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Article

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Transdisciplinarity: the search for the unity of scientific and technological knowledge

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ABSTRACT

Introduction: Reflections about the unity of knowledge have taken place at various times in history. Modern science, however, brings in its wake the issue of disciplinary specialization, which caused a profound change in the search for scientific knowledge. The new disciplinary order, increasingly specialized, hindered the integrated vision of science and knowledge, leading to a distancing from the various realities contained in the same problem or circumstance, and even disregarding the necessary integration among knowledges. Objectives: To understand the relevance of searching for all aspects of the same situation, this research aims to deepen the contributions and understandings of some of the first thinkers who dealt with the unity of knowledge, extending to Kurt Gödel, considered as the father of transdisciplinary, and to Mode 2 of knowledge production by Michael Gibbons. Method: This study consists of an interpretivist, qualitative research, resulting in a critical literature review, which synthesized the information through evaluation and in-depth discussion about the unity of scientific and technological knowledge. Results: Unity of knowledge refers to the fact that conditioned knowledge can only achieve its integrity through unconditioned knowledge, the latter not merely a contingent aggregate, but an indispensable system for the complete identity of conditioned knowledge. Conclusion: Transdisciplinary, in this respect, is the search for the unity of knowledge, beyond disciplinary boundaries, to capture the full complexity of the multidimensional and the multi-referential Reality of the conditioned element.

KEYWORDS

Unity of knowledge. Transdisciplinary. Scientific and technological knowledge.

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Transdisciplinaridade: a busca pela unidade do conhecimento científico e tecnológico

RESUMO

Introdução: Reflexões sobre a unidade do conhecimento tiveram lugar em diversos momentos da história. A ciência moderna, no entanto, traz em sua esteira a questão da especialização disciplinar, que causou profunda mudança na busca pelo conhecimento científico. A nova ordem disciplinar, cada vez mais especializada, dificultava a visão integrada da ciência e do conhecimento, levando a um distanciamento das várias realidades contidas em um mesmo problema ou circunstância e até mesmo desconsiderava a integração necessárias entre os saberes. Objetivos: Para compreender a relevância de buscar todos os aspectos de uma mesma situação, essa pesquisa tem como objetivo aprofundar as contribuições e entendimentos de alguns dos primeiros pensadores que trataram sobre a unidade do conhecimento, estendendo-se até Kurt Gödel, considerado o pai da transdisciplinaridade e ao Modo 2 de produção de conhecimento de Michael Gibbons. Método: Esse estudo consiste em uma pesquisa interpretativista, qualitativa, resultando em uma revisão crítica de literatura, que sintetizou as informações por meio de avaliação e discussão aprofundada sobre a unidade do conhecimento científico e tecnológico. Resultados: Unidade do conhecimento refere-se ao fato de que o conhecimento condicionado só pode alcançar sua integridade por meio do conhecimento incondicionado, este último não apenas um agregado contingencial, mas um sistema indispensável para a completa identidade do conhecimento condicionado. Conclusão: A transdisciplinaridade, nesse aspecto, é a busca da unidade do conhecimento, além das fronteiras disciplinares, a fim de captar toda a complexidade da Realidade multidimensional e a multirreferencial do elemento condicionado.

PALAVRAS-CHAVE
Unidade do conhecimento. Transdisciplinaridade. Conhecimento científico e tecnológico.

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1 INTRODUCTION

Reflections on the unity of knowledge have been widely expressed at various times in history. The first records come from the ancient philosophers, continue in the Middle Ages, are in the Enlightenment, in the theoretical foundations of the mereology of systemic thinking and throughout the philosophy of science. The theme intensifies as of the 16th century with the revolutionary ideas of Germans, French, English, and Italians about knowledge and the scientific method that will give rise to modern science, among them Francis Bacon, Galileo Galilei, René Descartes, Blaise Pascal, John Locke, Isaac Newton, Gottfried W. Leibniz, David Hume, and Immanuel Kant.

Modern science, however, brings in its wake the issue of disciplinary specialization, which caused a profound change in the quest for scientific knowledge. The new disciplinary order, increasingly more specialized, hindered the integrated vision of science and knowledge, leading to a distancing from the various realities contained in the same problem or circumstance and even disregarding the necessary integration between the knowledges. Observing this trend, numerous movements and initiatives emerged expressing concern about the disintegration of the unity of knowledge. The illuminists, for example, organized the Encyclopédie or Dictionnaire Raisonné des Sciences, des Arts et des Métiers,[i] a 17-volume collection launched between 1751 and 1772 to gather, organize, and disseminate available knowledge. Despite the grandiose undertaking, the fragmentation of science occurred and remains until today.

As of the 1990s, however, the discussion about the importance of seeking unity of knowledge returns and, strengthened by the concept of transdisciplinarity presented in the 1970s, the thesis that the traditional way of producing knowledge (Mode 1) has given way to a new way (Mode 2), more appropriate to capture the complexity of reality through scientific research. Briefly, for the mentors of the idea, Gibbons et al. (1994), Mode 1 acts on mostly academic problems of a specific community, as opposed to Mode 2 that acts in context, wherever it is; Mode 1 is homogeneous and Mode 2 is heterogeneous; Mode 1 is hierarchical and constant and Mode 2 is heterarchical and transient; and Mode 1 is disciplinary and Mode 2 is transdisciplinary.

In order to understand the relevance of seeking all aspects of the same situation, this research aims to delve into the contributions and understandings of some of the first thinkers who dealt with the unity of knowledge, extending to Kurt Gödel, considered the father of transdisciplinarity, and to Mode 2 of knowledge production by Michael Gibbons.

This study consists of an interpretativist, qualitative research, supported by a narrative literature review, based on the authors' consensus and criticism of the available scientific production, which considers the experience and evaluation of experts, familiar with the evidence of accumulated knowledge in the area. The result is a critical literature review, which synthesized the information through evaluation and in-depth discussion about the unity of scientific and technological knowledge. The ideas put forth here provided support for the proposition of a research method for transdisciplinary co-production, presented in the work Frameworks for scientific and technological research oriented by transdisciplinary co-production, by Alvares and Freire (2022).

2 THE CONCERN WITH THE UNITY OF SCIENTIFIC AND TECHNOLOGICAL KNOWLEDGE

2.1 The new science described by Francis Bacon (1561-1626)

Francis Bacon (1561-1626) devoted much of his intellectual energy to explaining the new science of the 17th century. In his seminal work Advancement of Learning[ii] he argued that the deductive logic (or Aristotelian logic) of the search for truth and knowledge, which originated in Antiquity[iii], was insufficient for the development of science in the modern era. Bacon systematized the inductive method, already widely used by his contemporary Galileo (1564-1642) in an innovative combination of experiments and mathematics, and even before these exponents of science and the scientific method. Lakatos and Marconi (1991) state that "induction, as a reasoning technique, has existed since Socrates and Plato". (p.64).

These two forms of reasoning - deduction and induction - are rational methods for understanding science. Rather than just freely following thought, the deductive and inductive methods are based on reflection, following a coherent procedure, starting from elements of reason. The first, called syllogism by Aristotle, starts from general statements (universal laws) to reach a conclusion in a particular case. Its objective is to explain the content of the premises. Since the premises are true, the conclusion can only be an incontestable truth, since the information was already in the premises, even implicitly. However, since the conclusion is drawn from the premises, it only confirms a truth, there is no novelty in the information generated from the analysis, even though it is far from obvious. This type of reasoning is widely used in physics and mathematics, for example.

Deductive reasoning is considered limited because it does not expand the possibility of new discoveries. It only confirms what is already estimated to be true, it emerges from the demonstration of what was already implicit in the premises and, as a result, science is reduced only to the knowledge originated from this path in search of truth, in the name of security and precision. On the contrary, the premises in inductive reasoning are the observations and experiments (the evidence) towards conceptual generalizations (conclusions) that may or may not be true. The conclusions reached are truths not contained in the premises considered; they bring, therefore, novelty, creation, revolution.

Unlike the deductive method, which reaches true conclusions if it is based on true premises, the conclusions of the inductive method are only probable. However, it enables the extension of knowledge because the goal is its expansion and new discoveries. It loses in precision, but if all premises are true, the conclusion is true (but not necessarily true). Induction, in short, is the relationship between observational evidence and scientific generalization. Today science recognizes other abstractions of the possibilities for conducting scientific research, each appropriate to the type of investigation being conducted, such as the hypothetico-deductive, dialectical, and phenomenological methods.

Returning to Bacon, in the second volume of the publication, emblematically entitled New Organon[iv1v2] , he organizes and proposes inductive reasoning, appropriate to the empirical search for knowledge, distinguished by a clear commitment to observation and experimental proof as a condition for scientific fact. Martin (1926) states that scientists before and contemporary to Bacon reflected science also from the perspective of analysis and testing, but concluded by deductive reasoning, while the New Organon defended the formal validity of the inductive method in a novel way. Underlying the main concepts, the work makes clear the benefit of the progress of science to society and warns of the state of permanent evolution of knowledge by stating that, "it is not expected that a thing can be fully completed in the course of a lifetime but provides for successors." (Bacon, 1605, in edition included in Martin, 1926, p. 13).

Bacon is hopelessly linked to the past and the present, he is the link between the renaissance[vi] and the modern era. A contemporary of Galileo and Descartes, he was among the first to understand the need to establish a new path in the search for true knowledge.

2.2 The scientific method of René Descartes (1596-1650)

Francis Bacon (1561-1626) and René Descartes (1596-1650) are considered the founders of modern science, Bacon as the pioneer of the experimental method and Descartes with the rigorous path in search of truth. The Englishman's work, Novo Órganon, the second volume of the Advancement of Learning collection, is the focal point of his thought, while the Frenchman recorded his fundamentals in several different moments, which confirm one by one the defense of the unity of knowledge, such as in the work Rules for the Direction of the Spirit, written in 1628, but only published posthumously in 1701 (in Latin). In this work Descartes makes the theoretical assumption that "one must believe that all the sciences are so interconnected that it is much easier to learn them all together than to separate them from each other. Therefore, if anyone seriously wishes to investigate the truth of things, he should not select any particular science" He goes on to conclude that, "one should simply think of increasing the natural light of reason, not in order to solve this or that scholastic difficulty, but in order that the intellect may show the will what must be decided in the particular situations of life." (Descartes, 1998, p. 69).

The circumstances that lead Descartes to his intellectual production was uncertainty about the principles that supported the quest for knowledge in that period and how scientific inquiry should happen. So he writes "Rules...", an unfinished set of three books of which only the first was published in full, with 12 rules, which become, in fact, the prelude to Discourse on Method[vii], of 1637 (in French), the monumental contribution of the mathematician, when he comes to the conclusion cogito ergo sum: "I am thinking, therefore I exist" (Descartes, 1637 apud Maclean, 2006, p. 32).

The work, moreover, synthesizes four rules, which the philosopher deems sufficient to establish a method, different from what there was, sufficient to sustain the logic that he revealed in the search for truth. They are (i) evidence, never accepting anything as truth without first judging indisputably that it is so, something which it would not be possible to doubt, avoiding prejudice and premature conclusions; (ii) analysis, dividing all difficulties under examination into as many parts as possible, and as many as were necessary to resolve them in the best way; (iii) order, conducting thoughts in a certain order, beginning with the simplest and most easily understood objects, and gradually ascending to the most complex; (iv) enumeration, the long chains of reasoning in the right order to deduce one thing from another, "there can be nothing so remote that one cannot eventually reach it, nor so hidden that one cannot discover it." (p. 20)[viii] .

In the preface to the French translation of Principles of Philosophy[ix] (Principes de philosophie, in 1647, 3 years after the 1644 Latin release) he presented an image of the relations of knowledge in the form of a tree, an analogy that goes back to Ramon Llull's 1296 publication entitled Tree of Science[x] , where each science is represented by a tree with roots, trunk, branches, leaves, and fruit. The roots represent the basic principles of each science, the trunk is the structure, the branches, the genera, the leaves, the species, and the fruits, the individual, his acts, and his purposes. Llull's representation, in turn, is influenced by the ancient Greek philosophers, especially the Aristotelian classifications and even the metaphor of a tree used by Descartes, where he projects that "philosophy as a whole is like a tree whose roots are metaphysical, whose trunk is physical, and whose branches, which grow out of this trunk, are all the other sciences" (Mattews, 1989, p. 87-88).

Matthews (1989) describes Descartes' body of work as a "systematic philosophy" encompassing all branches of knowledge which in turn is based "on some undeniable principles, and all knowledge would be deduced from them, so that metaphysics, physics, mathematics, morals and politics would all be coherent" From this foundation, Descartes concludes that "knowledge is an organic whole, in which all fields have the same method," thus giving rise to the metaphor of the tree. "This doctrine of a single, comprehensive method, is contrary to that of Aristotle, for whom the different fields of human knowledge all have their own subject matter and appropriate method." (p. 87-88).

Everything is evidence of Descartes' unifying thought. According to Ariew (1992), "From his earliest writings, the 'Private Thoughts,' for example, we have Descartes' dream of a chain of sciences that would be no more difficult to retain than a series of numbers"[xi] (p.111), or Rule 1 "an explicit denial of the doctrine that the sciences should be distinguished by the diversity of their subjects, 'all sciences being in truth only human wisdom, which always remains one and identical with itself, however different the objects to which it applies' [xii]" (p.111).

2.3 The whole and its parts by Gottfried Wilhelm Leibniz (1646-1716)

Gottfried Wilhelm Leibniz was born in Germany in 1646 shortly before Descartes' death in 1650. The polymath excelled in various fields of knowledge, among them philosophy, where he recorded his perception of reality in several documents. For example in: "true unity, unlike an abstract unity, is that it contains an infinite variety or a world of diversities[xiii]" (Cardoso, 2016, p.20) or "I realized that it is impossible to find the principles of true unity in simple matter [...] since everything there is just a collection or amalgam of parts to infinity[xiv]" (Cardoso, 2016, p.20) or in Luca's (2016, p. 18) placement on Leibniz's idea that "the unity of the world is represented from perspectives, that is, from divisions that we ourselves perform to better understand the whole"

Further explaining Leibniz's understanding of the whole and its parts, Luca (2016, p. 18) understands that by

> Systematically arranging the subjects, on the one hand, may undoubtedly be better for acquiring clear and distinct knowledge, because it is a practical response to our needs (indexes, taxonomies, classification systems), but, on the other hand, what should not be lost sight of, is that this whole body of particular sciences is one, continuous, uninterrupted, that is, it achieves its natural flow better by multiplying the relationships and connections that can be made between the knowledges.

Leibniz argues that a truth can be in several realities, depending on the point of view adopted and that the divisions of knowledge are arbitrary, "are not a consequence of the very nature of knowledge, but of our agency" (HIRATA, 2012, p. 24), for in the words of Theophilus[xv]: "This division was famous even among the ancients [...] But the main problem about the division of the sciences is that each of the branches appears to swallow the others." (LEIBNIZ, 2015, p. 258)[xvi] .

The mereology[xvii] presented in Leibniz's metaphysics originates from the work of Aristotle, whose part-all axiom is known by some as an Aristotelian principle (ATTEN, 2017), due to the words "The relation of that which exceeds to that which is exceeded is numerically indefinite, [...] while that which exceeds, in relation to that which is exceeded, is 'so much' plus something else" (ARISTOTLE, 1989, P. 1021a). According to Varzi (2016), the part-all relation represents a relation that is reflexive (since everything is part of itself), transitive (because any part of any part of a thing is itself part of that thing), and antisymmetric (since two distinct things cannot be part of each other).

For Burkhardt and Degen (1990), the part-all relation is an essential element of Leibnizian philosophy. In the Dissertatio de arte combinatoria[xviii] , Leibniz describes the doctrine of the whole and its parts, with an important distinction: "he separates the relation between the whole and its parts from the relation between the parts themselves, and he gives these different kinds of relations different names." In Nouveaux Essais (LEIBNIZ, 2015), the Latin expression "*dictum de omni et de nullo*[xix]" is used by Leibniz to illustrate "that on the one hand not every content is a whole and on the other hand every true is more than the parts, while the thing it contains and what is contained by it are in a sense equal." (BURKHARDT and DEGEN, 1990, p. 6).

2.4 The Roots of Systemic Thought in Johann Heinrich Lambert (1728-1777)

The ideas of Bacon, Descartes, and Leibniz lead to the effective dismemberment of science and philosophy in the modern era. Empiricism and the inductive method take over in the search for scientific knowledge and the years to come would bring in the 18th century the complexity conception of science, with Johann Heinrich Lambert (1728-1777). Best known as a physicist and mathematician, Lambert's paradigm discusses an approach to structure complexity as a set of interrelated elements, described as various types of systems, such as the systems of scientific knowledge, belief, cultures, religions, among many others (HARDORN, 2008).

His systems science, described in the Neues Organon, describes how the scientific approach (both experimental and theoretical) should be and constitutes the foundation of systems thinking. In the paper, he records that human knowledge is partial and that to achieve it in whole, an interactional approach should be adopted with the environment. Billick (2010) states that "almost every item in Lambert's scientific output [...] is evidence of his systematic spirit and his versatility in changing and adapting procedures to circumstances." (p.67).

It is worth noting that, like Bacon, Lambert used the word Órganon in his publication of how to conduct scientific work, but with the emphasis that it should be used and understood as originally conceived, as a collection of tools to be employed, combined and assembled according to the problem at hand. Lambert was concerned with the step-by-step of the scientific experiment, with the modus operandi, with routines and subroutines, partly taken from other scientists, partly developed by him (BULLYNCK, 2010). And for that reason, he conceived an open approach of interacting and interdependent parts, "mapping the ephemeral geography of thinking, researching, and finding. This is expressed in the conclusion of a long fragment on how to analytically transform experiments into a system" (p. 67).

2.5 Kurt Gödel's incompleteness theorem (1906-1978))

Another important foundation for understanding the search for knowledge is Kurt Gödel's Incompleteness Theorem (1906-1978). The scientist proved that mathematics is full of paradoxes, clearly demonstrating that there are true statements that cannot be proved, even if correct, and that the consistency of a system cannot be proved within the same system. These theorems revolutionized mathematics and expanded the foundations of the quest for knowledge, as the understanding of reality rose to another level.

In practice, the theorems led the scientific community to distinguish various levels of reality, to ever deeper and more comprehensive knowledge, and to the certainty that all knowledge is equally important, overcoming the prejudiced hierarchization of knowledge. Nicolescu (1996a, p. 9) notes that the Godelian structure of the levels of reality implies that it is impossible to construct a complete theory from a single perspective, that is, "a new Principle of Relativity emerges from the coexistence between complex plurality and open unity: no level of Reality constitutes a privileged place from which one is able to understand all other levels of Reality".

From this Principle one comes to recognize that "one level of reality is what it is because all other levels exist at the same time" and, it gives rise to "a new perspective on religion, politics, art, education and social life. And when our perspective on the world changes, the world changes. In the transdisciplinary view, reality is not only multidimensional, but also metareferential (NICOLESCU, 1996a).

Unlike the disciplinary approach, the multi-referentiality and multidimensionality of knowledge leads to the distinction of several levels of reality and with this view, the approach moves from the classical logic of disciplinarity to transdisciplinarity. Whatever the point of view, Gödel's propositions need to be considered in any modern study of knowledge, it is indeed, as Nicolescu (1996b) assures "at once the apogee and the point of decline of classical thought ... since the transformation came from the holy of holies of classical thought: mathematical rigor" (p.8).

The Incompleteness Theorem did not achieve repercussion in the 1930s, and indeed, only at the dawn of quantum mechanics did the Gödelian structure of the levels of Reality reach the dimension of being one of the most important contributions to science, unveiling the transdisciplinary approach. For this reason, Kurt Gödel is considered the father of transdisciplinary thinking, whose discussion only germinated four decades later, in the historic French event.

2.6 Transdisciplinarity

The contribution of Jean Piaget and André Lichnerowicz to transdisciplinarity began in the 1970's[xx] and extended for some time until each embraced their main areas of interest, for which they became known. The biologist Piaget devoted his entire life to studying the process of knowledge acquisition, especially by children. Lichnerowicz was devoted to the study of differential geometry and was recognized for his contributions to the field, including his chairmanship of the Lichnerowicz Commission, formed to examine the pedagogical design of mathematics education.

By the early 1970s both were involved with issues of science teaching and learning, and Piaget, in particular, was aware of initiatives in the scientific community for disciplinary discussion, including the Unity of Science movement of the first half of the 20th century (1922 to 1936), founded by a group of scientists and philosophers who met regularly at the University of Vienna (hence it was called the Vienna Circle, also known as the "Ernst Mach Society"). The movement held that there should be a unitary set of physical premises from which the regularities of all reality could be derived [xxi].

During the 1970 event, this view was contained in the reflections of his paper "L'épistémologie des relations interdisciplinaires", as well as the necessary distinctions between interdisciplinarity and multidisciplinarity, the results of which led him, in fact, to plough the term and the first concept of transdisciplinarity:

> Finally, we hope to see the succession of interdisciplinary relationships to a higher stage, which must be 'transdisciplinary,' that is, which does not merely recognize the interactions and or reciprocities between specialized research, but which locates these links within a total system without stable boundaries between disciplines (PIAGET, 1972, p. 144).

Throughout the Congress, it is evident that the educator understands transdisciplinarity as a new form of disciplinary relations, more integrative than interdisciplinarity, going beyond and even being a result of interdisciplinarity. Nicolescu (2006) points out that "the description is vague, but it has the merit of pointing to a new space of knowledge without stable boundaries between disciplines." (p. 1).

At the end of the paper, however, he attributes to André Lichnerowicz the deepening of the concept of transdisciplinarity: "As for specifying what such a concept can encompass, it would obviously be a matter for a general theory of systems or structures [...] it is up to the mathematician to tell us more and Lichnerowicz will enlighten us about this future[xxii]" (PIAGET, 1972, p. 171).

Lichnerowicz's approach is, as expected, mathematical, since that is his background. He adopts the concept of isomorphism to explain transdisciplinarity. In mathematics, isomorphism comprises recognizing the phenomena of one object in other objects, that is, if two objects are isomorphic, then any property that is preserved by one isomorphism is also true for the other object. This function can be used to investigate problems in one unknown field from another whose problems are clarified. Therefore, for him, "transdisciplinarity, consists in treating by the same mathematical model (isomorphism) disciplines of a very different nature, but according to the same laws[xxiii]" (LICHNEROWICZ, 1980, p. 22)[xxiv].

For him, the result of this understanding is that regardless of the field of knowledge, there is a homogeneity of theoretical activity in all science and technology[xxv], which "supposes and imposes a certain transdisciplinarity[xxvi]" (p. 31). In a simplified definition, the mathematician understands transdisciplinarity as an "angle of vision that goes far beyond the artificially limited disciplines as subjects of knowledge" (p.31) and clearly expresses his concern about higher education for ignoring this condition:

> All over the world, our present universities train, it seems to me, a very large proportion of specialists in predetermined, and therefore artificially limited, disciplines, while a large part of social activities, like the development of science itself, require men capable of both a wider angle of vision and an in-depth focus on new problems or projects, transgressing the historical limits of the disciplines. These are the men we also need to train[xxvii] . (LICHNEROWICZ, 1980, p. 32).

Piaget and Lichnerowicz's definitions are in the epistemological field. The third participant of the event who dealt with the topic, Erich Jantsch, takes another approach. He defined it from systems coordinated for a common purpose (JANTSCH, 1972). He ventured that knowledge should be organized into purposeful hierarchical systems and in articulating the design of such structures, he introduced the concept of transdisciplinarity.

He perceived that multi-level and multi-objective systems, based on a transdisciplinary coordination, would be the ideal structures for the complete achievement of scientific knowledge. From this point of view, he sees transdisciplinarity as the way to scientific development. Klein (2009) states that of the pioneers, Jantsch's model became the most influential. It was adapted as a conceptual framework in several fields, from the structuring of his concept of transdisciplinarity from General Systems Theory and Organization Theory. And a "new relationship between science and society echoed in the critiques of traditional notions of 'objectivity' and 'progress' (KLEIN, 2009, s/p.). Jantsch, in Klein's (2009) words:

> The effects would be widespread. New kinds of institutions would be needed and a new form of education capable of fostering judgment in complex and dynamic situations. In science, technology, and industry, long-range thinking would replace short-term thinking. In cities and the environment, the negative effects of technology would be reversed, and a systems approach would replace linear modes of problem solving. The university would also gain a new purpose (s./p.).

For Nicolescu (2006), Jantsch's historical merit was to highlight the need for an axiomatic approach (he imagined disciplines and underdisciplined coordinated by a generalized axiomatic) for transdisciplinarity and for the introduction of new values in this field of knowledge.

2.6.1 The Mode 2 of knowledge production by Michael Gibbons, Camille Limoges, Helga Nowotny, Simon Schwartzman, Peter Scott and Martin Trow from 1994

Research led by Michael Gibbons in 1994 understood that many problems are not within a disciplinary framework and a traditional mode of the search for knowledge, which he called Mode 1, characterized by homogeneity and hierarchy. Rather, the problems that give rise to learning are defined and solved in a context governed by the interests of a specific community. The new mode is non-hierarchical, heterogeneous, and involves the close interaction of many actors throughout the knowledge production process. As a result, knowledge production is becoming more socially responsible, more reflexive, and affects science at deeper levels of transformation. This new form of knowledge production, called Mode 2,

> results from a wider range of considerations. This knowledge is intended to be useful to someone whether in industry or government, or society in general, and this imperative is present from the beginning. Knowledge is always produced under an aspect of continuous negotiation and will not be produced unless and until the interests of the various actors are included. Such is the context of application. [...] knowledge production in Mode 2 is the result of a process in which supply and demand factors can be said to operate, but the sources of supply are increasingly diverse, as are the demands for differentiated forms of specialized knowledge (GIBBONS et al., 1994, p. 4).

To qualify the specific Mode 2 form of transdisciplinary knowledge production, the authors identified four distinct characteristics of transdisciplinarity. First, it "develops a distinct but evolving framework to guide problem-solving efforts [...] generated and sustained in the application context rather than developed first and then applied to that context by a different group of professionals" (p 5). The solution, therefore, will arise not only from the application of existing knowledge that will be integrated into the framework, but also from the experience and creativity of the application context itself. Once consensus is reached, the knowledge resulting from the solution can hardly be reduced to disciplinary parts.

According to the solution comprises both theoretical and empirical resources, since "transdisciplinary knowledge develops its own distinct theoretical frameworks, research methods and modes of practice [...] cumulative" (p.5) whose result is not necessarily disciplinary knowledge. Indeed, the cumulative results of an effort to solve a transdisciplinary problem, even if it originates in a specific situation, can certainly go in different directions beyond the academy and the application context, including the emergence of contents that may not be in the current disciplinary map.

Third, the communication of results begins during the knowledge production process itself. Then, the new destination of communication is the new problem contexts. Mode 2 highlights that both the problems and the team responsible for the solution can be highly transitory and therefore it is necessary to safeguard the information generated, especially in information networks that "tend to persist and the contained knowledge will be available to enter other configurations" (p.5).

Fourth, "transdisciplinarity is dynamic. It is the ability to solve problems in motion" (p.5), for Mode 2 is characterized by the increasing interaction of knowledge production with the problem context. Another aspect is that the results are most often outside a specific disciplinary context because the knowledge produced in this way is not molded to any of the disciplines that contributed to its solution.

2.6.2 The abundance of the concept for Julie Klein

Julie Klein (2013) circumscribes five main groups of meaning of transdisciplinarity: those focused on the conceptions of interdisciplinarity, those related to the unity of knowledge, the alignments of participatory and collaborative research, the new forms of knowledge contained in transdisciplinarity and about its transgressive aspect, which questions the existing structure of knowledge, culture, and education. The author emphasizes that, despite the differences in approach, these groups are in communication, in the construction of a "structured plurality of definitions", expression used by Pohl (2010).

In the first approach, the conception goes from disciplinarity to the restrictions of interdisciplinarity and emphasizes that the prefix trans leads to the idea of transcendence, synthesis, and integration. To demonstrate the holistic aspect of the concept, the author brings the OECD definition of transdisciplinarity as a "common system of axioms that transcends the narrow scope of individual disciplines through a comprehensive synthesis" (KLEIN, 2013, p.190) as opposed to the same OECD concept of interdisciplinarity, even if comprehensive: "any form of interaction, from borrowing a method to a new paradigm of research and education" (p.190).

From the group of definitions that bring the discourse of the unity of knowledge, the associated concepts are uncertainty, diversity, non-linearity, multidimensionality, heterogeneity, and relationality supplanting the concepts of certainty, universality, simplicity, linearity, and one-dimensionality. The dichotomies presented are derived from the problems created by the fragmentation of knowledge derived from the expansion of the number of disciplinary specialties, which ignores the logical axiom of transdisciplinarity, of the third term included, where all realities coexist and all matter. Derived knowledge production readily credits the values of interaction, intersection, and interdependence to the new logic of unifying approaches.

The approach that encourages collaborative research and participatory research alludes to cooperation, partnership, and mutual learning. Collaborative research is the result of scientific collaboration and has become increasingly common as it has the potential to solve more complex problems and promote new political, economic, and social agendas. "Scientific collaboration is also known as collaborative research" (SONNENWALD, 2007, p. 644) and can be defined as "the interaction occurring within a social context between two or more scientists that facilitates the sharing of meaning and task completion with respect to mutually shared and superordinate goal (p. 645). The phenomenon of collaboration is not new, but in recent years it has intensified in all areas of knowledge. Wray (2002) points to five reasons for the rise of collaborative research: (i) it increases the quality of research; (ii) it increases explanatory coherence, especially when it involves scientists from various disciplines, favoring "conceptual combinations that establish new theoretical frameworks"; (iii) it reduces the possibility of omissions or forgetting previous findings; (iv) it accelerates the obtaining of results; and, (v) it plays an important role in the training of young scientists, in collaborations that bring together masters and apprentices.

Participatory research became evident with the environmental and sustainability research developed in the 1980s in Germany and Switzerland. It refers to a strategy that emphasizes and explores local knowledge, with the participation and perception of actors from that reality. In participation, the emphasis is on a process of "reflection and action, carried out with and by local people, rather than on them" (CORNWALL and JEWKES, 1995, p. 1667) and whose main difference with conventional research lies in the location of power in the research process, which can be abstracted in the expression "knowledge for action" rather than "knowledge for understanding" (p. 1667).

Cornwall and Jewkes (1995) state that this mode involves various degrees of participation, which can be organized into four possibilities: (i) contractual, when people are hired by projects in order to take part in investigations; (ii) consultative, when context people are consulted about their views by researchers before interventions are made; (iii) collaborative, when researchers and context people work together on projects designed, initiated, and managed by researchers; and (iv) collegial, when researchers and context people "work together as colleagues with different skills to offer, in a mutual learning process where local people have control over the process" (p. 1669).

There are four relevant issues that lead to participatory research, structurally guided by the common good: (i) socially relevant issues, (ii) the need for transcendence and integration of disciplinary paradigms, (iii) the desirability of participatory research, and the (iv) the search for unity of knowledge. The underlying premise is that social problems, derived from an increasingly complex and interdependent society, are not isolated in academic disciplines, rather, "They are emergent phenomena with non-linear dynamics, uncertainties, high political risks in decision-making and divergent values and factual knowledge" (KLEIN, 2013, p. 193), which require academic integration for solutions arising from science (Science of Team Science[xxviii]).

The penultimate group highlights the forms of knowledge, especially the interdependence of system knowledge: target knowledge and transformation knowledge, which are also the principles for the transdisciplinary research project presented by Hadorn et al (2008). For them, transdisciplinarity is the necessary integration across the knowledge system (system knowledge) to deal with the uncertainties that also result from the lack of empirical or theoretical knowledge about a problem. Target knowledge addresses the multiplicity of social situations that lead to the need to specifically define a research problem and its stakeholders from society and science, considering that the respective participations should lead to the development of knowledge and practices that promote the common good (as also pointed out by the third group of definitions identified by Kockelmans, 1979). Transformation knowledge is the technologies, regulations, practices, and relationships that are in the context of the project. Existing infrastructure, power relations, and cultural preferences must be considered to constitute transformation knowledge.

Here it is worth noting the positioning of the infrastructure of transformation knowledge with the revealed knowledge industry. Recently, Ghassib (2012) analyzes and understands the knowledge industry, like any other industry, from: (i) production sites; (ii) producers; (iii) production tools; (iv) raw materials; (v) production methods; and (vi) production products. These are the foundations that give a glimpse of the infrastructure needed to sustain the knowledge of transformation. It is worth remembering that Fritz Machlup, in his 1962[xxix] work, already demonstrated the emergence of the knowledge industries, by mapping their production and distribution in some sectors of the economy in the United States.

Also in this group is the awareness of the coproduction of knowledge, "a new social distribution of knowledge is taking place when a wider range of organizations and stakeholders are involved, including NGOs, private companies, and government agencies" (p. 196). Or as pointed out in the extended work of Gibbons et al. (1994),

> contextualization of problems requires participation in the agora of public debate, incorporating the discourse of democracy. When lay perspective and alternative knowledge are recognized, a shift occurs from just "reliable scientific knowledge" to the inclusion of "socially robust knowledge," dismantling the academic expert/non-academic lay dichotomy (KLEIN, 2013, p. 196).

Social robustness is a term widely used to characterize transdisciplinary research - the quality and application of the results achieved, the relevance, effectiveness, and accessibility of the intervention in the social system. Nowotny, Scott, and Gibbons (2013) point out that robustness is not an absolute, nor is it a relative concept. It is a relational concept, depending on the following considerations: (i) it can only be judged in specific contexts, (ii) it describes a process that in the right time can reach a certain stability, (iii) there is a subtle distinction between robustness of knowledge and its acceptability (by individuals, groups or societies), (iv) it is produced when the is incorporated and enhanced by social knowledge, (v) socially robust knowledge has a strongly empirical dimension.

It is worth adding that socially robust outcomes may include mutual learning, consolidation of trust among stakeholders, establishment of new relationships, advancement in knowledge, and increased ability to work in teams and articulate common goals (POLK, 2011).

The last group of concepts reveals the critique of the existing structure of knowledge, culture, and education and the need for transformation. In addition to issues related to struggles for social change, to questions of culture about the boundaries of class, gender, race, ethnicity, and other identities, and to human rights, at the core of which are the foundations of transdisciplinarity (and even of movements that reject disciplinarity), the pattern here is related to the distancing (and even separation) between tradition and science, West and non-West, theory and practice, and other dichotomies that ignore the varied forms of knowledge. The challenge of transdisciplinarity here is the ability to overcome the divisions that affect research, practice, and learning, to intensify awareness of heterogeneity, incorporating previously excluded forms of knowledge, and thereby increase the relationality of knowledge.

3 FINAL CONSIDERATIONS

Until the Renaissance, science was founded on the corpus Aristotelicum. In the university curriculum, deductive logic was taught across the board. The works of the Organon were discussed in philosophy, theology, medicine, and law. However, from the middle of the 16th century on, those who began to distinguish between the obsolescence of the adopted science theory and the need for a scientific methodology, emphasizing empiricism through the inductive method, appeared on the scientific-philosophical scene of the time.

The transition to the modern period laid the foundations of the new science, and from then on, the foundations of the quest for scientific and technological knowledge and the definitive separation of science and philosophy were laid. This was followed by the scientific method, the foundations of systems thinking, and the critique of the division of knowledge. The 20th century adds new questions to the intended unity of knowledge, among them the distinction between various realities related to the same element. The evolution of the way of perceiving and searching for true knowledge leads to the Unity of Science Movement, which in turn will impact the study of disciplinary relations by Jean Piaget, Andre Lichnerowicz and Erich Jantsch, which would culminate in the first definitions of transdisciplinarity.

The content of this article was intended to bring the axes for the definition of unity of knowledge, the structuring conception of transdisciplinarity. The ideas presented are translated into the following words: unity of knowledge is the concept that recognizes that we must seek the systematic unity and integrity of knowledge, since the very nature of logic and reason resides in the activity of integrating propositions under increasingly general principles, to systematize, unify and complete the knowledge obtained through real understanding. It means unifying it increasingly in the light of the idea of a whole of knowledge, so that the interacting parts are displayed according to convenience. As a result, unifying knowledge means recognizing the multiplicity of theories, in various areas, that must complement each other to create increasingly integrated and efficient explanatory models for explaining the world. However, partially unified knowledge can progress in a law-like manner to a single final theory, which can never really be achieved, because the task of knowledge is infinite, there will always be more to understand and deeper explanations to give.

In other words, unity of knowledge refers to the fact that conditioned knowledge can only achieve its integrity through unconditioned knowledge, the latter not just a contingent aggregate but an indispensable system for the complete identity of conditioned knowledge.

The concept of transdisciplinarity, in turn, carries with it a great amplitude. It began in the 1970s with the works of Jean Piaget and André Lichnerowicz, investigating the disciplinary relations, seeking to advance knowledge beyond the discipline. On the same occasion, Erich Jantsch indicated the need to organize knowledge from hierarchical systems, in whose intersection, for coordination, would be transdisciplinarity. In this position, the concept of transdisciplinarity, according to the author, moves towards solidarity and common purpose. The foundations of transdisciplinarity are widespread and its seeds germinated in the theoretical advances of Joseph Kockelmans in 1979.

For a long time, these were the only landmarks of the transdisciplinary concept, until in 1994 Michael Gibbons and his group developed Mode 2 of knowledge production, reinforcing that problems are not within a disciplinary framework and need to be addressed in a non-hierarchical, heterogeneous manner and with the involvement of many actors (academic and non-academic) throughout the process. Transdisciplinarity thus gets closer to the relevant problems of everyday life, making it more socially responsible, on the one hand, and reaching deeper levels of transformation in science, on the other. This cycle ends in 1996 with Basarab Nicolescu's Manifesto for Transdisciplinarity, presenting the three fundamental axioms for the methodology of transdisciplinarity: the ontological axiom, the logical axiom, and the axiom of complexity, to ensure that it can advance and effectively contribute to the various spheres of its potential.

In the 2010s, Christian Pohl and Julie Klein, among others, assimilate and interpret the various meanings of the new way of understanding knowledge, plural and contextualized, and goes beyond, with a well-defined social purpose in the search for the common good. For them, transdisciplinarity proceeds in the direction of relevant social issues, the coproduction of knowledge and of course, the unity of knowledge. In this work, the long spectrum of meanings has been approached as a continuum, which starts from the disciplinary question and ends in the search for the common good.

The ideas presented are translated into the following words: transdisciplinarity is established as a concept that recognizes that the physical and cognitive structure to understand and seek knowledge needs transformation, to overcome the divisions that disregard other forms of knowledge, those that are beyond disciplinary limits. It seeks the unity of knowledge, in the interacting parts immediately connected to the conditioned element and proceeds as necessary to understand the multidimensionality and multi-referentiality of Reality, implicitly linked, in the search for the common good. As a result, transdisciplinarity reinforces the relationship between the whole and its parts (not only the part is in the whole, but the whole is in the part), allows maintaining duality within unity (it adopts the premise that there are two logics that are at the same time complementary and antagonistic, vital to the functioning of the system) and distinguishes processes as being at the same time products and producers, in a recursive perspective, that everything that is produced returns to what produces it in a cycle contrary to the idea of linearity.

In other words, transdisciplinarity is the search for the unity of knowledge, beyond disciplinary boundaries, to capture all the complexity of the multidimensional and the multi-referential Reality of the conditioned element, from the approach to relevant social issues, conferring deep levels of transformation in higher education, with a view to the coproduction of scientific knowledge aimed at the common good.

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Notes

[i] Diderot, Denis, & D'Alembert, Jean Le Rond. (1751–1772). *Encyclopédie ou dictionnaire raisonné des sciences, des arts et des métiers: par une societé de gens de lettres*. Paris: André Le Breton, Laurent Durand, Antoine-Claude Briasson, Michel-Antoine David.
[ii] Bacon, Francis. (1605). *The advancement of learning (of the proficience and advancement of learning, divine and humane*). (VI volumes). Oxford: Leon Lieffield.
[iii] Aristotelian logic (or the deductive method) for understanding reality and for the pursuit of knowledge was developed in classical antiquity and presented in the Organon, which roughly speaking refers to the following works of Aristotle: Categories, Of Interpretation, Earlier Analytics, Later Analytics (or both just called Analytics by the philosopher), Topics, and Sophistical Refutations (the latter is the final section of Topics). The thinker himself did not use the name Organon to refer to the set (which was only grouped under that name in the middle ages). Aristotle did not even treat them as parts of a single work. Many researchers associate to the set also the work Rhetoric, as confirmation of Topics (Stanford Encyclopedia of Philosophy, 2017a).
[iv] In latin: Novum Organum
[v] The New Organon is the second part (of a total of six) of Advancement of Learning: Book I "The Divisions of the Sciences"; Book II "The New Organon or Instructions for the Interpretation of Nature"; Book III "Phenomena of the Universe or a Natural and Experimental History Towards the Foundation of Philosophy"; Book IV "The Ladder of Intellect"; Book V "Precursors or Anticipations of the Second Philosophy"; Book VI "Second Philosophy or Practical Science".
[vi] *Middle Ages period from about 1348 to 1648.*
[vii] The full name was "Discourse on the method for the good conduct of reason in the search for truth within science" and was written anonymously as a prologue to three other scientific texts.
[viii] Descartes says: "I venture to claim that the scrupulous observance of the few precepts I had chosen gave me such ease in unravelling all the questions [...] not only did I solve some which I had earlier judged very difficult, but [...] I was able to determine, even in regard to questions which I had not solved, by what means and to what extent it would be possible to solve them" (p.21). (I venture to claim that the scrupulous observance of the few precepts I had chosen gave me such ease in unravelling all the questions [...] not only did I solve some which I had earlier judged very difficult, but [...] I was able to determine, even in respect of those questions which I had not solved, by what means and to what extent it was possible to solve them).
[ix] DESCARTES, Renati. (1644). *Principia philosophiae*. Amstelodami: Ludovicum Elzevirium.
[x] LULLI, Raymundi (Illuminati Patris, Maioricensis). (1515). Arbor scientiae: venerabilis et caelitus. 2nd ed. Lyon: Guilhelmi Huyon & Constantini Fradin. (Llull, Ramon. Arbre de la ciència. 1st ed. Rome: 1295-1296). According to Norman (2020), none of Ramon Llull's books appear to have been published before the 15th century, the editions of arbor scientiae, with its famous woodcuts of Llull's trees of knowledge, began to appear in the early 16th century in the edition printed in Lyon in 1515.
[xi] *From his earliest writings, the 'Private Thoughts' for instance, we have Descartes' dream of a chain of sciences that would be no more difficult to retain than a series of numbers.*
[xii] *an explicit denial of the doctrine that the sciences should be distinguished by the diversity of their subjects, "all the sciences being in effect only human wisdom, which always remains one and identical to itself, however different are the objects to which it is applied".*
[xiii] In Letter to Arnauld, April 1687.
[xiv] In New System (1695).
[xv] Theophilus is the character in the book "The New Essays on Human Understanding" which is an item-by-item refutation of John Locke's masterpiece "An Essay on Human Understanding". The two characters in the book are the friends Theophilus, representing Leibniz's rationalism and Philalethes, representing Locke's empiricism.
[xvi] The work was completed in 1704, but not published posthumously until 1764, in respect of Locke's death in the same 1704.
[xvii] In philosophy and mathematics, mereology is the theory of the relations between parts and the whole. It studies the behavior of relationships from part to whole and of relationships from part to part within a whole. Its roots lie in the earliest days of philosophy, beginning with the pre-Socratics and continuing throughout the writings of Plato, Aristotle, and Boethius. Middle Ages thinkers also deal with the subject, such as Peter Abelard, Thomas Aquinas, Raymond Lull, John Duns Scotus, Walter Burley, William of Ockham, and Jean Buridan. Contemporaneously, it is in the works of Brentano and Husserl. (Stanford Encyclopedia of Philosophy, 2016).

[xviii] Leibnüzio, Gottfredo Guilielmo. (1666). *Dissertatio de arte combinatoria*. Lipsiae: Joh.Simon Fickium et Joh. Polycarp. Seuboldum. É a versão ampliada de sua tese doutoral.
[xix] said of everything and nothing.
[xx] whose proceedings were published in 1972.

[xxi] Among their members, were Friedrich Waismann, Gustav Bergmann, Hans Hahn, Herbert Feigl, Karl Menger, Ludwig von Bertalanffy, Marcel Natkin, Olga Hahn-Neurath, Otto Neurath, Philipp Frank, Richard von Mises, Rose Rand, Rudolf Carnap, Theodor Radakovic, Tscha Hung, Victor Kraft, Hans Reichenbach, Kurt Gödel, Carl Hempel, Alfred Tarski, W. V. Quine, e A. J. Ayer (Stanford Encyclopedia of Philosophy, 2017b).

[xxii] *Quant à préciser ce que peut recouvrir un tel concept, il s'agirait évi- demment d'une théorie générale des systèmes ou des structures [...] c'est au mathématicien à nous en dire davantage et Lichnerowicz nous éclairera sur cet avenir*

[xxiii] *« transdisciplinarité », elle consiste à traiter par le même modèle mathématique (isomorphisme) des disciplines de nature fort différente, mais obéissant aux mêmes lois*

[xxiv] The 1980 work resumes the one published in 1973: Lichnerowicz, A. (1973). Mathématique, structuralisme et transdisciplinarité. In Rheinisch-Westfälischen Akademie der Wissenschaften (Ed.). *Natur-, Ingenieur-und Wirtschaftswissenschaften*. Wiesbaden (Alemanha): VS Verlag für Sozialwissenschaften.

[xxv] *qui supposent et imposent une certaine transdisciplinarité*

[xxvi] *Angle de vue dépassant largement les disciplines artificiellement bornées em tant que matières des connaissance.*

[xxvii] *A travers le monde nos universités présentes forment, me semblet-il, une proportion trop grande de spécialistes de disciplines pré- déterminées, donc artificiellement bornées, alors qu'une grande partie des activités sociales, comme le développement même de la science, demandent des hommes capables à la fois d'un angle de vue beaucoup plus large et d'une focalisation en profondeur sur des problèmes ou des projets nouveaux, transgressant les frontières historiques des disciplines. Ce sont ces hommes qu'il nous faut aussi former.*

[xxviii] SciTS

[xxix] Machlup, F. (1962). *The production and distribution of knowledge in the United States.* Princeton: Princeton University Press.