alignment and projection of structural knowledge between domains. This allows for the inference of a potential new knowledge, while constraining what is inferred to preserve cognitive plausibility. The entry also revisits ***Aristotle's early reflections on analogy***, the formal structure of analogical reasoning, and the criteria for evaluating analogical strength, situating analogy as a cornerstone of human inquiry.

Gentner and Jeziorski's (Analogical Reasoning and Conceptual Change: A Case Study of Johannes Kepler, 1977) exemplifies the transformative power of analogy in scientific thought. They show that Kepler's revolutionary causal theory of planetary motion emerged through extended analogical reasoning. Their analysis introduces four mechanisms, ***highlighting, projection, re-representation****, and* ***restructuring****, by which analogy facilitates knowledge change.* Situated within structure-mapping theory and computationally implemented in the ***Structure-Mapping Engine (SME)***[20], these mechanisms demonstrate how analogy is not merely a heuristic shortcut but a driver of ***conceptual innovation***. The Kepler example illustrates how analogical reasoning can bridge descriptive models and causal explanations, thus reshaping entire domains of knowledge.

In the legal sphere, Cass R. Sunstein's (On Analogical Reasoning, 1993) reminds us that analogy is not confined to science or philosophy but is also ***the backbone of legal reasoning***. Sunstein opens by noting: *"Reasoning by analogy is the most familiar form of legal reasoning. It dominates the first year of law school; it is a characteristic part of brief-writing and opinion-writing as well."* Yet, paradoxically, legal scholarship has often marginalized it, sometimes even dismissing it as unconstrained or not a "real" form of reasoning. This ambivalence reveals a tension within jurisprudence: the practice of law depends heavily on analogical reasoning (precedent, case comparison), but its theoretical status remains contested. Sunstein's contribution was to rehabilitate analogy in legal reasoning by showing that it operates with implicit norms of coherence and constraints, giving the legal system a way to adapt past rulings to novel cases.

The broader question of ***heuristics*** is closely related. Hjeij and Vilks, in (Brief history of heuristics: how did research on heuristics, 2023) they describe heuristics as rules of thumb that accelerate decision-making processes, including those in research contexts. Heuristics appear across economics, psychology, computer science, and operations research. Despite their diversity, scholars still lack a firm conceptual common ground. A promising unifying view sees heuristics as ***adaptive and simplified procedures*** that guide decision-making under conditions of limited information, scarce resources, or uncertainty. From this angle, heuristics can be conceived as ***cybernetically adaptive strategies***: they optimize the fit between goals, resources, and uncertainty, much like operations research methods along with their *heuristic mathematical algorithms*. This integrative perspective connects heuristics with *systemic and cybernetic notions of* ***rigor***, as articulated by Callaos and Marlowe's (Interdisciplinary Communication Rigor, 2020) and Callaos' (The Notion of Intellectual Rigor: A Systemic/Cybernetic Approach, 2020), generalizing the concept of rigor as to include intellectual, musical, sport, and even religious domains. The parallel to analogical reasoning is clear: *both heuristics and analogies are strategies for navigating bounded rationality by balancing efficiency, plausibility, and adaptability.*

Holyoak and Thagard, in (Mental Leaps, Analogy in Creative Thought, 1995), further reinforce this view by situating analogy at the heart of creativity. They argue that analogy is not a peripheral cognitive tool but ***a fundamental mechanism*** by which people learn, solve problems, and generate new ideas. By reframing the world not only in terms of objects but in terms of ***relationships between them***, analogy allows for mental leaps that connect disparate domains, fostering innovation and discovery.

In the educational field, Robert Morrison, in (Analogical Reasoning, Models of Development, 2013) reviews two major perspectives on the development of analogical reasoning. The first, known as the **relational knowledge perspective**, is associated with Usha Goswami (Analogical Reasoning in Children, 2001) and Dedre Gentner (Metaphor Is Like Analogy, 2001). It holds that

[17] Modal conclusions are expressed using modal verbs like must, have to, and have got to. These deductions can refer to the present (e.g., "She must be rich") or the past (e.g., "She must have studied

[18] Causal relevance means to determine if one variable, event, or piece of information is a genuine cause of another, rather than just a correlated factor. This is distinct from simple statistical correlation, where two things may be related without one directly influencing the other

[19] (Gentner, Bowdle, Wolff, & Consuelo, 2001) (Gentner D. , Structure-mapping: A theoretical framework for analogy., 1983)

[20] Computational system, developed by researchers including Dedre Gentner and Ken Forbus, (Gentner & Forbus, Computational Models of Analogy, 2011) that models human analogical reasoning by implementing the Structure-Mapping Theory of analogy

as children accumulate knowledge in specific domains, their analogical reasoning evolves from simple, feature-based comparisons to sophisticated analogies grounded in abstract relationships, a process often called the ***relational shift***. Crucially, this evolution depends less on chronological age than on the depth and breadth of acquired content knowledge. The second perspective, advanced by Morrison himself and others, emphasizes the ***maturation of executive functions,*** especially inhibitory control. From this view, young children fail relational analogy tasks not because they lack relational knowledge per se, but because they struggle to suppress distracting surface features. Development, therefore, is partly a matter of strengthening cognitive control processes that allow children to focus on abstract relational similarities. These two perspectives *are not mutually exclusive*: both domain-specific knowledge and executive functions likely contribute to developmental improvements, shaping the trajectory of analogical reasoning in distinctive but complementary ways.

Summarizing, the integrative notions supporting the above are:

- *Ampliativity:* Analogy extends knowledge beyond premises.
- *Computation:* Analogical reasoning can be modeled (SME).
- *Normativity:* Law shows analogy is not unconstrained but guided by systemic norms.
- *Bounded Rationality*: Both analogy and heuristics function as adaptive strategies under constraints.
- *Creativity*: Analogy fuels innovation by reframing relations.
- *Development*: Cognitive growth depends on the interplay between domain knowledge and executive function.

Bringing these perspectives together, analogical reasoning may be revealed as an inter- or even a ***transdisciplinary bridge motion.***

- In philosophy, it grounds ampliative reasoning (Bartha).
- In psychology, it explains cognitive development (Goswami, Gentner, Morrison).
- In law, it structures reasoning by precedent (Sunstein).
- In decision sciences, it unifies heuristics and cybernetic strategies (Hjeij & Vilks; Callaos).
- In creativity research, it underpins innovative leaps (Holyoak & Thagard).

Across these domains, analogy is not a side-process but a **meta-cognitive process, tactic, and strategy**; it is a way of creating, re-creating, and reorganizing knowledge by mapping structures, highlighting patterns, and bridging gaps. It fosters conceptual changes, supports decision-making under uncertainty, and enables scientific as well as technological, humanistic, and cultural creativity.

Analogy does not have just transdisciplinary application like mathematics, but it is also a transdisciplinary communicational means. Actually, it is via analogies and natural language that transdisciplinary communication may be feasible. Being a natural language, historically previous to disciplinary languages, is what makes it a solid bridge for analogical thinking and, hence, for transdisciplinary communication. To effectively communicate across different academic fields or disciplines, people rely on analogies and natural language. This is because natural language provides a shared foundation that allows for the creation of analogies, which can then be used to explain complex concepts from one discipline to someone in another.

We may briefly describe the support provided by analogy and natural language via a usual process of transdisciplinary communication:

1. *Identification or emergence of a problem:* when it is a complex problem, for example, public health, it requires knowledge and experience from multiple disciplinary or interdisciplinary fields

2. *Use natural language to frame the problem***:** The problem is initially discussed and understood using the common ground of natural language, allowing experts from different fields (e.g., biology, sociology, economics) to engage, via implicit natural language analogies.

3. *Employ analogical thinking***:** Experts then use explicit analogies to share their specialized knowledge. For instance, a biologist might use an ecological analogy to explain a complex system to an economist.

4. *Co-produce new knowledge***:** Through this analogical communication, participants from various fields co-create new understandings that transcend the boundaries of their original disciplines. This means that natural language supports the transdisciplinary communication of the problem via effective analogies because natural language is historical, what is common to communicate and get communicated. Once the problem is known, natural language allows transdisciplinary communication using explicit analogies between different knowledge fields via analogies between different knowledge fields and/or between fields and natural language.

This process shows how natural language and analogy are not just passive tools but active mechanisms for generating new insights and fostering genuine collaboration across knowledge domains.

3. ANALOGICAL AND LOGICAL THINKING INTERSECTION AND CYBERNETIC RELATIONS

With the intention of relating the above with this last section, let us very briefly summarize what the notion of Analogy is in the context of relating it with Logical Thinking via 1) cybernetic relationships and 2) both notions[21] intersecting each other.

As we addressed with more details, *Analogical Thinking*, or reasoning by *analogy,* is the mental process by means of which we explore connections between very different domains, trying to understand what is not known by means of what is known, to comprehend what is not familiar through what is already familiar. The known domain is named the *source analog*, because it is actually the source of the analogy, and the relatively unknown one is the *target analog*. Analogical Thinking is not "logical" in the sense of formal deduction or experimentally based induction. But it is a process of reasoning or thinking where the source domain *constrains* the mental process. This is why some authors consider that Analogical Thinking is based in some kind of logic that they propose to name as *analogic.*

Aristotle's Theory of Syllogism (in *Prior Analytics*) is frequently considered the origin of Modern Logic. But, he also presented a Theory of Analogy (in *Poetics*), which he used in *practice*-oriented thinking, especially in ethics (in *Nichomachean Ethics*), to which we may also add scientific and engineering *practice*. Hence, some authors interpret that *Aristotle believed that logic and analogy are both valid forms of thinking.* But today, many authors consider Logic as primary, and analogy can be, or should be, reduced to logic. In this sense, analogical thinking is accepted as legitimate as long as it is part of logical thinking (Figure 3). In this context, logical thinking about analogical thinking has been used to work out different models of analogical thinking, which support computer algorithms made with the purpose of implementing Analogical Artificial Reasoning. An example of this approach can be found in Davis and Russell (A Logical Approach to Reasoning by Analogy, 1987)But, there are also opposite perspectives, i.e., regarding Analogical Thinking may contain Logical Thinking (Figure 4) or vice versa (Figure 3)

(Thagard, 1989), for example, views analogy as a form of logical reasoning (Figure 3) , integrating it into a broader framework of coherence computation.

From an opposite perspective, Sowa and Majumdar in (Analogical Reasoning, 2003), for example, suggest that logic is a specialized subset of analogical reasoning, emphasizing the foundational role of analogy in logical processes (Figure 4). They affirm, "***formal logic is actually a highly constrained and stylized method of using analogies."*** Before any subject can be formalized to the stage where logic can be applied to it, analogies must be used to derive an abstract representation from a mass of irrelevant detail. After the formalization is complete, every logical step —of deduction, induction, or abduction— involves the application of some version of analogy." (p.16) [Italics and bold added].

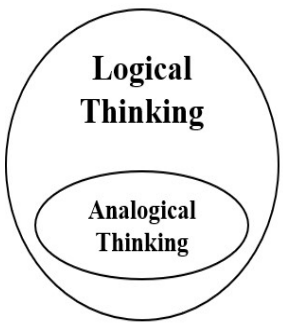

Figure 3

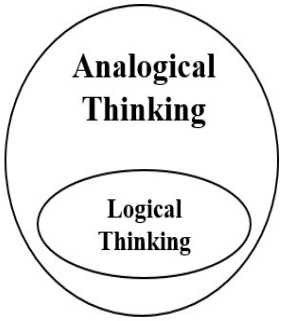

Figure 4

We propose, from a *systemic* and *non-reductionist* perspective, that Logical and Analogical Thinking might be conceived as complementing each other in regulative and co-reinforcing cybernetic loops, by means of negative feedback, feedforward, and positive feedback (Figure 5).

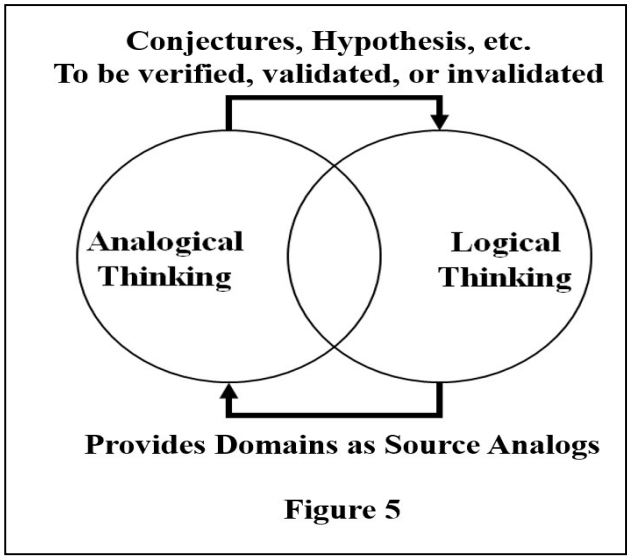

Figure 5

We are using the word "logic" in its more general meaning: inference or the study of inference (the act or process of deriving conclusions from premises); which

[21] In (Callaos, the Notion of 'Notion', 2013) we concluded that, linguistically, notion is a related or relatable set of senses (denotation and connotation) of a term. This set might be a Fuzzy set, so a notion may be a Fuzzy System.
.

includes the 4 notions distinguished by Thomas Hofweber (2004) in the Stanford Encyclopedia of Philosophy, i.e.

- "The mathematical study of artificial formal languages,
- the study of formally valid inferences and logical consequences,
- the study of logical truths,
- the study of the general features, or form, of judgments."

Thomas Hofweber in (Logic and Ontology, 2004/2023) presents 4 kinds of Logics [ii], which are categorized by what they study: Formal Languages, Valid Inference. Logical Truths, Form of Judgment, and concludes that "there are many ways in which [these four notions of Logic] are connected, and many in which they are quite different." Because it is not our objective, in this article, to adhere to any particular notion of "logic" or to restrict it to some of its differences or relationships, we prefer to use the word "logic" in its general meaning, i.e., any of the four senses distinguished by Hofweber (2004)

Our objective in showing figure 5, an intersection among the domains of logical and analogical thinking is a) to be as comprehensive as to include, as special cases, both reductionisms visualized in figure 4 and 5, and b) to represent a gray area (between logic and the analogic) which is allowing the generation of different perspectives produced by different meanings of both concepts and different intellectual points of view.

Authors who value analogies in the scientific domain explain the role of analogies as aids in scientific research. But some authors affirm that analogies are not just aids in the establishment of scientific theories, but they are an ***utterly essential part*** of scientific theories. The diagram of Figure 5 takes into account both perspectives.

Analogical thinking processes, explicitly or implicitly, provide conjectures and hypotheses as input for deductive and inductive logics to be proved or validated as belonging to a certain kind of truth, or otherwise falsified or invalidated. Furthermore, *the output of analogical thinking might be the required input for its logical* processing. On the other hand, logical constructions are usually the source of analogical *thinking. Analogies provide inputs to Logic, and Logic is among the sources providing, implicitly or explicitly, input for analogical thinking.* Logic and Analogies require and complement each other for ***integral, integrated, and integrative*** thinking. This is why the System Movement, since its very beginning, promoted the explicit use of analogical thinking, and tried to legitimate this kind of thinking as a way of identifying qualitative *isomorphisms*, which may lead to mathematical ones.

Some authors, such as the English physicist N. R. Campbell, affirm that "analogies are not 'aids' to the establishment of theories; they are an utterly ***essential part*** of theories, without which theories would be completely valueless and unworthy of the name. It is often suggested that the analogy leads to the formation of a theory, but that once the theory is formulated, the analogy has served its purpose and may be removed or forgotten. Such a suggestion is absolutely false and perniciously misleading." (Campbell, Physics, *The Elements*, p. 129. Cfr. (Hess, 1966, pp. 4-5) [Italics and bold added]

Analogies are even necessary for human understanding of his/her internal and external environment. Pask (2003) affirms that "Analogy is a way of thinking and *understanding* the world, of gaining insight into different phenomena in nature, which are linked by common properties or similar behavior. To comprehend the depth at which analogy is rooted in our consciousness, it is worth noting that *human beings operate with analogies even at the neuron level* [Quoted by (Dragoman & Dragoman, 2004, p. 1)]

Analogy is also an important strategy for reasoning and *problem-solving*. Analogical thinking is also a powerful *learning process*. The process of comparison involves a structure-mapping, in which the two representations are aligned, and further inferences are projected from one to the other: Gentner (1983), (1989). (1988). Thus, one way that analogy facilitates learning is via the projection of knowledge from a well-understood situation to another that is less familiar or more abstract.

Another important form of analogical learning occurs when two situations are compared, and their common relational structure is highlighted. There is abundant evidence that such highlighting renders the common structure more available for subsequent processing, including transfer to new contexts (Gentner, Loewenstein, & Thompson, 2003); (Gick & Holyoak, 1980)

4. CONCLUSIONS

The reflections and analyses we presented in this work suggest that the relationship between analogy and logic should not be understood in hierarchical or reductionist terms but as a systemic polarity that generates both novelty and validation in human cognition. Analogical and logical thinking form mutually reinforcing feedback loops: analogies seed conjectures, conjectures shape heuristics, both guide logical validation, and validated knowledge, i.e., epistemological knowledge, becomes, in turn, the source for new analogies. *This recursive cycle positions analogy not as an occasional aid but as a* ***constitutive element of knowledge generation*****,** *including epistemological knowledge*

.

From this perspective, logic without analogy is sterile or, at least, risks sterility, while analogy without logic risks fragility and not generating epistemological knowledge. Their synergy enables hybrid reasoning that is both creative and verifiable. *This dynamic is especially relevant*

*for inter- and **transdisciplinary communication,** where analogical bridges make disciplinary knowledge intelligible to outsiders, and logical frameworks ensure verification, coherence, and credibility. Natural language, with its historical precedence over disciplinary vocabularies, remains the key medium that allows analogical reasoning to facilitate integrative dialogue across fields and societal sectors.*

We think that the findings and/or the suggestions of this work open, or may, avenues for further exploration.

- One is the systematic and/or systemic development of methodological frameworks that explicitly integrate analogical and logical reasoning oriented to transdisciplinary communication and, hence, inter- and trans-disciplinary research designs.
- Another is the reconsideration of analogy as an enduring component of scientific, engineering, humanistic, technological, philosophical, and other scholarly theories and professional practice, and not merely a temporary scaffold.
- A third is the investigation of how analogical–logical loops function at multiple scales: from individual cognition to collective inquiry to complex adaptive systems. This may have more importance than what some may imagine.

In conclusion, *analogy and logic, conceived as **systemic complements**, generate the creativity and rigor needed to address the complexity of contemporary challenges*. By adopting a systemic–cybernetic perspective, we hope that this work shows some evidence on how ***hybrid thinking*** can foster knowledge integration as well as integrative and integrated knowledge, support meaningful communication, transdisciplinary communication, and may contribute to pragmatic solutions in research, education, practice, and societal problems and issues.

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END NOTES

[i] The Modern Synthesis, the cornerstone of today's evolutionary theory, emerged in the mid-20th century as scientists combined Charles Darwin's theory of natural selection with Gregor Mendel's genetic discoveries. This groundbreaking framework, forged between the 1930s and 1950s, offered a comprehensive explanation for how populations evolve, spotlighting genetic mutations as the change generator, and taking foundation in other key mechanisms like gene flow and genetic drift to explain how traits spread and shift over time.

At the heart of the Modern Synthesis is the idea that populations don't just change at random, natural selection acts as a molder favoring features that give some individuals an edge in survival and reproduction. The intellectual architects of this vision blended insights from genetics, statistics, and biology, ultimately shaping the most robust evolutionary theory to date. Their collective efforts bridged the gap between "Darwinism" and the new science of genetics, laying the foundation for modern evolutionary biology.

[ii] Very brief descriptions of the four notions of Logics, according toThomas Hofweber in (Logic and Ontology, 2004/2023) are as follows:

1. ***Logic as the study of formal languages*** **(L1):** This is the modern mathematical approach to logic, which focuses on the properties of artificially constructed formal systems. This project studies the syntax and semantics of languages like those used in predicate and propositional logic.
2. ***Logic as the study of valid inference*** **(L2):** This notion focuses on the conditions for good reasoning and what makes an inference or argument formally valid. It is a more traditional and epistemological approach, investigating logical consequence—the relationship where the truth of premises guarantees the truth of the conclusion.
3. **Logic as the study of logical truths (L3):** In this view, logic is considered a science that aims to describe the most general, topic-neutral facts or truths. Thinkers like Gottlob Frege held this position, viewing logical laws as fundamental truths about reality itself.
4. ***Logic as the study of the form of judgments*** **(L4):** This is a more metaphysical or psychological notion that understands logic as the study of the general features of thoughts or judgments, rather than the linguistic representations of those thoughts. It is concerned with the fundamental structure of our cognitive processes