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Knowledge and Understanding: Differences and Relationships

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ABSTRACT

We explore in this article the distinction and interaction between *knowledge* and *understanding*. While epistemologically, knowledge is often defined as a justified belief, understanding emerges from the interpretation and application of that knowledge. Importantly, one may exist without the other, though both can also intersect and reinforce one another through dynamic feedback loops.

These relationships can be understood cybernetically: negative feedback loops reduce discrepancies between knowledge and understanding, while positive feedback loops strengthen congruence. The interplay becomes particularly evident in *Action Research, Action Learning*, and *Action Design*, where applying knowledge generates or deepens understanding.

A special case is *transdisciplinary communication*, which requires intellectual effort to effectively share knowledge across domains. ***This effort often produces neurological effects that transform knowledge into understanding*** or raise its level. Consequently, applying knowledge to real-world problems may generate understanding in two ways: (1) through the application itself, which links abstract knowledge with specific contexts, and (2) through transdisciplinary communication, when it is required for problem-solving via multidisciplinary teams or effective Transdisciplinary Communication.

Understanding is, therefore, both a prerequisite for and a result of transdisciplinary communication. It requires a minimal level of understanding in order to convey knowledge, yet successful communication almost inevitably enhances the communicator's own understanding. In both application and communication, the intellectual effort involved increases neural complexity, raising the likelihood of understanding as an emergent property.

1. PURPOSE

1. **"You do not really understand something unless you can explain it to your grandmother."** *Attributed to Albert Einstein.* [Italics and emphasis added]
2. **"I couldn't do it. I couldn't reduce it to the freshman level. That means we really don't understand it."** *Richard Feynman* (Albert Einstein Award, 1954; Nobel Prize in Physics, 1965). [Italics and emphasis added]

These two well-known quotations from Nobel Laureates in Physics, Albert Einstein and Richard Feynman, served as part of the inspiration for combining reflections, reflexivity (self-reflections), and bibliographic inquiry in order to clarify both the hyperbolic tone of Einstein's remark and the effectiveness of Feynman's methodology. The latter enabled him to explain to his students what is difficult, abstract, and/or complex, including quantum mechanics. This approach is often referred to as the *Feynman Technique*, which some eventually summarized as "learning by teaching."

Before returning to the notion of reflexivity or self-reflection, it is useful to pause and briefly review the two quotations with which this section began. Effective communication must begin with a shared medium through which what is not yet shared can be transmitted. Put differently: to transfer new meanings, skills, or knowledge, it is essential first to identify and employ a channel or code already ***common*** to both interlocutors. The primary responsibility for this lies with the communicator, who must learn and adapt to the recipient's common means of communication. In order to convey what is not yet common. From there, the common ground can be expanded and new elements introduced.

A widely known example is the interaction between a mother and her newborn child. Long before verbal language is possible, communication occurs through nonverbal channels: touch, gaze, gestures, and sounds, which both can interpret, or the mother gradually learns to interpret. By carefully attending and responding through nonverbal cues, the mother effectively "learns" the baby's language. Through this common medium, she then introduces new forms of meaning: verbal language, cultural gestures, emotional references, and so on.

This same principle applies and should be applied in teaching and in scientific communication. Richard Feynman, for instance, designed his lectures as if he were addressing a young student without prior scientific training. He rehearsed explanations to this imagined interlocutor repeatedly, cycling through adjustments in wording and examples until he identified the most effective language for comprehension. In doing so, he not only facilitated his students' learning but also deepened his own understanding of the material.

In a transdisciplinary context, such a communicative model becomes indispensable. To communicate across disciplines is to engage with distinct conceptual frameworks, terminologies, and methods. The starting point must be a "common ground", a shared language, metaphor, analogy, or example, mostly analogical thinking, cybernetically related to Logical Thinking. This is the kind of intellectual support that enables communication and provides a bridge toward what is not common. From this shared foundation, it may become possible to move into concepts, theories, or techniques unfamiliar to one or more parties, thereby enriching both sender and receiver: the former with greater understanding and the latter with, at the very least, increased knowledge or associated information.

In summary:

- Effective communication, especially in transdisciplinary contexts, should begin with a shared language or medium or, at least, with the intention and the intellectual effort to find it, metaphorically or potentially analogically, similar to trying to find a common language to communicate with her newborn baby. An intellectual from another discipline is equivalent. The communicator must first adapt to the language and context of the interlocutor from another discipline, and vice versa.
- This already existing, or created, common medium becomes, then, the foundation for introducing new meanings.
- The process benefits both parties: it enhances the communicator's understanding and the receiver's knowledge (or, at least, information) and often also contributes to the receiver's understanding. Both sides enhance their respective Analogical Thinking, which generates the analogies and heuristics for hypothesis or conjecture formulations, which, in turn, provide input to Logical Thinking.

The self-reflection introduced earlier refers to the act of reflecting on one's own reflections, and reflexivity is to thinking about one's own thinking. This is a necessary condition in Second-Order Cybernetics. In other words, *cognition should be accompanied by meta-cognition*. This implies a dual cognitive process: first, thinking about the object or situation at hand, and second, reflecting on our reflection or thinking about how that thinking is being carried out. Such meta-cognition, required in Second-Order Cybernetics, facilitates not only the clarification of knowledge but also the deepening of understanding, especially for the communicator, provided the communication itself has been effective.

The aim in this article is to demonstrate that the *intellectual effort*[1] *required to apply knowledge effectively to real-world problems, or to engage in effective transdisciplinary communication*[2]*, leads to a deeper grasp of the knowledge being applied and, in many cases, improves one's level of understanding of this knowledge. Conversely, the more fully we understand what we know, the more effective our transdisciplinary communication becomes.*[3] It may be affirmed that any academic who has also practiced as a consultant has continually raised the level of their own understanding. Moreover, academics who seek effective communication in the classroom must themselves fully understand the knowledge they teach. The ultimate beneficiary of this process is not only the student but also the professor, the faculty, the lecturer, or the teacher who transforms knowledge into understanding,

[1] Intellectual effort" refers to the mental demands and cognitive activities involved in tasks such as problem-solving, critical thinking, learning, and creative processes. In this case, it designates a combination of these four activities. Problem-solving helps in identifying patterns or connections; critical thinking enables the analysis and evaluation of information; learning provides the foundation for understanding; and creativity allows innovative approaches to grasp abstract concepts. Taken together, these cognitive processes constitute the intellectual effort required for effective de-abstraction. i.e., the process of translating abstract knowledge into applications for real-life problems. We will provide further details on this subject, particularly regarding how understanding emerges from the complexity of cognitive and neurological systems of knowledge. More on this will follow.

[2] This type of communication is necessary when interacting with users, managers, company presidents, and similar roles. The need for transdisciplinary communication is especially essential in the case of consultants or engineers who must communicate with clients, engineers, and scientists from other disciplines, as well as with the heads and managers of the client organization, who are usually from different fields. The intellectual effort required plays a vital role in this kind of communication.

[3] You can find more details regarding to the notion of Transdiciplinary Communication, (Callaos & Leon, Comunicación Transdisciplinaria, 2024) and, as related to the field of transdisciplinarity at (Nicolescu, 2008)

or elevates understanding to a higher level if it was already present.

There are, in fact, at least implicitly, *cybernetic relationships* between understanding and transdisciplinary communication, characterized both by (1) regulatory mechanisms (through negative feedback or anticipatory *feed-forward*) and (2) reinforcing dynamics (through positive feedback). This is the essence of the so-called Feynman Technique: imagining a twelve-year-old child, or at least a first-year university student, and explaining the material iteratively, i.e., cybernetically, until it can be understood at that level. This cybernetic method explains his oft-quoted remark: *"I couldn't do it. I couldn't reduce it to the freshman level. That means we really don't understand it."*

As will be shown later, knowledge and understanding are cybernetically related, for notional (linguistic), conceptual (abstract), and biological (neural) reasons:

1. Knowledge guides thought, while understanding is the *sine qua non* condition for making transdisciplinary communication effective and for applying knowledge.
2. The biological processes at work in the communicator's neural networks exhibit the same cybernetic dynamics.

Both types of cybernetic relationships will be addressed in the following two sections.

2. UNDERSTANDING AS AN EMERGENT PROPERTY[4]

Having outlined in the previous section the challenges of transdisciplinary communication and the intellectual effort it entails, we now turn to the deeper question of *understanding* itself, particularly as an emergent property that cannot be reduced to mere knowledge.

The reflections that follow may help illuminate the two quotations cited earlier from Einstein and Feynman, along with similar remarks regarding the challenge of translating abstract and/or complex concepts into simpler and more familiar terms. This is often by means of analogies or metaphors. As noted in footnote 1, the "intellectual effort" required for effective transdisciplinary communication is comparable to the effort required to apply knowledge to real-life problems. To recall Einstein's hyperbole: explaining university-level knowledge to one's grandmother presupposes genuine understanding. An effective explanation to a grandmother is, in effect, an application of that knowledge. In less hyperbolic, but real-life terms, academics engaged in consulting are constantly adapting their knowledge into a language accessible to clients, end-users, managers, executives, or policymakers. Explaining is thus both an act of applying knowledge and, simultaneously, both a *cause and an effect of understanding the knowledge being applied*. The more this is absent, the more additional intellectual effort must be undertaken to communicate effectively.

Further elaboration is needed, particularly regarding the meaning of "intellectual effort" and its relationship to intellectual complexity, emergent properties grounded in neurological complexity, and the emergent features that arise from it. To clarify, let us begin with a well-known empirical example of the notion[5] of an "emergent property." At room temperature, *liquid* water arises from the combination of two *gases*: H_2 and O. The liquid state is a property of the *whole*, not of either of its parts, which are themselves gaseous. Other emergent properties of water, such as its capacity as a solvent, its solid state (ice) at low temperatures, or its gaseous state (vapor) at high temperatures, likewise, do not belong to its constituent parts. *These properties* ***emerge*** from the specific arrangements and interactions of hydrogen and oxygen atoms (and subatomic elements) within the water molecule.

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[4] Within empiricism, there is a tendency to avoid the ontological connotations attached to the expression "emergent property." Instead, one often finds preference for terms such as "interactive complexity" or "interactivity within complexity." Other empiricists have opted for alternatives like "observable patterns," "empirical regularities," "epiphenomenal phenomena," "systemic dynamism," "interactions within complex systems," or "patterns of self-organization." Yet, in essence, all of these designations point back to what Aristotle articulated in the *Metaphysics*, namely his claim that "the whole is greater than the sum of its parts." In our view, the distinctions here are primarily semantic rather than conceptual, since all refer to the same underlying phenomenon as observed.

[5] The term "notion" has two main senses: 1) In the context of thought, it refers to a general idea, 2) in a linguistic context, it can be understood as a related and/or relatable set of denotations and/or connotations of the term as it is used in different contexts (Callaos, 2013) . This set can be a fuzzy set, meaning that its components may have varying degrees of membership rather than a simple duality of belonging or not belonging. This is important, at least in the case of understanding, because a person may possess different degrees of understading of a given body of knowledge. For example, the more often the associated knowledge is applied, the more understanding is reinforced, along with the meanings of both its denotations and connotations. The weight of these meanings is constantly shifting depending on the changing contexts in which the same term or notion appears.

This classic example shows how emergent properties arise from the interactions and organization of simpler components, yielding characteristics and behaviors that cannot be reduced to those of the individual parts. The concept is central to understanding how complex systems, whether natural or cognitive, exhibit properties and behaviors that are not directly predictable from their constituent elements. We underscore this here because it provides the foundation for much of what follows, especially in critiquing reductionist theories that collapse the mind into a single function: computation. Such theories are necessarily incomplete. While a computational account of the mind has proven highly useful in developing artificial intelligence tools that support and enhance the efficiency of cognitive computation, it cannot account for other essential mental properties; for instance, the rofound distinction between *knowledge* and *understanding/Comprehension*[6].

That the whole is greater than the sum of its parts is a phenomenon recognized, at least, since Aristotle. Its relevance extends far beyond chemistry into multiple domains. Yet the extraordinary technological advances enabled by reductionist processes have increasingly oriented us toward reductionist perspectives, sometimes at the expense of *recognizing wholes and their undeniable* ***emergent properties.*** This point is critical because understanding itself is an emergent property of knowledge systems, conceived both as a complex system and as part of cognition, which is itself complex. At the neurological level. Indeed, understanding may even be regarded as an emergent property of *intellect*, where ***cognition, conation (motivation), and affect (emotion) are cybernetically interrelated within a whole we have long referred to as "intellect."*** This whole is fundamental for relating our internal worlds to our external worlds, both of which are themselves complex systems characterized by emergent properties rather than mere sums of parts.

In light of these considerations, it is crucial to maintain a balanced perspective in scientific research and technological development: *valuing reductionist approaches for their analytical power while also recognizing holistic approaches for their attention to emergent phenomena.* These two perspectives are complementary, and their implicit[7] cybernetic interrelation generates a whole greater than either alone.

We therefore suggest that reductionism and holism, rather than being contradictory, are polar opposites that complement and even require one another. Distinguishing them, however, is essential. Holism, in pragmatic terms, may risk sterility, whereas reductionism has repeatedly demonstrated its utility and fertility. Their true complementarity lies in ensuring that usefulness is teleologically oriented, framed within both holistic and ethical contexts. And ***this orientation depends on understanding what we know***.

The relationship between these two poles has long been implicit. Making explicit their cybernetic interrelation could enhance both the efficiency and the effectiveness of each perspective, as well as of the whole they form together. Articulating this relationship explicitly may foster more integrated approaches to scientific inquiry, technological development, and real-world problem-solving. Ultimately, this integration could drive progress and innovation not only in technology but also in philosophy and the humanities. In philosophy, for instance, examining how reductionism and holism interact within complex systems may enrich discussions in the philosophy of science, mind-body dualism, and the nature of consciousness. Likewise, in the humanities, acknowledging the cybernetic interplay of reductionist and holistic perspectives may strengthen critical analyses of cultural phenomena, social structures, and historical processes. In both domains, this recognition could advance not only *knowledge* but also *understanding.*

This perspective of understanding as an emergent property highlights the limits of reductionism and the value of complementing it with holistic views. In the next section, we will explore how this balance shapes not only scientific inquiry but also practical applications in communication, problem-solving, and real-world contexts.
Having clarified the nature of emergent properties through both examples and contrasts with reductionism, we can now return to the central issue of understanding as an emergent property of knowledge and examine its implications for communication, cognition, and intellectual effort.

[6] We will sometimes use the notation *understanding/comprehension*, not to indicate synonymy, although it is common for both notions to be treated as synonyms in general, but formally, they are not identical in meaning. This becomes clear from their respective etymologies: 1) *Comprehension* derives from the Latin *comprehensio*, referring to the act of encompassing, containing, or mentally grasping; 2) *Understanding* derives from the Latin *intellectus*, referring to the faculty of discerning, of grasping essence. Consequently, 3) *Comprehensive understanding* would mean "an understanding that is broad and far-reaching." Thus, when we use the notation *understanding/comprehension*, it is intended to evoke any of these three meanings. Although the central focus of this article is on *understanding*, we will sometimes employ the notation *understanding/comprehension* because it encompasses two of the three senses we have just summarized in this footnote.

[7] It should be noted that when this implicit relationship of complementarity becomes explicit, there is a high probability that such complementarity will prove to be more productive and synergistic.

It is possible to:

1. Know without understanding.
2. Understand without knowing.
3. Know and understand simultaneously.

Let us consider a few simple examples, potentially familiar to most, if not all, people:

- ***Knowing without understanding***: memorizing the multiplication table without understanding the concept of multiplication, e.g., as repeated addition.
- ***Understanding without knowing***: understanding the notion of addition without having memorized the addition table. Anyone who has seen a child use their fingers to add will notice that the child understands what it means to add, but does not recall (i.e., does not *know*) the addition table.
- ***Knowing and understanding simultaneously***: memorizing the addition table and also understanding the concept of "adding."

In another context, we may note that axioms in mathematics (self-evident intuitions) are examples of understanding that do not constitute knowledge, at least not knowledge in the epistemological sense, since they are not justified beliefs. However, such axioms can generate deductive knowledge if they are accepted as ***understood starting points***. These are examples of understandings that are not knowledge but can generate deductive knowledge, the respective deduced theorems.

In a general sense, knowing is having awareness of information acquired through observation or learning. Epistemologically, however, knowledge is a justified belief. This justification may rest on verification, which in turn depends on the notion of truth underlying such verification. This notion of truth often depends on the discipline or interdisciplinary field. For example:

- ***Empirical truth***: based on observation, methodological experience, evidence, and Inductive Logic.
- ***Rational truth***: based on logical reasoning, based on initially accepted axioms.
- ***Pragmatic-teleological truth***: based on praxis and goal-oriented. We suggest this last one as a general notion, since it depends on the researcher's aim, which may be linked to any disciplinary or epistemological approach and its justification methods.

By contrast, understanding involves the interpretation, processing, and application of the acquired information or justified belief. This requires additional intellectual effort, at a minimum, to apply what is known or to generate a related intuition.

One may *know* a fact without truly *understanding* its meaning, importance, or implications. Understanding is often considered a deeper, broader, and more active mental state than knowledge (especially when it is based on memory) since it involves the organization and interpretation of knowledge.

3. KNOWLEDGE, UNDERSTANDING, AND THEIR INTERRELATIONSHIPS

We must reiterate that *knowledge* and *understanding* are two different notions or concepts, even though their meanings (sets of senses) intersect. This common intersection is a commonality that communicates them. Furthermore, they maintain cybernetic relations with each other (Figure 1).

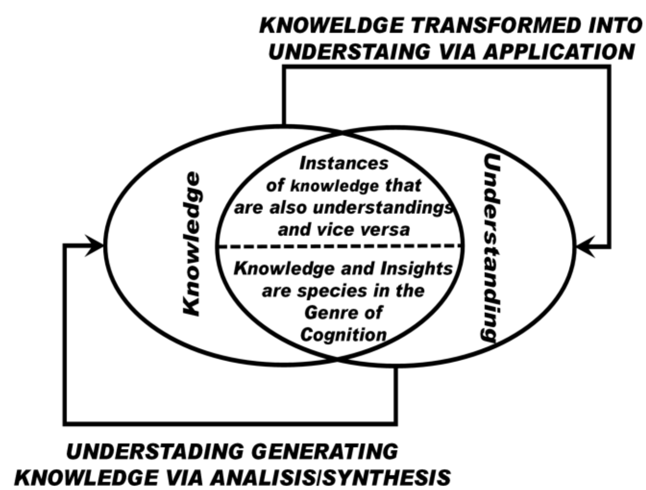

Figure 1: Knowledge and understanding are related through two dimensions: 1) ***Intersection***, and 2) ***Cybernetic relations***. The intersection includes cases where knowledge also constitutes understanding, with both functioning as species within the broader genus of cognition. Their cybernetic relations operate through negative and positive feedback, forming a whole that is greater than the sum of its parts, due to the emergent properties they both share.

Through these cybernetic relationships:

a. Knowledge can generate its own understanding, for example, through its effective application.
b. Understanding can support the generation of knowledge, as in the case of axioms (understanding) that generate new knowledge (theorems) through logical reasoning (Figure 1).

To summarize: Figure 1 is a synthetic diagram that represents the relationships between the notions of knowledge and understanding, namely, as already indicated above, intersection and cybernetic relations. The relationship between knowledge and understanding is multifaceted, characterized both by intersection and cybernetic relations. That is:

3.1. Intersection

The intersection between knowledge and understanding occurs 1) in terms of instances and 2) in conceptual categories.

1. ***Instances****:* There are units of knowledge that are adequately understood. For example, when individuals understand the principles of physics, then the inferred knowledge is also understood; or when an engineer effectively applies knowledge (or a related set of knowledge), this initiates or increases their level of understanding.
2. **Categories**: Knowledge and understanding also intersect as two species within the broader genus of cognition. That is, the genus *cognition* is common to both, and what is predicated of the genus is also predicated of its species (Predicate Logic). Thus, both knowledge and understanding share what belongs to cognition as a genus.

The first type of intersection is set-based; the second is based on shared predicates in Predicate Logic, i.e., as species of the same genus, they share the genus's predicates. Both are part of their cognitive interconnectedness and, consequently, influence each other reciprocally, for example:

- The acquisition of information (in the general sense of knowledge) or the justification of a belief (in the epistemological sense).
- Understanding based on adequate interpretation, capacity to abstract the essence, and/or potential connections with other information in general and specific knowledge (justified belief). One way to generate understanding from knowledge is by making the effort to apply knowledge to a theoretical or real-world problem. The more knowledge is applied to diverse problems, the greater the degree of understanding. *Knowledge is a matter of "yes or no" (either it is known or not known), while understanding is a matter of "more or less"*: that is, understanding can always increase, for example, through more applications of knowledge to real-world problems. This makes our understanding more comprehensive.

Understanding is not limited to the mere accumulation of knowledge stored in memory, but involves the ability to actively relate internal and/or external reality to prior knowledge. This process requires interpreting reality in the light of existing knowledge and, in turn, reformulating and enriching that knowledge through experience. Thus, ***understanding emerges from a recursive dynamic between knowledge and experience,*** where interpretation plays a key role in constructing meaning. This recursive dynamic is achieved through cybernetic feedback relations, both negative and positive. Negative feedback reciprocally regulates knowledge and experience, while positive feedback reinforces them, also reciprocally.

In other words, ***understanding arises and grows from linking two cognitive components: memory (knowledge) and action, grounded in the brain's neural complexity and its emergent properties, one of which is understanding itself.*** It is, therefore, the result of the intellectual effort of relating parts of our cognitive system to larger parts, or to the whole.

The more frequently and diversely this relation between thinking and doing occurs, the more we understand the knowledge we hold. Frequency and diversity of action develop an understanding of what we know[8]. Hence, ***thought and action regulate and reinforce each other reciprocally.*** This explains why the mutual regulation and reinforcement between thinking and acting are not only fundamental to learning but also the engine of intellectual development.

The action referred to here can be:

1. **External**: applying knowledge to real-world problems.
2. ***Internal***: translating disciplinary or interdisciplinary language into a transdisciplinary framework, enabling communication beyond disciplines.

The latter is essential for end-users, managers, professionals, and other actors involved in applying knowledge to problem-solving.

[8] It is often assumed that laboratories in theoretical subjects designed for the transmission of knowledge provide the experience needed to understand the knowledge acquired. However, in reality, the way these laboratories are prepared and/or how the activities within them are designed often leads more to the verification of knowledge than to the process required for its genuine understanding. A laboratory requires an active mind, not a passive one that merely follows instructions to confirm what is already known. Such verification can be passive and may lack the mental action necessary to transform knowledge into understanding. This note serves as a possible alert. To address this issue more comprehensively would require a separate article or another section within this one, which could move beyond the intended scope and/or risk dispersing the reader's attention.

Let us recall once more[9] the earlier quotes by Albert Einstein and Richard Feynman, which illustrate the ability to explain disciplinary knowledge:

1. Hyperbolically, to one's grandmother (in the case of the quote attributed to Einstein).
2. Understandably, to a freshman student (in Feynman's case, who developed a methodology based on an iterative process where the educator reformulates and repeats explanations to an imaginary student until achieving sufficient understanding to transmit it to a real student). This process combines thinking/reflection with action (externally, by explaining aloud, and internally, by carefully selecting the words to be used) in a cybernetic dynamic of feedback. This reflection/thinking practice includes self-correction, adjusting discourse when the words employed are not comprehensible to a freshman student.

3.2. Cybernetic Relationships

The relationship between knowledge and understanding is also characterized by cybernetic interactions (Figure 1). These interactions include both negative and positive feedback loops, in which each component influences and is influenced by the other through:

- Negative feedback, discrepancies between knowledge and understanding are corrected, allowing for refinement and clarification.
- Positive feedback, on the other hand, reinforces and amplifies congruencies between them, fostering deeper or more comprehensive understanding and greater conceptual clarity.

These cybernetic relationships give rise to a synergistic whole that transcends the mere sum of its parts. This synergy is made possible by the emergence of unique properties within the integrated system of knowledge and understanding, enriching both components and contributing to the advancement of cognition as a whole.

At a macroscopic level, two main relationships complement each other synergistically:

1. Knowledge generates its own understanding through actions based on it, such as application to problems, situations, or internal/external requirements.
2. Understanding generates knowledge through thought, especially logical reasoning. To reiterate the earlier example: axioms, which are understood but are not knowledge because they have not been induced or deduced, generate deductive and/or inductive knowledge. Inductive knowledge rests on the assumption that the future will resemble the past—something that cannot be inductively proven, since we lack an empirical window into the future.

The interrelationship between knowledge and understanding manifests across several dimensions:

- ***Cognitive nature***: Human cognition is a dynamic and complex system, characterized by continuous interactions, recurrent feedback, and the generation of emergent phenomena.
- ***Cybernetic dynamics between thought and action:*** Which have been seen in action-learning, action-research, and action-design, modalities of "thinking in action" sustained by negative and positive feedback loops, as well as feedforward, between thinking and doing.
- ***Application of knowledge as a pathway to understanding***: Understanding what we already know requires applying it, whether intellectually or empirically.
- ***Intellectual dimension***: Linking given knowledge with other cognitive content and with the other two intellectual components, i.e., conation (motivation) and affect (emotion).
- ***Empirical dimension***: Creating new knowledge or using it to develop technological innovations or solve real-world problems. The greater the complexity of the problem successfully addressed, the greater the understanding achieved.
- ***Diversity of application*s**: The more diversified the applications of knowledge, the more comprehensive the resulting understanding.
- ***Effective transdisciplinary communication***: A dual application:

  - *Intellectual*: reformulating knowledge into frameworks comprehensible to other disciplines.
  - *Empirical*: transmitting it to non-disciplinary or non-interdisciplinary audiences through accessible language. In oral communication, this process integrates verbal and nonverbal elements (body language, gestures, eye contact, facial expressions, and paralinguistic aspects such as tone, volume, rhythm, and intonation.
  - ***Educational dimension***: Every mode of education requires translating technical or disciplinary language into a common language that enables the effective transmission of information/knowledge to the learner. Communication, by nature, involves using the common/shared to convey what is not yet common or shared. Adequate transdisciplinary communication thus becomes an effective

[9] We make some reiterations because of its importnance and/or because nre contexts enhace the respective meaning

support for integral understanding, expanding and deepening what is already known.

- ***Audience diversity:*** The heterogeneity of an audience or readership requires a higher degree of understanding by the communicator, closely linking the notion of understanding to that of *comprehensive understanding*.
- ***Intellectual effort and semiotic translation***: Translating a disciplinary semiotic system into a transdisciplinary one implies an intellectual effort that deepens the understanding of the translator. This process benefits both the *personal good* (the one who gains greater understanding) and the *common good* (the broader community, which gains new information and/or knowledge).

To summarize: the application of knowledge to real-world problems increases understanding through two complementary mechanisms:

1. The act, itself, of applying knowledge, which links the abstract and technical to the specificity of the problem to be solved.
2. The translation of technical or disciplinary language into natural language facilitates communication with those involved in or affected by the problem (*stakeholders*).

We may summarize this section in Table A. More Details are provided in Appendix A.

4. PROCESSES LINKING KNOWLEDGE AND UNDERSTANDING

Learning and repetition are the most frequent and necessary processes for increasingly understanding what we already know. All these processes rely on the ***increase in complexity*** of our learning and, consequently, on the complexity of the neural networks that support it. This complexity is what generates the ***emergent property[10] of understanding what we know***. And as this complexity grows (for example, through the variety of applications), the level of understanding increases.

Table A
Knowledge vs. Understanding

Subject	Essence
Distinction	Knowledge is data/facts, verified information. Understanding is integration, an emergent property, and meaning.
Knowledge	Structured, verified, or validated information (may be explicit or tacit).
Understanding	Active, relational; integrates cognitive, motivational, emotional, and ethical dimensions.
Relation	Knowledge without understanding is sterile; Understanding without knowledge is unfounded (Foundations, axioms, insights, principles)
Applications	Education: explicit consciousness of knowing and/or understanding (critical thinking), Research & Innovation, Decisions (implications),
Conclusion	Balanced integration fosters thinking orientation, more effective praxis, doxastic (opinion) orientation, and supports transdisciplinary communication.

Therefore, to the learning of new knowledge, we must add ***internal relationships*** (via thought) and/or ***external relationships*** (empirically observed) with what we already know. This embeds our knowledge into a broader, more complex whole, generating ***emergent properties***, among which is the understanding of what we previously knew.

As we already mentioned above, understanding is related to the whole of which our knowledge is a part. To what we know, we usually add at least ***"what it is for"***. And if we can also add knowledge of ***"how," "where," "when,"*** etc., then our understanding of what we know increases. That is why ***relational thinking****, the* ***cybernetic interconnection between thought and action****, and the* ***repetition of learning processes (relearning)*** are essential to understanding and continuing to understand more of what we already know.

This process is what 1) embeds our knowledge into an increasingly complex whole, and 2) regulates and reinforces this whole, which becomes progressively more complex. This complex whole is necessarily based on our ***complex neural networks***. These networks must be used in order to strengthen and grow; otherwise, they may atrophy. All of this requires (as mentioned before): ***learning, re-learning*** (relating our learning through additional learning processes), and ***repetition***. Initial learning is a necessary first step, but it must be followed by iterative steps to be neurally reinforced. If these subsequent steps are related to other knowledge and actions, our neural network necessarily becomes more complex, thereby generating understanding, or greater understanding, based on already existing knowledge.

[10] Details on this notion were provided above in section 2

We can use a ***metaphor*** (potentially an analogy) to illustrate the difference between knowledge and understanding: we can ***know*** the meaning of a word from a dictionary, but to ***understand*** that meaning, we need to see it in different contexts and use it repeatedly also in different contexts. The more the different contexts in which we encounter or use the word, the more denotations and connotations we acquire, directly increasing our understanding of its meaning. ***Repetition in different contexts*** is an effective way to deepen our understanding of knowledge. Embedding our knowledge in various contexts increases the ***conceptual, notional, and neural complexity*** necessary to understand what we know and to continue raising our level of understanding or ***comprehensive understanding***. Repetition generates complexity, especially when associated with cybernetic loops; ***active, repeated learning*** is more effective in strengthening neural networks.

Since ***applying knowledge initiates the process of understanding it***, the more knowledge is applied, the greater the understanding, particularly when repetitions occur in different contexts. This applies both to knowledge applied to real-life problems and to knowledge applied for ***communication through transdisciplinary language***.

Transdisciplinary communication is both an ***effect and a cause of understanding***. It is a cybernetic relationship of ***regulation and reinforcement*** between understanding and application. Moreover, because transdisciplinary communication is a way of applying knowledge, this cybernetic relationship is generated through the application of knowledge to real-life problems and/or transdisciplinary communication.

Because transdisciplinary communication requires understanding, the intellectual effort we exert to achieve it **increases our understanding of what we know,** and the **repetition of this activity further increases our understanding.** This is why transdisciplinary communication and understanding are associated with cybernetic loops, making each both a cause and an effect of the other.

In ***consulting activities***, transdisciplinary communication is essential. As has been emphasized, it relies *on* ***intellectual effort that creates new neural connections and/or reinforces existing ones***. The ***repetition of this process*** generates and strengthens the ***intellectual skill*** required for transdisciplinary communication. The more repetitions are performed, the more effective this skill becomes. The continuous development of this intellectual skill ***enriches the communicator's understanding*** of the knowledge being transmitted in transdisciplinary terms.

4.1. The Technique or Methodology of Richard Feynman:

The methodology of ***Nobel Laureate Richard Feynman*** is based on ***continuous reiteration (via cybernetic loops)*** to improve understanding to the point of being able to explain complex and abstract concepts of Quantum Mechanics to very young students, including first-year university students. In this way, Feynman progressively increased his understanding of the knowledge he already possessed, which earned him a reputation as the best teacher, regardless of how abstract or complex the topic he was teaching. Figure 2 schematically illustrates Feynman's technique.

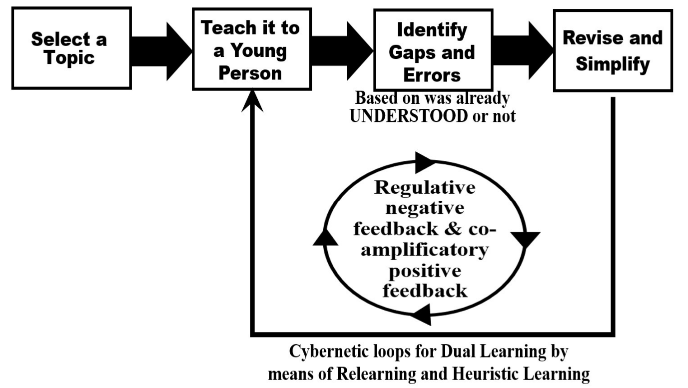

Figure 2: Diagram of the Feynman Technique, which Richard Feynman did not formally write about but constantly advocated. Consequently, there are several versions of it, yet almost all coincide in that there are four steps, of which three steps are repeated as many times as necessary ***until the educator understands***. Only when the educators understand can they effectively use language, analogies, and metaphors that a young person can grasp. Some versions specify that the young person may be around 12 years old. It is likely that Feynman used the hyperbole of a 12-year-old child, just as Einstein used the hyperbole of a grandmother. The diagram in this figure is based on interpretations from Saint Mary's University https://studentsuccess.smumn.edu/wp-content/uploads/sites/35/2024/09/SS-Feynman-Technique.pdf and the University of Limerick

The repetition of explanation allows the explainer to deepen their understanding, provided they engage in the necessary intellectual efforts. These efforts generate new neural connections and/or reinforce existing ones via the corresponding neurotransmitters.

As shown in Figure 2, the Feynman Technique consists of four key steps designed to promote deep understanding and effective learning:

1. ***Choose a Topic or a Concept and Study or Understand It:*** Write everything you know about it on a blank page, creating a visual map of your current understanding.

2. ***Explain It Simply*** (different from Simplistically): Teach the concept as if explaining it to a 12-year-old or someone unfamiliar with the subject. *Using simple language helps reveal how well you truly understand the topic*. You can do this by writing or explaining aloud, ideally to another person who can give feedback.
3. ***Identify and Fill Knowledge Gaps***: When you come across areas where your explanation is unclear or incomplete, return to your source materials, books, notes, lectures, etc., to study those parts until you have a clearer grasp. Then, refine your explanation accordingly.
4. ***Review and Simplify***: Review your explanation ***repeatedly***, simplifying and clarifying it further with each iteration. Test yourself by teaching it to others without referencing your notes. Archive your clear, boiled-down version for future review.

This process is iterative, meaning you repeat the steps until you achieve solid comprehension. It helps build mental models by breaking complex ideas into manageable chunks and ***reinforcing neural connections.*** The Feynman Technique promotes active learning, self-testing, and continuous refinement. It has also been called ***learning by teaching.*** It may also be suggested to call it ***understanding by reiteratively trying (via cybernetic loops) to be understood.***

4.2. Using Generative AI to Support Richard Feynman's Technique or Methodology

With Generative AI, Feynman's methodology may be used, asking AI to behave as a young person and inform about what was not understandable. IMPORTANT: This is different from asking Generative AI to translate your writing so that it can be understood by a young person. In this way, you **KNOW** how to do it, but this does not make you **UNDERSTAND** it more. Let us, ex[mad a little bit this issue.

Generative AI offers a powerful way to implement the Feynman Technique by acting as a young or novice learner who can identify what parts of your explanation are unclear or confusing. Unlike simply asking AI to translate or simplify your writing for a young person, a task that only helps rephrase but doesn't foster your own understanding,

Here is how this approach can work:

- ➢ You explain a concept to the AI, asking it to respond as if it were a curious 12-year-old learner.
- ➢ The AI then points out parts of your explanation that are vague, incomplete, or incorrect *without attempting to rephrase or summarize.*
- ➢ You use this feedback to study and refine your own understanding, then repeat the process until the AI no longer finds gaps.

This iterative dialogue with AI simulates the essential step of the Feynman Technique, *testing your understanding by explaining to another who questions you*, thereby enhancing your understanding.

Several recent developments actively apply this method, such as AI-driven Feynman Bots that engage learners in question-and-answer discussions based on their notes, guiding self-regulated learning and producing higher learning gains.

This method maintains the ethos of active, reflective, and, potentially, reflexive learning, using AI as a tool to challenge and develop your understanding rather than simply receiving simplified content.

Generative AI offers a powerful way to implement the Feynman Technique by acting as a young or novice learner who can identify what parts of your explanation are unclear or confusing. Unlike simply asking AI to translate or simplify your writing for a young person (a task that only helps rephrase but doesn't foster your own understanding), engaging AI this way helps you truly identify gaps in your knowledge.

Here is how this approach would work:

- ➢ You explain a concept to the AI, asking it to respond as if it were a curious 12-year-old learner.
- ➢ The AI then points out parts of your explanation that are vague, incomplete, or incorrect without attempting to rephrase or summarize.
- ➢ You use this feedback to study and rephrase your text. This is what enhances your understanding, then repeat the process until the AI no longer finds gaps.

This iterative (cybernetic) dialogue with AI simulates the essential step of the Feynman Technique, testing your understanding, by explaining to another who questions you, thereby deepening your understanding.

Several recent developments actively apply this method, such as AI-driven Feynman Bots that engage learners in question-and-answer discussions based on their notes, guiding self-regulated learning and producing higher learning gains.

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5. EMPIRICAL EVIDENCE

In this section, we will refer to several empirical evidences, from cybernetic methodologies as well as from observation via neuroimaging. In both cases, the reasoning is as follows: the intellectual effort required to translate from semiotic systems and intra-, inter-, or trans-disciplinary cultures (for example, epistemological values, methods, etc.) into a transdisciplinary and intellectually transcultural semiotic system requires learning, which often involves repeated relearning (as observed in Feynman's Technique). This learning process (which is relearning) engages and strengthens neural networks, thus increasing the complexity of the brain's neural system and reinforcing parts of the existing one. Richard Feynman's case is an empirical example because of its widely recognized effectiveness. It is good to complement this with empirical evidence at the level of neural networks. We will present that below, e.g., in subsection 5.1.

As a result of cybernetic reiterations[11], new properties emerge, including the reiterated understanding of concepts already known and/or the enrichment of existing understanding through deeper and more comprehensive understanding. We will now explore the neurological empirical evidence that corroborates this perspective. We will focus on "learning" and, in particular, on "learning a new language," since the intellectual effort required for "Transdisciplinary Communication" involves learning, especially a type of learning similar to that of a second language, because it also entails translation between two potentially different semiotic systems.

As we reiterated above, it is about applying knowledge in order to understand it better. And if the application is doubled, the understanding of knowledge increases even more. For example, applying scientific or engineering knowledge to real-life problems, situations, or organizations is, in itself, a double application of such knowledge:

1. The one related to translating into a transdisciplinary language to interact with users, clients, etc., who use natural language in addition to terms that have meanings specific to a given organization; and
2. The one related to connecting abstractions, theories, and knowledge in *genera*l with the *specificity and particularity* of the corresponding problem.

This is a double application: 1) at the human level, and consequently dependent on the effectiveness of the language used in interpreting the problem, and 2) at the level of the most adequate knowledge for the specificity of the problem.

As a result of these complex processes (be they implicit or explicit), 1) new properties emerge, including understanding of previously known knowledge, and/or 2) enrichment of existing understanding through deeper and more comprehensive understanding.

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We will now explore the neurological empirical evidence that corroborates the perspective just presented. We will focus on "learning" and, in particular, as we anticipated above:

1. The learning required to connect knowledge with real-life problems, that is, abstract with concrete, and
2. "Learning a new language," since the intellectual effort required for "Transdisciplinary Communication" with the client and their organization involves learning, especially a type of learning similar (though to a lesser extent) to that of a second language, because it also entails translation between two different semiotic systems: the one of the person applying the knowledge and the one used by the organization that has the problem (which, we repeat, also tends to include organizational terms in addition to the natural language common to both sides of the relationship).

The following are the fields of research most related to the essence of the previous paragraph and of this article:

5.1. Neuroimaging

Neuroimaging shows empirically and clearly that the structure of the brain's gray matter exhibits remarkable plasticity and reorganizes in response to learning experiences throughout life. Y. Chankg. In (Reorganization and plastic changes of the human brain associated with skill learning and expertise, 2014) affirmed that "Advances in non-invasive neuroimaging have provided new *knowledge into the structural and functional reorganization associated with skill learning and expertise acquisition*." [Italics added]. Since skill acquisition requires repetition, we can conclude that learning, especially active learning and repetition**, *reorganizes the brain both structurally (formation of new neurons and synapses) and functionally (formation of***

[11] It is worth making explicit that we are not referring to spaced repetition or reteration, which has been useful for supporting long-term memory. We are not referring either to intentionally continuous repetition, which has shown effectiveness in generating understanding from knowledge and, consequently, in being more effective at explaining disciplinary or technical knowledge in terms that are comprehensible to a student or to academics from other disciplines. What we are talking about is ***relearning***, but in other terms. It is similar, and even analogous, to learning a second language. It is the same content but in another linguistic form that is more accessible to the student or to the academic from another discipline.

new neuronal connections and synapses). We will address this topic in greater detail in the next subsection.

5.2. Language Learning

Translating between two semiotic systems and especially learning a new language, as well as other forms of skill acquisition or strengthening, generate changes in the brain's structure and function. This relates directly to:

- The very application of knowledge (which we have been reiterating in this article), since it connects knowledge with the complexity of a real-life problem, necessarily increases the complexity of neural networks;
- Effective transdisciplinary Communication, since it requires translation between two different semiotic systems, both of which are complex systems.

Thus, the intellectual effort to translate from one language to another is equivalent to the intellectual effort of learning a new language. Tao, Zhu, & Liu, in (The influence of bilingual experience on executive function under emotional interference: Evidence from the N1 component, 2023), for example, affirmed that *"learning a second language increases the gray matter density in the left subparietal cortex, and second* ***language proficiency is significantly associated with neurophysiological changes."***

5.3. Transdisciplinary Communication

Various interdisciplinary and transdisciplinary studies have shown that the cognitive or intellectual effort required to overcome disciplinary barriers, such as translating concepts, dealing with contrasting theoretical frameworks, and synthesizing diverse contributions, generates significant cognitive growth, fosters creativity, and develops strong problem-solving skills. A specific example is Engineering Education for Interdisciplinary Communication in the context of multidisciplinary teams in charge of managing multidisciplinary projects.

This might deserve a more reasoned and comprehensive treatment, but to stay within the scope of this article, let us draw on more extensive works on the subject.

- Gyory, Song, Cagan, & McComb, in (Communication in AI-Assisted Teams During an Interdisciplinary Drone Design Problem, 2021), affirm that "*Interdisciplinary teams that engaged in frequent, high-quality communication showed richer idea development and better collective performance in problem-solving, suggesting* ***greater cognitive integration among team members."*** [Italics and bold added]. If such collective cognitive integration occurred, it is because individual cognitions increased in complexity, generated by interdisciplinary communication.
- Ye & Xu concluded in (A Case Study of Interdisciplinary Thematic Learning Curriculum to Cultivate '4C Skills', 2023) that *"The interdisciplinary thematic curriculum provided students with opportunities to apply knowledge from multiple areas in collaborative problem-solving, which not only strengthened their critical thinking and communication skills but* ***also fostered adaptive cognitive flexibility****."* [Italics and emphasis added]
- Both quotes reinforce the idea that interdisciplinary interaction and communication *not only improve project outcomes but also activate and expand complex cognitive processes in participants.* Although neural networks are not explicitly mentioned, the concepts of cognitive integration and adaptive cognitive flexibility relate directly to neuroscientific literature describing how ***varied collaborative experiences can increase the connectivity and complexity of functional neural networks***.

5.4. Educational Psychology

Education has provided multiple empirical validations of the effectiveness of active learning, including the Feynman Technique mentioned earlier (Figure 2), which is based on repeated relearning of what is already known. This process of active relearning is a strategy based on the idea that teaching a concept to someone else requires a high degree of understanding of the knowledge being transmitted. Through active learning strategies, such as teaching or explaining concepts to others, higher levels of understanding and better knowledge retention are promoted.

However, it is important to warn readers: some studies have reported not finding such effectiveness, but this was due to *a misinterpretation of the Feynman Technique and its purpose. It is not a teaching technique per se, but a technique based on simulated teaching and relearning, whose purpose is to help the teacher or educator understand a concept better before teaching it, thus enabling them to explain complex and/or abstract terms to young students. For this reason, it is also known by the phrase "learning by teaching."* It is based on active learning, on intentionally reiterative relearning, whose effectiveness has been widely demonstrated.

Regarding active learning, which also applies to reiterative learning, or relearning, there is abundant empirical evidence for its effectiveness compared to the traditional method based on passively listening to lectures or one-way classes, with occasional questions if time permits.

(Davidson & Katopodis, 2022), citing (Freeman, et al., 2014), state:

> “A frequently cited meta-analysis covering more than 225 independent studies on learning found that, by every measure, *active learning is more effective for all types of students, in all disciplines, than traditional lecture mode or guided Q&A discussion. In fact, the authors of the study… conclude that,* ***if their study had been a pharmaceutical trial, traditional learning would have been taken off the market.”*** [Italics and emphasis added].

(Davidson & Katopodis, 2022) adds that “Active learning has clearly been shown to be more effective than traditional modes, and its multiple merits are emphasized for those who still resist adopting it.” If it is more effective for students, it is even more so for their educators, teachers, or professors. *Consequently, there can be no doubt about the effectiveness of active learning in the relearning that occurs in cybernetic iterations* (such as the one Richard Feynman used in his technique to improve his educational effectiveness, Figure 2). It is evident, then, that active relearning would be even more effective for educators if they decided to use the Feynman Technique based on active and reiterative relearning. This would allow them to understand better what they already know and, therefore, explain it more effectively, just as Feynman did with his students. *Moreover, it would provide them with the necessary ability for transdisciplinary communication, regardless of the disciplines with which they attempt to communicate.*

Furthermore, when acquired knowledge is applied to a new real-life problem, active relearning also occurs. The greater the understanding of that knowledge, the more effective and efficient the communication becomes between the person applying it and the organizational language of the one facing the problem. This improved alignment reduces errors or misunderstandings in the interaction between the two "languages": technical and organizational. Such alignment can be the difference between an effective or ineffective application, with all the financial, emotional, and time costs that failures of inadequate "translation" can produce. These costs decrease as the knowledge of the person applying it is more fully understood.

At this point, it is worth reiterating, especially because reiterating in a new context enhances the meaning of what is repeated in the enhanced: 1) the cybernetic relationship (Figure 1) and hence 2) the more repetitions are feasible and adequately made in the conversation between the technical and the organizational part, the less probable is misunderstanding due to trasnaltion betweeb the two langiajes. The required time is an inversion, not necessarily a waste; it is a kind of insurance for diminishing the risk of misunderstanding. In the case of students and professors, lecturers, or teachers, the student would be paying a higher cost than the educator if there is an inadequate translation between the language understandable by the student and the one used by the educator.

This is why active learning should be applied to both students and educators. Active learning, including the Feynman Technique, is a highly effective approach, supported by a large body of research evidence, and would undoubtedly be even more beneficial for educators by enhancing their own understanding and teaching skills. Education in general would benefit more from active learning, whether for educators, students, or both. If educators adopt it, it would improve the traditional monologue-based method. If adopted by both educators and students, it would have a multiplier effect, especially because cybernetic relationships would be established between educators and students, including regulating loops (through negative feedback and feedforward) and reinforcing loops (through positive feedback). All of this would generate additional multiplier effects in both students and educators. This would also increase the effectiveness of knowledge integration, as it would facilitate knowledge applications and more effective Transdisciplinary Communication, thereby increasing the understanding of all academics involved, as well as other academics and students.

Evidently, all this would also positively impact society in general, especially (though not exclusively) due to the etymological sense of transdisciplinary communication, which implies communicating effectively across and beyond disciplines. This second sense could become more plausible and effective, since academics and students would undoubtedly increase their understanding of their own knowledge. This may seem like a dream, and it is, but a feasible dream that recalls the phrase by Leon Joseph Suenens: *“Happy are those who dream dreams and are willing to pay the price to make them come true.”*

Although this perspective of widespread adoption of active learning may seem like a dream, it is, in fact, an achievable dream with great potential for the future of education. As Suenens’ quote suggests, making this vision a reality may require effort and dedication, but the potential benefits make it an effort worth pursuing. This would be similar, if not analogous, to the iterative effort required in sports and music education.

What we wish to emphasize is the transformative potential of active learning in education, through increasing the understanding of present and future knowledge, highlighting the importance of adopting innovative approaches in both teaching and learning to foster a more dynamic, engaged, and interconnected educational community.

As Suenens’ quote suggests, realizing this transformative potential may require dedication and effort, but the benefits make it a goal worth pursuing. Adopting innovative teaching and learning approaches, such as active learning, ***by both students and educators***, is crucial to elevating education to new levels and fostering a more dynamic, engaged, and interconnected academic community.

5.5. Neuroscience of interdisciplinary collaboration

In this subsection, we will summarize some neuroscientific studies showing how collaborative work across different disciplines develops new neural connections in participants and consequently increases the complexity of their respective neural networks. As we argued earlier, this would increase the probability of producing emergent properties, including understanding of knowledge already possessed, expanding that understanding, and even reaching a comprehensive understanding. The latter would result from the variety of experiences gained in applying knowledge to different situations and cases.

This increase in complexity has been addressed in the previous four subsections, especially the last one, since such an increase could occur both at the individual and collective level (social meta-neurological networks). This is why transdisciplinary communication, providing this kind of dual support, would intensify and more directly strengthen the relationship between the academic world and society at large, particularly in terms of communication ***beyond*** and not only ***across*** disciplines.

The four previous subsections referred to empirical evidence on cognitive growth, changes in brain structure and function, and the reorganization of the neurological system that result both from the intellectual effort inherent in active learning and from the application of knowledge, including processes such as translating from one language to another. Transdisciplinary communication is analogous to both learning a new language and active relearning that supports knowledge transfer, since it involves 1) "translating" from a disciplinary semiotic system to a transdisciplinary one, as well as 2) identifying relationships between the abstract and the concrete. In both scenarios, a process of neural reorganization occurs, resulting from intellectual effort.

Paraphrasing Marks, Robin, in (Struggling to Learn a New Language? Blame It on Your Stable Brain, 2021), we could say: ***"If you find difficulties in transdisciplinary communication, blame your stable brain."*** This intellectual effort is comparable to that demanded by any advanced form of knowledge application, as it confronts ***two opposing and complementary forces: the stability of our neural networks versus the reorganization required for true understanding***. The latter, understood as an emergent property of the whole, can only arise from an increase in the complexity of our neural networks. This is due to the tension between 1) the stability of brain organization, which is a necessary condition for everything we have already learned and is essential for our identity and consciousness, and 2) the new experiences we may have, including learning a new language, engaging in transdisciplinary communication, or applying our knowledge in new ways. This process requires learning different (internal and external) languages from the one we use to acquire our disciplinary knowledge and culture (epistemological values, methods, etc.). Thus, the same plasticity of our brain that allowed us to learn what we already know undergoes (creative) tension when it is also required to apply knowledge to new situations of transdisciplinary communication, including applying knowledge for the purposes of such communication. This may be among the reasons why we have reiterated the intellectual importance of repetition and have analogically compared it to the repetition required in sports and musical activity.

This section could warrant a full article, or even a book. Therefore, let us end it with a necessary synthesis before addressing the next.

The transformation of academic knowledge into 1) understanding and 2) gradually into a more comprehensive understanding takes on special relevance in interdisciplinary contexts, as well as in connecting the academic world more directly with society at large.

In the last decade, interdisciplinary research has moved beyond the simple integration of theoretical or methodological perspectives, incorporating rigorous neuroscience approaches to analyze how systematic and systemic collaboration among professionals from different disciplines can transform participants' cognitive processes and neural networks and, potentially, vice versa.

Under the subtitle *"Neuroscience of Interdisciplinary Collaboration*, recent studies show that this interaction not only enhances creativity and innovation but also induces measurable neurobiological modifications. These include strengthening brain circuits associated with memory, reward, and critical reasoning, as well as developing neuronal connections that facilitate cognitive flexibility and collective knowledge construction.

From this perspective, understanding interdisciplinary collaboration implies recognizing that converting knowledge into understanding is a dynamic process of brain reorganization and increased neural complexity.

Therefore, the importance of transforming academic knowledge into understanding lies in the fact that this process is not merely a transfer of information but an activation and reconfiguration of the brain that allows the emergence of new cognitive skills essential for innovation, complex problem-solving, and integrative knowledge generation. This neuroscientific view strengthens the justification for fostering transversal competencies in academic and professional environments, aimed at maximizing collective cognitive potential and individuals' adaptive capacities in multidisciplinary teams.

6. BRAIN PLASTICITY

Brain plasticity, encompassing neurogenesis and synaptic plasticity, underlies the formation, adaptation, and increasing complexity of neural networks. Neurogenesis produces new neurons that integrate into existing circuits or form new ones, thereby enhancing neuronal complexity. Synaptic plasticity modifies the strength and number of neural connections, enabling the brain to reorganize in response to experience, learning, and environmental stimuli. This dynamic process is fundamental to learning, memory formation, and overall brain function.

Empirical evidence supporting these processes is as follows. Shors, Anderson, Curlik, and Nokia in (Use it or lose it: how neurogenesis keeps the brain fit for learning, 2012) state:

> "The presence of new neurons in the adult hippocampus indicates that this structure incorporates these neurons into its circuitry for functions related to learning and/or associated cognitive processes. *Most of these cells die unless they participate in some form of effortful learning experience*. *When learning occurs, new neurons integrate into the brain circuits involved in learning.* Certain learning processes and mental activities appear to depend on their presence. *A substantial body of literature now demonstrates that effortful learning, involving sustained concentration on present experience, supports new neuron survival.* During such cognitive processing, rhythmic electrophysiological activity patterns engage the new neurons synchronously with existing hippocampal and efferent networks. *This concurrent activity facilitates the integration of new neurons with established ones,* ***allowing current experiences to relate to recent memories to support learning***. Thus, neurogenesis and learning interact to maintain a fit brain." [Italics and emphasis added]

This evidence demonstrates that neurogenesis and synaptic plasticity expand neural networks through the formation of new synapses.

Both neurogenesis and plasticity are closely linked to learning. ***It is well-established that learning creates new neural connections and increases overall brain complexity, which, in turn, enhances the capacity for further learning***. This reciprocal relationship is formed by cybernetic principles, highlighting an ***interdependence between brain complexity and learning***. *This also applies to relearning through cybernetic reiteration, as previously discussed, such as in Richard Feynman's Teaching Technique.*

This reciprocal dynamic between learning and brain complexity exemplifies a fundamental cybernetic principle, where internal cognitive processes interact with external stimuli. These cybernetic interactions encompass regulatory loops with negative and anticipatory (feedforward) feedback mechanisms, as well as co-reinforcing loops driven by positive feedback. Essentially, as brain complexity increases, readiness for learning improves; conversely, *enhanced learning fosters greater brain complexity.*

Further empirical research corroborates brain plasticity regarding the synaptic connections that link new neurons with existing networks, facilitating network enhancement and potential reorganization due to novel experiences and learning.
A growing body of studies shows that thousands of new neurons are generated daily in the adult brain, with these neurons implicated in learning and novel experience adaptation. For example, Shors et al. in (Use it or lose it: how neurogenesis keeps the brain fit for learning, 2012) observe:

> "Thousands of new neurons are added to the adult hippocampus daily; nonetheless, most do not survive. One of the most effective ways to prevent their death is through effortful learning. Successful learning sustains the survival of these new neurons. Furthermore, these cells establish anatomical connections with other neurons, impacting neuronal activity not only within the hippocampus but also presumably across afferent brain regions."

> "Initially, the notion that new neurons could be influenced by and play roles in learning was met with skepticism. Before the discovery of neurogenesis, it was assumed that learning and memory formation primarily involved modification of synaptic connections among pre-existing neurons. However, recognizing neurogenesis requires reconsidering these assumptions: Are new neurons passive bystanders or active participants? Essential or modulatory? Why does the brain generate new neurons, and how is their number optimized to be functional without disruption? This review proposes a ***positive feedback loop between neurogenesis and learning, wherein learning enhances new neuron survival, thus supporting more efficient future learning***. [Italics and emphasis added]

From this, the following inferences can be made:

1. Cybernetic relationships exist between learning and neural complexity (see Figure 3).
2. Increasing learning correlates with enhanced neuronal system complexity.
3. As complexity escalates, emergent properties arise within the neural system.

This principle extends to the intellectual effort required for effective transdisciplinary communication, clearly exemplified by the Feynman Technique. This method promotes iterative relearning through teaching or simulating teaching of the same material until transdisciplinary communication is achieved effectively.

It is widely accepted that both learning and relearning foster new neural connections and augment brain complexity, directly linked to learning capacity. Thus, learning and brain complexity form a reciprocal cause-and-effect relationship: increased learning (or relearning) yields increased brain complexity, which prepares the brain for even greater learning.

In summary, increased learning leads to heightened neuronal system complexity, thereby enhancing the efficiency and efficacy of future learning. This cybernetic relation comprises both regulatory feedback (negative and anticipatory) and positive reinforcement. This dynamic underlies the proven effectiveness of methodologies such as Feynman's reiterative learning technique.

This principle applies to intellectual efforts made in achieving effective transdisciplinary communication, though other methods also exist. Feynman's Technique explicitly exemplifies this principle methodologically, relying on iterative learning and relearning, through teaching or its simulation, until communication with very young students is achieved.

To reiterate, ***it is well-established that learning and relearning foster new neural connections, increasing brain complexity and its learning capacity***. Consequently, learning and brain complexity form a mutual cause-and-effect cybernetic relationship; the more one learns, the more complex the brain becomes, and the better prepared it is for subsequent learning.

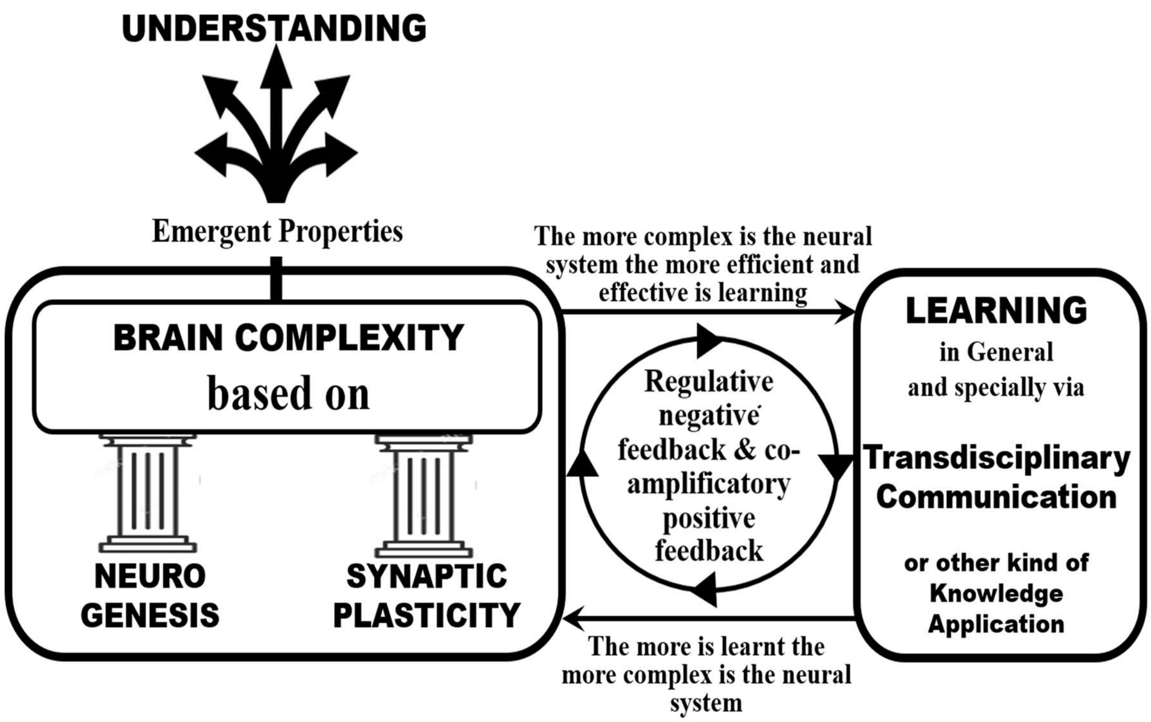

Figure 3: Understanding is an emergent property derived from brain complexity, based on neurogenesis and synaptic plasticity, both of which support learning processes. These processes maintain cybernetic relationships with brain complexity through 1) regulatory negative feedback and 2) reciprocally reinforcing positive feedback. The greater the complexity of the brain's neuronal systems, the more effective and efficient the learning processes become. Conversely, the greater the intellectual effort dedicated to learning, as in transdisciplinary communication or in the application of knowledge to real-life problems, the greater the increase in the complexity of neural networks, which in turn generates more emergent properties and a deeper and, potentially, more comprehensive understanding of the respective knowledge.This potentialty deppend of the diversity of the applications.

Succinctly, enhanced learning complexity leads to a more efficient and effective neural system for future learning, a cybernetic relationship maintained through negative, anticipatory, and positive feedback. This relationship underpins the effectiveness of reiterative learning methods such as the Feynman Technique.

7. CONCLUSIONS

This article has shown that *knowledge* and *understanding*, although closely related, are distinct concepts and notions. Their meanings overlap in shared and/or coexisting dimensions, while in their differences, they may sustain cybernetic relations of regulatory or reinforcing feedback. These common and uncommon aspects arise because knowledge, conceived as justified belief or validated information, can exist without understanding; while understanding, conceived as the capacity to interpret, apply, and relate what is known, can manifest even in the absence of prior formal knowledge. Yet, when integrated synergistically, the two significantly amplify effectiveness in generating new knowledge, as well as in deepening its understanding and making more effective applications of knowledge.

The theoretical and empirical evidence reviewed indicates that the intellectual effort required to apply knowledge (including its use in transdisciplinary communication and in the resolution of complex real-world problems) enhances the complexity of neural networks, thereby increasing the likelihood that understanding emerges, or, if already present, is enhanced and may become more comprehensive. This process is reinforced through reiteration, active learning, and relearning, as exemplified by Feynman's Technique, which transforms teaching (whether real or simulated) into a mechanism of more understanding via cybenetically ***reiterated relearning.***

Transdisciplinary communication also appears not merely as a vehicle for knowledge transfer but as a catalyst of understanding. It demands translation across different semiotic systems and adaptation to diverse conceptual frameworks. Such translation, comparable to learning a new language, functions both as a cause and as an effect of understanding, with benefits multiplied in collaborative and interdisciplinary settings.

Accordingly, understanding may be identified as an *emergent property* of complex cognitive systems, whose development depends on the dynamic interplay between thought and action. This recognition suggests the need to rethink educational, research, and professional strategies. Specifically, the integration of reductionist and holistic approaches within a cybernetic framework could enhance both effectiveness and efficiency in the construction of knowledge, its transformation into understanding, and its transfer to society. Promoting the intersection and feedback between knowledge and understanding is, therefore, not merely an academic aspiration but an essential condition for sustainable innovation, for adaptation in an increasingly complex world, and for more directly connecting academia with the society that sustains it: both 1) through human resources (students, professors, instructors, and educators in general) and 2) financial resources (tuition fees, academic charges, scholarships, and public subsidies, the latter largely derived from taxpayers).

In sum, the central thesis advanced here is that effective communication relies on what interlocutors already share, so as to make possible the transmission of what they do not share. This principle reflects the very essence **of *communication***: employing the ***common*** in order to convey the ***uncommon*** (a deliberate threefold play on the term *common*).

This conceptual thesis found empirical validation in an experience carried out by coauthor María Silvia Cadile, together with her student María Valentina Zatti Duplant: teaching basic principles of chemistry to the student's grandmother, using culinary practice as a shared intergenerational ground.

The episode served not only as an innovative pedagogical exercise but also as a vivid demonstration of the principle defended here: knowledge, as a specific form of information, can only be effectively communicated when anchored in a common ground that renders the unfamiliar intelligible. For the first author, the revelation this experience entailed reinforced Albert Einstein's conviction when he employed the hyperbolic metaphor cited at the beginning of this article: a metaphor which, through this pedagogical experiment, professor Cadile and her student transformed into empirical reality. Similarly, it seems reasonable to conclude that another Nobel laureate in Physics likewise achieved such empirical reality through his repeatedly tested pedagogical technique for transmitting abstract and complex concepts, such as those of quantum mechanics, to first-year undergraduates.

In this context, it is timely to reiterate the distinction between ***academic work*** and ***academic employment or academic job.*** Academic employment or job constitutes only one dimension of academic work, which by its intrinsically human nature should not be reduced to contractual or institutional functions. Academic work also includes formative, communicative, and affective dimensions that both encompass and transcend the merely instructional and occupational scope.

An essential element of such work is the *educator's ability, often requiring relearning, to communicate in the language of their students*. Effective knowledge transmission requires beginning with what is shared (the common) as a basis for introducing the novel (the uncommon). The clearest example of this principle is the relationship between mother and infant: the mother first learns the infant's non-verbal language (touch, gaze, facial expressions, and varied sounds) in order to introduce, on that foundation, verbal language. She may even imitate the infant's sounds to create a communicative bridge that enables ***mutual learning***.

Analogously, Richard Feynman transformed this practice into a pedagogical technique. To make complex physics comprehensible to first-year undergraduates, he had to "translate" his knowledge into terms accessible to them. This required the exercise of relearning what he already knew, but in the language of his students. To accomplish this, Feynman relied not only on cognition but also on motivation (conation) and affection (the emotional dimension that sustains motivation), thereby restructuring his cognitive processes through a reiterative, cybernetic relationship with consecutive loops of negative and positive feedback.

Feynman's experience illustrates that the ***act of relearning one's own knowledge***, by reformulating it across contexts and discourses, not only facilitates students' comprehension but also deepens and broadens the educator's understanding of their own knowledge. The more an educator reiterates and reformulates knowledge in relation to students' horizons, the more deeply that knowledge is understood by the educator and better communicated to the students.

A similar process occurs when professionals, students, academics, or professors working as consultants seek to apply their knowledge to real-world problems, whether in business, academic projects, thesis, organizations, public institutions, or universities. Application of knowledge in practice raises the practitioner's own level of understanding, particularly when the application is effective.

To summarize: applying knowledge is, in itself, a process of understanding it more deeply and comprehensively. One key form of such application (the central focus of this article) is the effective explanation of what one knows. Yet, for explanation to be minimally effective, a minimum level of understanding of the knowledge to be applied is indispensable, whether in teaching or in solving real-world problems.

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We wish to acknowledge the importance our students have had in our academic, professional, and daily lives. *Thanks to them, we ourselves have improved. With our students, we learn what is not available in books, whereas what they learn from us, when reduced to the merely instructional, is often already found in texts*. To restrict our activity to the instructional alone would be to neglect that this constitutes only one dimension of a broader educational whole, which is part of academic work as an intrinsically human activity, and which should never be reduced exclusively to academic employment or a job.

Instruction is, without question, an absolutely necessary condition, but is it sufficient? Or is a minimum level of understanding also indispensable in order for knowledge to become meaningful and transformative learning?

Consider the simple example of memorizing a mathematical formula. Knowledge is the ability to recite it and apply it mechanically on an exam. Understanding, however, is evident when facing a real-world problem, such as calculating the materials required to build a ramp for wheelchair access, where applying the formula depends on one's understanding, or at least on the intellectual effort to understand it in that particular situation. Whoever possesses the minimum necessary understanding can connect it to a practical, human, and social purpose, or explain it in a way that prevents it from remaining mere information to be memorized. In the first case, one possesses knowledge; in the second, one achieves understanding. ***It is precisely in this transition that students play a decisive role: their questions and needs reveal the limits of knowledge and the urgency of understanding.***

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APPENDIX A

Table A: Knowledge vs. Understanding

Subject	Main Idea	Key Details	Association with Other Works
Main and Basic Distinction	Differentiating between knowledge and understanding is key to rigorous academic analysis.	Knowledge involves the accumulation of data, facts, and theories; understanding requires integrating, interpreting, and relating that knowledge to generate meaning.	This distinction aligns with epistemological approaches that separate the descriptive (*episteme*) from the interpretive (*noesis*).
Knowledge	Knowledge is a structured set of validated information.	Includes explicit (documented) and implicit (tacit) knowledge, and depends on cultural, historical, and disciplinary contexts.	Matches the definition of (Nonaka & Takeuchi, 1995) regarding tacit and explicit knowledge.
Understanding	Understanding is an active and relational process.	Goes beyond memorization, integrating cognitive, emotional, and ethical dimensions. Enables anticipation of consequences and acting with prudence.	Close to the Aristotelian concept of *phronesis* (practical wisdom).
Relationship Between the Two	Knowledge without understanding can be sterile; understanding without knowledge may lack foundation.	Their interaction generates greater depth, applicability, and adaptability.	Reinforces Ausubel's notion of meaningful learning, where new information is related to prior knowledge (Moreira, 2003).
Applications of the Distinction	This distinction is relevant for education, research, and decision-making.	In education, it fosters critical thinking. In research: drives innovative interpretations. In decision-making, it helps assess implications.	Linked to critical thinking theories (Paul & Elder, 2022), which can serve as a bridge between knowledge and understanding.
Main and Brief Conclusion	The balanced integration of knowledge and understanding is essential for academic, practical, and professional praxis.	Understanding supports the transfer of knowledge to different, complex, and/or changing contexts.	The understanding of knowledge is aligned with transdisciplinary and/or systemic perspectives and is effective in Transdisciplinary Communications.