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Multidisciplinarity, Interdisciplinarity, Transdisciplinarity, and the Sciences

David Alvargonzález

The ideas of interdisciplinarity and transdisciplinarity have been widely applied to the relationship between sciences. This article is an attempt to discuss the reasons why scientific *interdisciplinarity and transdisciplinarity pose specific problems. First of all, certain questions about terminology are taken into account in order to clarify the meaning of the word 'discipline' and its cognates. Secondly, we argue that the specificity of sciences does not lie in becoming disciplines. Then, we focus on the relationship between sciences, and between sciences and technologies: we argue that multidisciplinarity and interdisciplinarity are a common practice among strict sciences and technologies. Finally, we discuss the different meanings of transdisciplinarity when it is applied to sciences.*

1. 'Initium doctrinae sit consideratio nominis'

Following the recommendation of the Stoic philosopher Epictetus that 'initium doctrinae sit consideratio nominis', we will begin by considering the meaning we will give, in this article, to the word 'discipline' and its derivatives. The word 'discipline', in the sense that is used in the word 'interdisciplinarity' and the like, means a branch of knowledge, instruction, learning, teaching, or education. The Latin root *discere*, 'to learn', confirms this meaning. So, 'discipline' is a body of knowledge or skills that can be taught and learned. This is the use which already appears as early as in the fifth century, in Martianus Capella's *De septem disciplinis*. The core of the process of teaching and learning is a social relationship between the teacher and his or her disciples (*discipulus* also has the same Latin etymology as *discere*). Techniques, arts, skills, rhetoric, theology, and philosophy, among other things, are likely to be taught and learned and, therefore, in a suitable institution, can become disciplines.

Although the terms multidisciplinary, interdisciplinary, and transdisciplinary are often used interchangeably, we believe it is worth establishing, as clearly as possible,

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some differences in meaning. To establish and clarify these differences, let us now consider the meaning of the prefixes 'multi', 'inter', and 'trans', when applied to the abstract noun 'disciplinarity'.

If we are to be respectful of the common uses of English, the prefix 'multi', from the Latin *multus*, means 'many' ('multimillion'), 'much', 'multiple', 'more than one' ('multiparous'). So, multidisciplinarity refers to an activity associated with many, multiple, or more than one existing discipline. The Latin prefix 'inter' means 'among', as in the word 'international', or 'together', 'mutually' or 'reciprocally', as in the word 'interchange'. Hence, interdisciplinarity refers to an activity that exists among existing disciplines or in a reciprocal relationship between them. But just as international relationships between different countries do not imply denying the sovereignty of each, interdisciplinarity would not negate the independence of each discipline. The Latin prefix 'trans' means 'across', 'beyond' (as in 'transoceanic' or in 'transilient'), 'transcending' (as in 'transubstantiation'), 'through' (as in 'transpiration') and 'change' (for instance as in 'transliterate'). Following these meanings, transdisciplinarity is that which concerns transcending the disciplines, going across and through the different disciplines, and beyond each individual discipline.

Bernard C. K. Choi and Anita W. P. Pak made an exhaustive literature review concerning the use of these three words. Their results seem to be compatible with the Latin roots of the prefixes:

> Multidisciplinarity draws on knowledge from different disciplines but stays within their boundaries. Interdisciplinarity analyzes, synthesizes and harmonizes links between disciplines into a coordinated and coherent whole. Transdisciplinarity integrates the natural, social and health sciences in a humanities context, and transcends their traditional boundaries. … The common words for multidisciplinary, interdisciplinary and transdisciplinary are additive, interactive, and holistic, respectively. (Choi and Pak 2006, 351)

Consequently, they recommend the following definitions:

> *Multidisciplinarity* draws on knowledge from different disciplines but stays within the boundaries of those fields.
> *Interdisciplinarity* analyzes, synthesizes and harmonizes links between disciplines into a coordinated and coherent whole.
> *Transdisciplinarity* integrates the natural, social and health sciences in a humanities context, and in doing so transcends each of their traditional boundaries. (Choi and Pak 2006, 359)

In this article, I will follow this well-grounded recommendation.

Julie Thompson Klein has been studying the history and progress of these ideas (Klein 1990, 2004; Klein et al. 2001), from the first typology published by Leo Apostel (Apostel et al. 1972), and has recently proposed a classification of interdisciplinarity (Klein 2010). Her results are fully consistent with those of Choi and Pak. Multidisciplinarity involves encyclopaedic, additive juxtaposition or, at most, some kind of coordination, but it lacks intercommunication and disciplines remain separate: it is, in fact, a pseudo-interdisciplinarity. True interdisciplinarity is integrating, interacting, linking, and focusing. Social psychology, economic anthropology, biogeography, economic history, and the like are examples of scientific interdisciplinarity. Transdisciplinarity is transcending, transgressing, and transforming, it is theoretical, critical, integrative, and restructuring but, as a consequence of that, it is also broader and more exogenous (Klein 2010, 16).

2. Sciences and Disciplines

Strict sciences, such as Euclidean geometry or Newtonian mechanics, not only can become disciplines but, as they are not transmitted by heredity, should be taught and learned if they are to be kept alive. However, strict sciences, while giving rise to disciplines, are not only disciplines: teaching and learning are moments of scientific activity, but they are not necessarily the moment of constitution of scientific theorems but the moment of their transmission. The idea of discipline is generic with respect to science because there are many non-scientific disciplines. Therefore, 'disciplinarity' is not a specific characteristic of science. As we have pointed out, the core of the idea of discipline is a social relation between the teacher and his or her disciples. Sciences are social institutions but, once more, there are a lot of social institutions that do not give place to sciences.

When a sociological idea, such as the idea of discipline, applies to strict sciences, which are not only social institutions, certain misunderstandings could arise. An educational institution can create all disciplines it considers useful to teach, but you cannot create a strict science wherever you want, because strict sciences compromise the reality itself. Scientific theorems, such as Pythagoras's theorem, biological evolution, or atomic theory, do not compromise reality because they 'represent it adequately' but 'because there are certain parts of reality itself which are incorporated into the constituent chains of scientific body' (Bueno 1992, 900). Reality should be regarded as a process *in fieri*, which is dependent, in many of its parts, on the structure of scientific truths. We can speak about a kind of 'hyper-reality': it is an 'extended reality' that takes into account not only what appears directly to our senses (appearances, phenomena) but also everything that determines other things, that works and that exists, but it is not directly perceived, as electromagnetic waves, atomic structures, geometric relations, or evolutionary processes. So the most characteristic feature of science is its function to constitute certain important parts of this hyper-reality. Science builds a hyper-reality as it expands progressively. If so, science does not 'describe' or 'represent' reality, but significant sections of pre-existing reality become part of science to lead to a new reality. Therefore, the truth of Pythagoras's theorem, evolutionary biology, or atomic physics must be understood as a truth that constitutes certain parts of our present reality and, at the same time, constitutes our own logical consciousness. Our present reality cannot ignore Pythagoras's theorem, biological evolution, or atomic structure. In addition, our logical consciousness may miss a lot of important phenomena, concepts, and ideas if we dismiss Pythagoras's theorem, evolutionary biology, or atomic structure. Therefore, those who renounce these scientific constructions have missed an important part of the now-accessible reality, and this waiver is dangerous when these scientific patterns are replaced by a set of myths or by metaphysical ideas.

Each science is materially different from every other and has a different field because it has different materials filled with a different operational closure. Operations themselves, which are established between certain corporeal materials, are responsible for shutting down an operating system through a mechanism that is similar to that given in algebra when we speak of structures such as 'body' or 'ring', or when we speak of the closure of a set, given some operations. That is, there comes a time when operations (to join, to separate, to mix, to heat, to break, and so on) deployed on certain bodies (substances, compounds, organisms, mobiles, and the like) give as a result some other terms of the same set at the time they eject many other irrelevant aspects. It makes no sense, for example, within the field of geometry, to wonder about the taste, colour, or weight of geometric figures, since operations with colours or weights are typical of other fields (optics, mechanics, or psychology). The operations closure of sciences, unlike the algebraic concept of closure, includes material corporeal objects that are bound together through operations. It is within each field that characteristic theorems and principles of each science will appear (Bueno 1992). These sciences are relatively autonomous from each other because their material fields (the fields where they make their own operations) were being closed as their principles and theorems were being developed. For example, classical chemistry, with its characteristic terms (elements, oxides, acids, salts, bases, or carbohydrates) and its own operations (heating, cooling, distilling, filtering, decanting, centrifuging, and so on), was closing its field around some principles (those of Lavoisier, of Dalton, of Proust, and the like) and a few theorems (about oxidation reduction processes, valence exchange, etc.). Today, we refer to the field of classical chemistry by noting the periodic table of elements and the different compounds formed by its elements. It should be added, albeit in passing, that this process of formation of new sciences is not the result of the exclusive application of an analytical method. Sciences include as much as or more than analytical processes, the synthetic processes of articulation and composition of some terms with others, because the analytical method is nothing more than an abstract extension of a more general process which is always of a synthetic nature.

Therefore, the configuration of one or more fields under their operations' closure is not something that can be prescribed before having been given the actual operations which lead to these closures, because it depends on the results of operations. The bonding process between two sciences (for example, the process that we take for granted today, following the development of the quantum atomic theory, of the unification of one part of classical physics and chemistry) is neither something that can be prescribed, even encouraged, from philosophy, nor the result of a process of formal unification, but it has to do with the establishment of a continuity between the operations (and between the terms) of both fields. In our case, this operative unit is achieved when some typical operations of classical chemistry are linked with other operations, for example, with vacuum tubes, cloud chambers, photoelectric devices, spectrophotometers, and so on. Some philosopher in the eighteenth century might have prescribed the unification of these two fields, as a result of adding or juxtaposing propositions of physics and chemistry or as a result of a unified language, but this prescription would have been of no use because the operators (equipment, instruments) which allow for effective operations closure (the material closure and not just the propositional one) had not yet been developed.

By way of example, the epistemological opposition between psychology and brain physiology, and the difficulty of unifying these sciences, have to do with the fact that terms and operations of each science have different principles: physiology operates with cells, tissues, substances, solutions, and so on, and its operators are fistulas, microtomes, microscopes, stains, and the like; psychology operates with animal behaviour, stimuli, responses, enhancers, cognitive states, and its operators are Skinner boxes, labyrinths, or tests. Physiology often works with dead individuals that need to be slaughtered, while psychology is not possible with corpses. The unification of these two sciences is neither the result of systems or chaos theories, nor is it the result of the unification of language. This unification would require that physiological and psychological operations could take place in continuity (for example, without killing the individual to see its cells under a microscope). New functional magnetic resonance technologies are very important when we try to understand the relationships between these two fields, as these new devices are operators that allow us to study metabolic activity of some formal parts of the brain while the subject is displaying some behaviour or is reporting about his/her cognitive and emotional status. Anyway, the future of these technologies, and their limits, cannot be known beforehand and the unification of these fields cannot be predicted (for instance, it cannot be predicted if that unification will have the form of the colonization of one field by the other).

The example outlined may serve to illustrate that the reasons why the fields of two different sciences unify themselves, or the reasons why this unification does not take place, have to do with the material elements of each field, and its terms, its operations, its characteristic theorems, and its principles. It is not obvious that physics and biology are in a unification process (through systems theory, deterministic chaos theory, or cybernetics), for the simple fact that, using only the principles of physics, the emergence of a complex biological organism cannot be explained. The probability that by randomly collecting hadrons and leptons we can obtain an elephant is simply negligible, as negligible as the probability of obtaining *Don Quixote* by hitting randomly at a keyboard. From this standpoint, disunity is an inseparable attribute of the sciences because it is in their structural, constitutive condition: separation, fragmentation, and isolation of the sciences are due to their internal constitution and development, they are the result of that operational closing we have referred to, and they are not just a consequence of guild specialization. Nancy Cartwright, in *The Dappled World*, has given some good examples of the local character of scientific discoveries (Cartwright 1999). Besides, if we defend the internal material construction of hyper-reality by the sciences, this pluralism is not only epistemic but, at the same time, ontological and methodological. The established differentiation into several strict sciences is neither arbitrary nor contingent: this is what Jan C. Schmidt (2008) calls the 'ontological dimension' of disciplinarity. John Dupré (1993) has spoken about 'the disorder of things' when referring to this ontological aspect of the disunity of sciences.

But, from the idea of science outlined above, this 'ontological dimension' cannot be separated from the 'epistemological dimension', as in Schmidt's proposal. Anyway, strict sciences, even if they are a 'corpus of knowledge that can be taught', do not behave like other disciplines that can be separated or joined for convenience in an arbitrary manner. These are some of the reasons why interdisciplinarity, multidisciplinarity, and especially transdisciplinarity pose special problems when applied to strict sciences, and philosophy of science has to deal with these problems which are specific to strict sciences.

3. Multidisciplinarity, Interdisciplinarity, and the Sciences

When human activities have a practical objective, the participation of a diverse set of scientific, technical, and technological disciplines is usually required. This is the case in the manufacture of a complex machine such as a aeroplane, the performance of civil works, such as building a road, or the resolution of a legal process that requires the assistance of experts in police investigation, and it is also the case in many other activities. This polidisciplinarity or multidisciplinarity is usual in medical practice, which requires collaboration of biologists, chemists, pharmacists, opticians, psychologists, X-ray, or nuclear magnetic resonance technicians, and many other scientists and specialists. Some other examples of current problems with multidisciplinary treatment are global warming, or gender studies (Dölling and Hark 2000). War is another area of multidisciplinarity, and perhaps one of the oldest from a historical point of view. Needless to say the point when we refer to modern warfare: nuclear, submarine, air war, chemical, biological, electronic. Applied oriented research does not replace the research of each discipline.

As we will argue later, transdisciplinarity, when understood as solving life-world problems, mode-2 knowledge production, post-normal science, and transdisciplinary research is, from the standpoint of sciences, a variety of multidisciplinarity.

Another problem, when it comes to multidisciplinarity, is posed by technoscience. When a particular science, for instance high-energy physics or astrophysics, uses, in an essential, endogenous way, sophisticated technologies, without which its development would not be possible, then, that science–technology is, for internal epistemological reasons, a multidisciplinary activity. Therefore, around large particle colliders and telescope facilities, a multitude of scientists and engineers from different disciplines are gathered. This high-tech equipment is an essential operator for the establishment and development of these sciences, and its design and use, requiring the assistance of many technicians and engineers, is formally incorporated into certain theorems of these sciences. Therefore, in the practice of all those sciences that are 'technologized', multidisciplinarity is the norm. Many other examples could be given in areas such as modern microscopic cytology, molecular biology, nanotechnology, or neurosciences in which the involvement of multiple technologies is very evident (Schmidt 2008, 62–63).

Interdisciplinarity would arise in a near symmetrical way when two or more disciplines converge in a given field, as they would, for example, in biochemistry, bioinformatics or geophysics. This convergence can lead to a practical and theoretical integration of the disciplines involved, which would be unified. Paradoxically, these convergences, on many occasions, give rise to new independent and sovereign disciplines, at least when they are considered in terms of their academic institutionalization. In these cases, unity of sciences works: Newton unified celestial and terrestrial mechanics; light, optics, radiant heat, electricity, and magnetism were unified by electromagnetism; classical thermodynamics and statistical mechanics were unified in the molecular theory of gases. But these cases were not only theoretical unifications but the constitution of an effective causal continuity between a lot of different operations and their embodied technology.

As noted earlier, the word 'interdisciplinarity' has been reserved for some situations in which a transfer of content takes place from one discipline to another. Without denying that this transfer can take place among the most heterogeneous of sciences, interdisciplinarity has to face the problem of the place that formal sciences (the different branches of mathematics and logic) have in the 'republic of sciences'. Many cases of the transfer of structures and mathematical theorems to other sciences could be cited: the use of geometry in kinematic astronomy, mathematical development of rational mechanics, the use of non-Euclidean and *n*-dimensional geometries in relativistic physics, the use of logic in computer science, the application of statistical methods in many different contexts (mechanical, economic, psychological, epidemiological, and so on), and the use of growth functions (linear, exponential, asymptotic) in many different fields. Many of the examples proposed by Schmidt when talking about the 'epistemological' dimension of interdisciplinarity would fit here (Schmidt 2008, 63). Recent (and not so recent) developments of formal sciences, such as non-bivalent logic, fuzzy logic, fractal geometry, and catastrophe and deterministic chaos theory, have attracted the interest of certain theorists who claim that the wide use of these methods is evidence of the imminent triumph of the unification of sciences. But this content is a kind of monism of theological lineage, which means that the world is 'written by God in mathematical characters': the stance of physicist and mathematician André Lichnerowicz is an example of this monism of order (Connes, Lichnerowicz, and Schützenberger 2001). As Dupré has stated, 'at any rate, the omnipresent neo-Pythagoreanism of contemporary science is surely not adequately justified by its empirical successes. If it is motivated by any legitimately theoretical considerations, I suspect that these amount to some kind of commitment to a universe amenable to one systematic and orderly description; a universe in the existence of which, I have argued, we have every reason to disbelieve' (Dupré 1993, 224).

When adopting a materialistic approach in philosophy of science, the fact that certain sections of formal sciences can be exported to other sciences can be explained without resorting to the monism of order. The characteristic scale of formal sciences is precisely that of the typographical material with which the formal sciences are built, an anthropic operative level which has to be also present in the rest of the sciences. Moreover, in many cases, said formal sciences are developed along the lines of other human activities and practices, and in connection with the requirements of those sciences to which, at the same time, they 'serve' and 'shape': geometry can serve as an example.

Other times, as in the case of fractal organization of many biological structures, the explanation of its interdisciplinarity can be integrated smoothly into the biological evolutionary patterns: a simple algorithm, codified in a small number of genes, can lead to complex redundant, robust structures, with adaptive significance. Pluralism of sciences is compatible with the recognition of common mathematical structures in various areas (technical, technological, scientific) such as feedback, dynamic balance, growth functions, topological structures, and so on. But the mere sharing of mathematical structures, statistics or computer simulations generates no intrinsic interdisciplinarity but some kind of pseudo-interdisciplinarity (Klein 2010). The exogenous analogy between the human brain and the inside of a walnut creates neither integration nor convergence between neurology and botany. As mentioned before, the unification, integration, or convergence of two given sciences is not just a formal process (linguistic, logical, or mathematical) but it requires operational, material continuity between these fields, and it implies the establishment of common, material principles (such as the principles of mechanics or thermodynamics). The strategy of taking any of these formal structures (fractals, deterministic chaos, systems, and the like) as the key to unify all sciences leads to a reductionist monism (of formal character) which could induce confusion.

4. Transdisciplinarity and the Sciences

As stated before, in the representative literature on the topic, it is common to reserve the word 'transdisciplinarity' to refer to knowledge that goes over and above disciplinary boundaries following a process that assembles disciplines and recombines information (Kerne 2005; Choy and Pak 2006; Klein 2010). This recombination implies breaking down the existing compositions into their elements and recombining them into a new form. 'Transdisciplinarity requires deconstruction, which accepts that an object can pertain to different levels of reality, with attendant contradictions, paradoxes, and conflicts' (Klein 2004, 524). Transdisciplinarity claims to provide holistic schemes that subordinate disciplines and look at the dynamics of whole systems. The latest taxonomy by Julie Thompson Klein defines four major trends of transdisciplinarity. The first is the contemporary version of the systematic integration of knowledge: this historical quest 'spans from Greek philosophy, the medieval Christian *summa*, the Enlightenment ambition of universal reason, Trascendentalism, the Unity of Science movement, the search for unification theories in physics, and E. O. Wilson's theory of consilience' (Klein 2010, 24). The activities of the Centre International de Recherches et Études Transdisciplinaires (CIRET) follow this tradition, according to Klein.

The second transdisciplinarity trend puts its focus in 'transgressiveness': transdisciplinarity is 'pushing boundaries of class, gender, race, ethnicity, and other identities' (Klein 2010, 25). The contributions of Douglas Kellner (1995) and Irene Dölling and Sabine Hark (2000) could serve as good examples of this tendency.

The third trend attempts to transcend the scope of disciplinary views by articulating them in a holistic framework. Marxism, phenomenology, and the so-called 'policy sciences' are the examples of this.

The fourth trend focuses on problem-solving of the life-world. It is necessary to focus on research questions and practices, not the disciplines. Environmental research is the main example of this tendency as can be seen in Transdisciplinarity Net and in the Swiss Academic Society for Environmental Research and Ecology. 'Mode 2 knowledge production' (Gibbons et al. 1994), 'post-normal science' (Funtowicz and Ravetz 1994; Ravetz and Funtowicz 1999), and transdisciplinary research are also important ideas relating to this fourth way of understanding transdisciplinarity (Hirsch Hadorn et al. 2008). Each of these trends has its motto: 'integration', 'transgression', 'holism', and 'problem-solving'.

We will not refer here to the second trend (transdisciplinarity as 'transgressiveness') as it affects the boundaries between races, genders, classes, and ethnicities, and it does not refer directly to the relations between sciences. Firstly, we will discuss the first and third trends that share a common interest in the unity and integration among the sciences that could lead to a holistic conception of knowledge and the world. Secondly, we will refer to the fourth trend (and its relation to the third) that it is focused on solving life-world problems.

5. Transdisciplinarity as Unification of Sciences: Why It Matters whether Scientific Disunity Is Inescapable

The issue about the integration of different sciences has been a matter of philosophical speculation from the moment the multiplicity of modern sciences started to become evident. In classical Greece or in the middle ages, when only geometry was a science (and kinematic-geometrical astronomy was a proto-science), philosophy and science were a common block, in which the philosophical systems taken as reference (Aristotelianism, Neoplatonism, the scholastic *Summa*, and so on) flooded everything. In the sixteenth and seventeenth centuries, the emergence of scientific physics involved the rupture of this common block and, hence, the progressive distinction between science and philosophy was made possible (without thereby admitting that science arises from philosophy, as is often claimed by certain philosophies that conceive science as a set of theories). In the late eighteenth and early nineteenth centuries, there were several sciences in progress: not only classical physics and mathematics, but also chemistry, geology, and biology, and these were already in an advanced state of constitution. In this context of the establishment of the new sciences, Auguste Comte enunciated his system, with the well-known thesis about positivization of knowledge and his tiered classification of sciences. The independence of different sciences, and their regional character, was, from the beginning, uncomfortable for all those who wanted to restore the unity of sciences and the global scientific world view. In the second half of the nineteenth century and in the early twentieth century, the constitution of the so-called 'human sciences' (sociology, economics, psychology, cultural anthropology, positive history, scientific linguistics, and so on) was a confirmation of the plurality of the sciences, and brought about the discussion of a new issue: the problem of the division of knowledge into 'two cultures' (to use the successful formula of C. P. Snow), the cultures of science and humanities. *Einleitung in die*

Geisteswissenschaften ('Introduction to the Human Sciences'), by Wilhelm Dilthey, is a sample of the issues raised by this process of the institutionalization of human sciences.

In the twentieth century, the proposal to build a unified science went on to become a prime topic of the philosophy of science, through the work of the neo-positivist philosophical movement that managed to gather a large group of authors on the project. The promoters, R. Carnap and O. Neurath, noted members of the Vienna Circle, were seconded by H. Reichenbach, R. von Mises, and W. Dubislav from the Berlin group, K. Grelling, J. Jörgensen, J. Hedenius, A. Naess, A. Ross, E. Kaila, and E. Stenius, representatives of Scandinavian and Finnish positivism, and by the Frenchman L. Rougier, among others. Neo-positivists sought to lay the foundation for an epistemological monism, a 'monism without metaphysics', in Jörgensen's own words. But the stubborn reality of the plurality of sciences, and of their mutual irreducibility, ended exposing the idealistic nature of the proposal of unified science.

Ian Hacking (1996) has spoken about a specific type of 'unity of sciences' in a thesis called the 'metaphysical unit' which presupposes the unity of the world. Natural theology is the most influential philosophy of this kind of monism: one world, one book, and one author. The non-theist version of this metaphysical unity states that there is one world, one reality, and one truth. Hacking quotes Maxwell as an example of the belief in the unity of one universe amenable to scientific description. Faraday, Einstein, Weinberg, and Glashow, among others, had followed this conception. Although this does not mean that science exhausts all human knowledge, many positivists suppose that there is no knowledge except scientific knowledge and so that science has to be progressively unified in order to understand the harmony and the interconnectedness of different parts of the world (Hacking 1996, 44–49).

An important variety of this metaphysical unity is physical reductionism: economics is reduced to sociology, sociology to psychology, psychology to biology, biology to chemistry, geology to chemistry and geophysics, chemistry and geophysics to physics, and physics to one single theory, a theory of everything. Reductionism is, no doubt, the strongest sense of unity as it requires the unification of everything under the laws of a master discipline. An example of this intentional physical reductionism is the consilience project of Wilson (1998). I call it 'intentional' because Wilson himself recognizes that the current state of sciences cannot justify his belief in their future unification. Dupré calls this physical reductionism 'the imperialism of the microphysical world'. He has convincingly argued against the causal tyranny of the microphysical, and against the supervenience thesis that pretends that the microscopic completely determines the macroscopic. Following Dupré's theory, macroscopic phenomena are much too complex for there to be any tractable microscopic analyses. For those areas of biology devoted to the study of interactions between organisms, the fundamental units are not atoms or molecules but individual organisms (Dupré 1996).

Hacking recognizes another type of unificationism that concentrates on the method of science. He says that 'a wide spectrum of analytical philosophers of science have asserted that there is one scientific method applying across the board in the natural and human sciences' (Hacking 1996, 43). The claim is now that there is 'one reason and one scientific method'. Methodological unity of Imre Lakatos's scientific research programmes could be a good example. Nevertheless, Hacking and Peter Galison, while studying several scientific experiments, show how different sciences make use of different methods depending on the nature of their fields (Hacking 1983; Galison 1987, 1996). Dudley Shapere (1984) also recognizes that each scientific domain has its own procedures, and so does Cartwright (1994, 1999) in her study of the boundaries of sciences. From the philosophy of science outlined above, we also defend that scientific methods are, generally speaking, characteristic of each science because they depend on the specific operations, relationships, and terms within each field. For this reason, methods of mathematics are completely different from those of geology or biochemistry. This is why each scientist knows about the methods of his own discipline. Anyway, as recognized above, specific methodologies can be transferred from one science to another: Schmidt presents mathematical modelling and computer-based simulations as examples (Schmidt 2010, 40).

When speaking about the transdisciplinarian thesis of the unity of sciences it is worth referring to Edgar Morin, Basarab Nicolescu, and CIRET because, in the field of diffusion of French language, they enjoy great prestige. Edgar Morin developed his idea of transdisciplinarity in his book, *Method* (Morin 1992), and in other more recent works (Morin 1994a, 1994b), aimed to achieve, not simply the unification of sciences, but also the unification of multiple heterogeneous disciplines and beliefs. Morin recognizes three fracture sites of knowledge which he calls the three 'emergence levels': physical, biological and anthropo-sociological. Morin proposes to address this fragmentation, which would endanger our culture, with a new method that seeks to entrench the social sciences in the life sciences, and these in the natural sciences, and then, in a circular manner, seeks to entrench physical and biological thought in culture. According to Morin the cognitive maps that allow unification are provided by today's systems theory, cybernetics, and information theory. Nicolescu, in his *Manifesto of Transdisciplinarity*, stated that transdisciplinarity covers both what is between the disciplines, everything which occurs through them, and what is beyond them all, because its goal is to understand the present world without sacrificing the imperative unity of knowledge (Nicolescu 2002). Nicolescu emphasizes the need to combat ethnocentric attitudes, and 'academic nationalism' which he considers 'feudalistic' and protectionist. It is a matter not just of the unity of knowledge but also of a new *art de vivre* ('art of living') with a trans-cultural, transnational, trans-religious and trans-political vision, where 'everything is related to everything', by using dialogue as a method. Nicolescu's proposals to 'transdisciplinarize' science and religion, and build a new cross-cultural, trans-religious spirituality, using Hans-Georg Gadamer's idea of 'fusion of horizons', try to unify religion, science, and any other forms of knowledge. This fusion will lead to a new reality: the 'Homo sui transcendentalis' (Nicolescu 1996).

Morin and Nicolescu, whom we have taken here as a reference for being leaders of the transdisciplinary movement, have explicitly postulated that there is immeasurability and discontinuity in the real world. However, they seem unwilling to realize that, hence, the unity of knowledge about the world is compromised, since these discontinuities are impossible to resolve even with the transdisciplinarian approach. They stated a principle of absolute emergence that is used to jump from one reality level to another without further explanation. But this 'emergence' (understood as 'absolute emergence') is nothing but an obscure idea disguised by a misleading terminology. The technical, positive concept of emergence requires that what emerges exists previously submerged, such as a dolphin or a submarine in the sea.

Although unification of the sciences has not been accomplished, it seems relevant to discuss why a research programme that attempts to achieve it should be criticized. Unitary science could be understood as a fruitful working hypothesis, no matter whether it has been achieved or not. No argument could be made against such a claim: a numerological, metaphysical research programme, like that of the Pythagoreans, led to some important geometrical discoveries; certain astronomical observations that proved to be essential in the formation of Greek, spherical astronomy were the result of the astrological programme of the diviners of Sumer and Akkad; modern physics appeared in Christian Europe around certain pious men (Copernicus, Tycho, Kepler, Galileo, Newton) who were trying to understand the laws God had chosen in the moment of creation; Einstein still fought for the unification of physics through the belief that 'God does not play dice with the universe', and although 'He is subtle, He is not malicious'. The objective of making a perpetual-motion device could guide the construction of finite, real engines with improved performance. Ignatius of Loyola, the creator of the Society of Jesus, cleaned his horse *ad maiorem Dei gloriam* (the Jesuits' motto) while Sancho Panza cleaned his donkey just because he was dirty. A good scientist does not need to know anything about critical ontology or philosophy of science.

One thoughtful reviewer of this article pointed out that a relevant question is why would people be interested in 'predicting' unification, and why should that be an interesting or important question. There has been a powerful attraction to the unity and integration of the sciences from many authors during the last three centuries, as evidenced by the brief, but significant, selection of transdisciplinary unificationism quoted above. Dupré outlined several undesirable practical consequences that follow from the tenets of the intentional unity of science. The first one is a truly important one, and I find it of greatest interest for philosophers of science. In Dupré's own words: 'A belief in the unity of science tends to distribute the epistemic credentials earned by genuinely scientific inquires across the entire range of practices that satisfy merely sociological criteria of scientificity' (Dupré 1996, 116). When certain 'scientists' argue about the 'theories of everything', the anthropic cosmological principle, or the big bang theory, among others, they are probably abusing the epistemic credentials earned by strict science.

Besides, when we deal with a methodological unification, scientific credibility is supposed to be largely contingent 'on the extent to which claims are expressed in a quantitative, mathematical form'. However, social, mathematized disciplines claim a strictly scientific status. But, as Dupré comments, 'one may well suspect that these uses of mathematics [in social sciences such as economics] have more to do with providing barriers to entry to lucrative professions than with illuminating the natural world' (Dupré 1996, 117).

If transdisciplinarity is grounded on an exclusive, ontological unification, Dupré recognizes that certain parts of nature are not susceptible to scientific analysis, as natural chaotic systems illustrate. There is not a divine mind with a complete understanding of the whole world, and we have to recognize that 'the empirical success of abstract modelling in science has been, at best, moderate' (Dupré 1996, 113). In other words, the question of how much order there may prove to be in the world remains open.

On the other hand, transdisciplinarity minimizes the idea that an analysis of a particular domain provided by a canonical science (such as physics, biology, geology, and the like) does exist. As an example, Dupré refers to evolutionary theory: 'While there is certainly some demonstrated scope for understanding particular microevolutionary processes, generalization about the overall patterns of macroevolution might be few and far between' (Dupré 1996, 117). Cartwright has argued how the yearning of a single ordered world can guide research in the wrong direction (Cartwright 1999, 15–19).

Finally, there is another reason why philosophers of science would be interested in the prospects of achieving transdisciplinarian unification: given that this unification has not been achieved; and as the convergence of sciences into one great scientific discipline is some kind of chiliastic forecast, philosophers of science should wonder about the epistemological status of such prognosis.

6. Transdisciplinarity as Solving Life-World Problems: Mode-2 Knowledge Production, Post-normal Science, and Transdisciplinary Research

There is a shifting knowledge context in contemporary society that implies changing roles of certain educational institutions such as universities (Apostel et al. 1972). Certain authors suppose that, to respond to new educative demands, transdisciplinarity has a wide potential: it includes problem focus, evolving methodology and collaboration between different people and institutions. The triple helix relationship, university–industry–government, is an example of a new framework of collaboration between institutions (Etzkowitz and Leydesdorff 1997; Russell, Wickson, and Carew 2008). As C. A. Bowers has pointed out, the world has problems, and universities have departments. Hence, universities have to evolve and adapt to new requirements (Brewer 1999).

Michael Gibbons and Helga Nowotny claim that a new form of knowledge production has emerged, the so-called mode-2 (Gibbons et al. 1994; Nowotny and Gibbons 2001). Mode-2 knowledge production refers to problem-solving processes that imply the activity of multiple drivers and skills, so that the intellectual endeavour and solutions arise within disciplines, transgressing institutional boundaries. Hence, this mode-2 knowledge is transdisciplinary from a structural standpoint. Nowotny characterizes mode-1 science as having a clear separation between science and society, while in mode-2 boundaries between science and society are transgressed.

Silvio Funtowicz and Jerome Ravetz have coined the term 'post-normal science', which was derived from their interest in ecological economic studies that consider the epistemological and governance challenges presented to sustainability. In issues relating to health and the environment, 'truth' is not yet the goal of science but some kind of unimportant distraction, and the relevant guiding principles are now quality, plurality of legitimate perspectives, and mutual respect and learning. Post-normal science has to face radical uncertainties and conflicting values, and it occurs in the interface between science and public policy where stakes are high and decisions urgent: science in the policy context becomes post-normal. As a result, normal science needs to be liberated from its dogmatic style and, simultaneously, philosophy of science needs recasting (Funtowicz and Ravetz 1993, 1994; Ravetz and Funtowicz 1999): 'We are now witnessing the emergence of a new approach to problem-solving strategies in which the role of science, still essential, is now appreciated in its full context of the uncertainties of natural systems and the relevance of human values' (Funtowicz and Ravetz n.d., 9).

Closely related to mode-2 knowledge and post-normal science, there is a new branch of activities called 'transdisciplinary research'. When knowledge about relevant, practical problems is uncertain, transdisciplinary research, by taking into account the diversity of life-world and linking abstract and specific knowledge, grasps the complexity of problems and promotes the common good (Pohl and Hadorn 2007; Hadorn et al. 2008). The website Td-net is the most important network for transdisciplinary research.

Even if we recognize that higher education needs to adapt its structures to the new challenges of contemporary society, this does not necessarily have to affect our ideas about the sciences and the relationships between them. Moreover, the solution to societal problems brings us back to what we have called multidisciplinarity but it is unclear whether this will lead to a new variety of science. As mentioned, current technoscience is multidisciplinary and it has always been very careful to consider specific practical problems: the two world wars and the ensuing cold war provide many examples of this. Attempting to extend the idea of science to include Funtowicz's post-normal science, Nowotny's mode-2 knowledge production and transdisciplinary research, has the disadvantage of grouping under a single idea two different things: strict sciences and political action. The resulting idea of science is anomalous and induces confusion. As Martin Carrier (2001) states, most of actual science is not post-normal. Besides, the problems of complex human–natural system management are as much constituted of scientific facts as of moral, ethical, and political values. 'This means that experts wielding credentials of holistic insight in arguing for action in the human world, and experts on the medical system, or the climate system, or whatever—anyone who claims to know what is to be done—are always in fact political entrepreneurs. *Claims of holistic expertise are always political claims*' (Sarewitz 1996, 73; emphasis in the original). One wonders if some authors are using the prestige of the word 'science', and the prestige taken from strict sciences, to justify certain political choices.

Besides, as Sarewitz states, although 'we need knowledge about the system we are trying to manage (economic; geopolitical; socio-technical) we cannot find powerful evidence that holistic approaches to inquiry improve our ability to act or to make effective decisions'. Sarewitz just refers to the case of 'climate scientists' who have been given billions of dollars of research support over two decades without very much success in their holistic view of climate change (Sarewitz 1996, 68). The same seems to occur in the field of global economics and its questionable capacity to forecast economic crises. As these examples strongly suggest, the expectation that more holistic inquiry is the key to solving certain problems (such as climate change, economic crises, or global terrorism) should be reconsidered.

On other hand, if we refer to strict sciences (such as physics, biology, or mathematics), internal problems are always defined in relation to the current theorems and principles of a given scientific field (Schmidt 2010). Interrelationships between technical, scientific, technological, social, legal, political, and philosophical disciplines have always existed, to a greater or lesser extent. Nobody doubts the need to use every resource at our disposal (technical, scientific, technological, etc.) to resolve certain societal problems in our world (Schäfer 1988; Klein et al. 2001). But the assumption that these problems have a *scientific* solution (in post-normal science or in future unified transdisciplinary science) may be an illusion similar to that of the *scientific* Marxism of the Soviet Union, a Marxism that is often given as an example of transdisciplinarity (Choi and Pak 2006, 355).

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