Transdiciplinarity. A must for sustainable education.

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1 THE NEED OF TRANSDISCIPLINARITY

1.1 The need of transdisciplinarity

In our world characterised by rapid change, uncertainty and increasing interconnectedness, science is increasingly, called to contribute to the solution of persistent, complex problems, not only environmental issues such as climate change and biodiversity loss, but also related issues such as poverty, security and governance. For all of these problems, the increase in availability of scientific knowledge has not been reflected in decisive action to overcome the demand for knowledge to contribute to the solution of societal problems.

Knowledge demands from society are about issues that call for change in societal practices. These can be complex matters, “where facts are uncertain, values in dispute, stakes high and decisions urgent. In such a case, the term ‘problem’, with its connotations of an exercise where a methodology is likely to lead to a clear resolution, is less appropriate” [1]. The situation is not solved, as frequently attempted by creating supposed teams conformed of specialists in different areas, around a given problem. With such a mechanism one can only hope to achieve an accumulation of visions emerging from each of the participating disciplines. As Max Neef stated ‘an integrating synthesis is not achieved through the accumulation of different brains. It must occur inside each of the brains and, thus, it's needed to orient higher education in a way that makes the achievement of such a purpose possible' [2]. The 'problem' situation demands a problem-solving strategy that is achieved through transdisciplinary orientation in research, education and institutions aims [3].

In a correspondence to the journal Nature in 2010, a group of international scientists claimed funding for transdisciplinarity scientific collaboration, that is capable of properly understand the ways in which our technology impacts the complex, interconnected systems we depend on, against rely on maintaining and reinforcing only disciplinarity sciences [4]. Interventions like this explain the perceived need of the scientific community to address their work in a collaborative framework that coheres with the complex structure of pressing problems. Also, remind us that, after years of debate, cultures and practices have still not been established in that way.

However, the interest in transdisciplinarity increases. At the 2012 Sustainability Summit at the Leuphana University of Lüneburg [5], Thomas Jahn started his intervention pointing out that that publications on transdisciplinarity have hugely increase in the last mid decade. Since the first publication of transdisciplinarity is 1972 [6], we see some increase from the Conference on Environment and Development in Rio de Janeiro in 1972, where the importance of science to stakeholder development was highlighted and the need to transform research by involving stakeholders and promoting mutual learning between science and life-world was stressed [7].

After 40 years of intensive scholarly discourse a universally accepted definition is not available and consequently, approved equally guiding standards for transdisciplinary researchers, program managers and donors are also lacking. One reason could be that, at first sight, transdisciplinarity appears to be a rather elusive concept. Yet where concepts or ideas are not properly defined, the risk is that a rather shallow interpretation prevails—a fate that paradigmatically befalls the notion of sustainability. The likely damage that can occur with such a mainstreaming is that the true challenges of transdisciplinary collaboration are underestimated [8].

Beyond cross-disciplinary methodologies [9], 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 [10]. Thus by bringing about mutual learning, collaborative research, and problem solving among business, government and civil society, can serve as an important guiding concept for sustainability science and practice. Transdisciplinarity emerged to counteract the tendency of disciplines to place rigid boundaries around knowledge, and to separate it into artificial compartments. Building transdisciplinarity requires a strong commitment to flexibility and rejection of the temptation to institutionalize transdisciplinary excursions [11].

The three most important cognitive objectives for crossing disciplinary boundaries that
have influenced the development of the sciences in the 20th century are (1) the ideal of a unity of all sciences and other disciplines, (2) solving problems in basic research

by innovation, and (3) responding to the knowledge demands of the knowledge society. These objectives can be combined and they may cross-fertilise each other [12].

The considered central challenges of transdisciplinarity are:

- Crossing boundaries: disciplines, academia-society, individuals-companies, forms of generating knowledge, forms of communicating
- 'Not for society, but with society' [13]
- Integration: considered the main cognitive challenge of transdisciplinary process

1.2 From discipline to transdisciplinarity

1.2.1 Disciplinarity

The early Universities[1], started with Faculties of Medicine, Philosophy, Theology and Law. It was around these four areas that the totality of knowledge was contained, with versatile academics. As Faculties became more and more specialized, disciplines and sub-disciplines arose and multiplied. The departmentalization of disciplines consolidated itself at the end of the XIX Century, maintaining disciplinary autonomies, for the competition of research funds, and for the consolidation of academic prestige. Disciplinarity is about mono-discipline, which represents specialization in isolation [2].

Defined academic research methods and objects of study constitute disciplines. They include frames of reference, methodological approaches, topics, theoretical canons and technologies. Disciplines can also be seen as 'sub cultures' with their own language, concepts, tools and credentialed practitioners [14].

1.2.2 Multidisciplinarity

A person may have studied, simultaneously or in sequence, more than one area of knowledge, without making any connections between them. Members of multidisciplinary teams of researchers or technicians carry out their analyses separately, as seen from the perspective of their individual disciplines, the final result being a series of reports pasted together, without any integrating synthesis [2]. Different disciplines come together in a specific context (typically to deal with a real world problem) but with each group working primarily in its own framings and methods. This is a working approach that juxtaposes rather than combines separate disciplinary perspectives, adding a breadth of knowledge, information and methods. Work is done independently following separate perspectives [15].

1.2.3 Pluridisciplinarity

Pluridisciplinarity implies cooperation between disciplines, without coordination. It normally happens between compatible areas of knowledge, on a common hierarchical level. Examples could be the combination of physics, chemistry and geology, or history, sociology and language. The study of each one of them reinforces the understanding of the others [2].

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[1] Such as Salerno, Bologna, Oxford and Cambridge

1.2.4 Interdisciplinarity and transdisciplinarity

The term 'interdisciplinary research' refers to a range of approaches from the simple communication of ideas to mutual integration of organising concepts, methodology, epistemology, etc. (OECD, 1972 cited in [15]). Rather than disciplines operating in parallel, it involves a synthesis of knowledge, in which understandings change in response to the perspectives of others. The aim is to seek coherence between the knowledges produced by different disciplines [14].

Max Neef [2] explains interdisciplinarity and transdisciplinarity as different kinds of relationships between different hierarchical levels of groups of disciplines, which he calls the '*hierarchy disciplinarity pyramid*' (Fig. 1)

Interdisciplinarity is organized at two hierarchical levels. It thus connotes coordination of a lower level from a higher one. '... *A sense of purpose is introduced when the common axiomatic of a group of related disciplines is defined at the next higher hierarchical level*' [2]. Disciplines as mathematics, physics, chemistry, geology, ecology, sociology, genetics, economics (in addition to others) can be considered as the base of a pyramid, identifiable as *the empirical level*. Immediately above is another group of disciplines that constitute the *pragmatic level* (engineering, architecture, agriculture, medicine, etc). The third is the *normative level*, including disciplines such as planning, politics, design of social systems, environmental design, etc. Finally, the top of the pyramid corresponds to a *value level*, and is occupied by ethics, philosophy, and theology. Thus a hierarchical image is defined in which the purpose of each level is defined by the next higher one (see section: *Knowledge generation*).

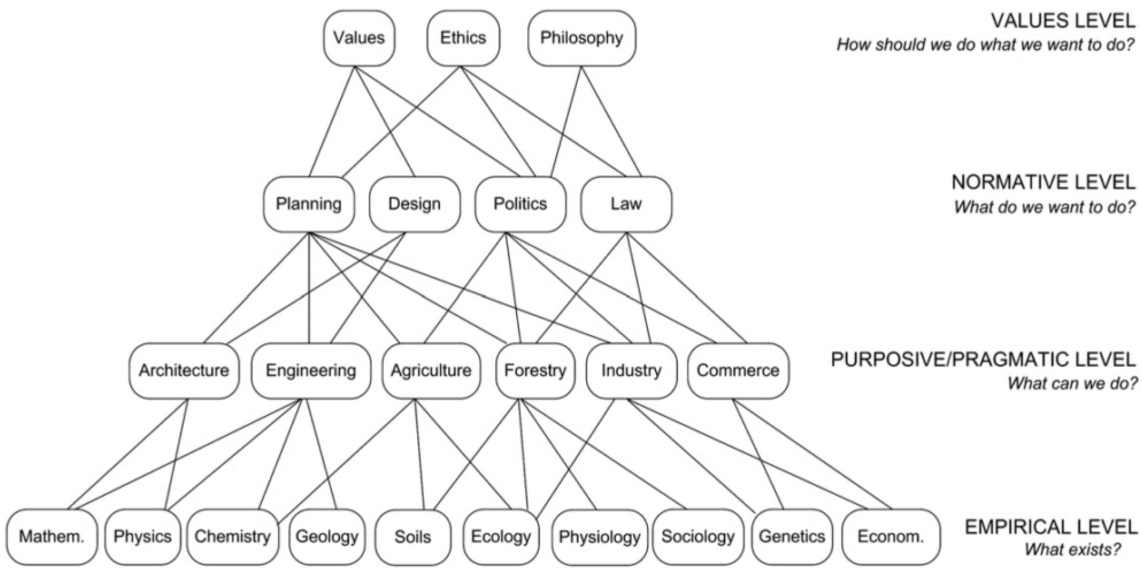

Fig. 1. The pyramid of transdisciplinarity [2].

Transdisciplinarity is the result of coordination between all hierarchical levels. The disciplines at the base of the pyramid describe the world as it is. This level asks and answers the question *what exists?* And the organizing language of this level is logics. The next level is composed mainly of technological disciplines. This level asks and answers the question *what are we capable of doing* with the knowledge gained from the empirical level? The organizing language of this level is cybernetics that emphasizes only the mechanical properties of nature and society. The normative level asks and answers the question *what is it we want to do?* The organizing language of this level is planning. The value level asks and answers *what should we do? How should we do what we want to do?* The organizing language of this level that goes beyond the present and the immediate should be some kind of deep ecology (Schulz, cited in [2]).

1.2.5 Differences between multi-, inter- and transdisciplinarity

Multidisciplinarity and interdisciplinarity do not break with disciplinary thinking (Fig. 2). In the case of multidisciplinarity, the aim is mainly the juxtaposition of theoretical models belonging to different disciplines. Disciplines are considered as being complementary in the process of understanding phenomena. The point is not to take into account the entire model, but only part of each model, which can be the object of bilateral consensus, in order to maintain coherence. The advantage of this approach is that it highlights the different dimensions of the studied object and respects the plurality of points of view. These aspects of multidisciplinarity are most visible in colloquia.

Interdisciplinarity differs from multidisciplinarity in that it constructs a common model for the disciplines involved, based on a process of dialogue between disciplines. For this reason, interdisciplinarity is often implemented within the same disciplinary field and its purpose is to create synthesis. However, the second important aspect of interdisciplinarity lies in the practice of transfers, either of models or of tools (such as mathematics, statistics), from one discipline to another. In any case, however, regardless of the form it takes, interdisciplinarity, like multidisciplinarity, avoids paradoxes and having to solve them. Both interdisciplinarity and multidisciplinarity approaches are fragmented dealing with disciplinary thinking.

Transdisciplinarity breaks away with this type of thinking in a significant way, since the objective is to preserve the different realities and to confront them. Thus, transdisciplinarity is based on a controlled conflict generated by paradoxes. The objective is no longer the search for consensus but the search for articulations. The aim is thus to avoid reproducing fragmentary models typical of disciplinary thinking [16].

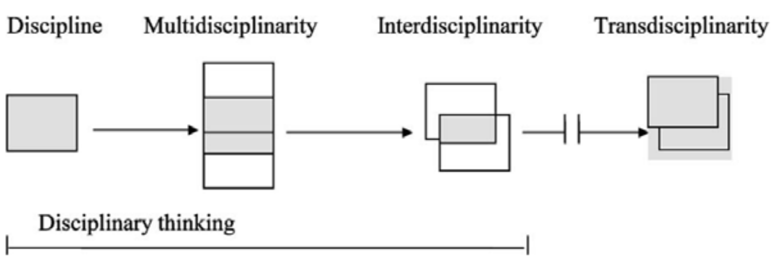

Fig. 2. From discipline to transdisciplinarity [16].

1.3 Historical perspective of the production of knowledge: unity, science and life-world

In Greek antiquity the idea evolved that science is basically a cognitive faculty for explaining the development of natural things, based on principles inherent to them, that humans are capable to be aware of through "contemplation"[2] (as Aristotle claimed). This kind of scientific knowledge (epistême) is of no use for day-to-day living. To lead their life, humans need skills to act (praxis) and to produce (poiêsis), and they need prudence (phronêsis) to deliberate about things that allow choice. So, science born detached from practical life or the life-world, namely ideal scientific knowledge is dissociated from the various aspects of practical knowledge [17].

This ancient ideal is still influential today, although the concept of science and the relationship between science and the life-world has changed. The emergence of transdisciplinary orientations in the knowledge society at the end of the 20th century is the most recent step in reshaping the concept of science and the distinctions between science and the life-world [17].

On the other hand, the idea of the unity of the knowledge has been longer pursued. In the Middle Ages, there were universities divided into "faculties", which all answered to the School of Theology. This responded to the wish to create a synthesis between the different branches of knowledge to reach its unity [16] with an ideological aim. In the 18th century, the *Enlightenment* extended knowledge to society (cities, salons, academies, press, etc.), to enrich culture with scientific discoveries. The wish to create relationships between different disciplines, on the contrary, became a pragmatic aim, that led to the division of scientific activity into more or less independent disciplines and the emergence of specialists. Thus, regardless of whether the wish to establish relationships between different scientific disciplines is due to pragmatic or ideological reasons, the construction of pan-disciplinary[3] knowledge is mainly motivated by the idea that there is only one reality [16]. The thought in the industrial period assumed that this unity could be synthesized from analyzing the preserved form of disciplinary thinking. However, nowadays, disciplines and ever more sub-disciplines seem to make it difficult to consider an object of study as being indivisible and pertaining to only one reality. As a result, synthesis is no longer able to integrate what disciplinary analysis has previously separated [16]. Cross-disciplinary approaches (multi-, inter-) consider all the overlapping aspects of different disciplinary approaches, to deal with.

The dissociation of the natural sciences from philosophy started in the modern period (the late 16th Century) and continued into the 19th century by the establishment of the humanities and the social sciences. Science is conceived dissociating philosophy from natural sciences, which processes are explained by general principles on the scientific knowledge. An example is the Newtonian science, which reduces the plurality of phenomena in nature to some basic laws, closely related to practical issues, as production of goods. Francis Bacon (1561–1626) also Though that scientific collaboration is of upmost importance for scientific progress, and he shows little interested in benefiting society [18].

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[2] "Contemplation" is the meaning of the Greek term "theoria".
[3] "Pan", Greek sufix that means "implying the union of all branches of a group".

In the 19th century, modern science was criticised as a model for all of science. In the second half of the century and in the early 20th century, influenced by the serious problems of rural and industrial working classes, the constitution of the so-called ‘human sciences’ (sociology, economics, psychology, cultural anthropology…) 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’ (using formula of C. P. Snow) [18], the cultures of science and humanities, as separate specialised disciplines in universities [17].

In this context a new rationality appears. The Chicago School of Sociology in USA, Karl Marx and Max Weber[4] in Europe and others, bring “Human Ecology” and “Social Action”. Max Weber related research in social sciences with knowledge demands for societal problem solving. Jürgen Habermas conception of communicative rationality[5] providing foundations for models of dialogue is broadly referred to in transdisciplinary research. This typology of the sciences and their rationality replaces the antique distinction between science (episteme) and knowledge of the life-world (poiêsis, praxis and phronêsis), by relating science with different types of interests: production, action and deliberation [17].

By the beginning of the 1940´s, the System theory that studies the abstract organisation of phenomena, independent of their substance, type, or spatial or temporal scale of existence had been developed in many fields[6]. The huge importance for integrative approaches (inter-, trans-) is related to the generation of the idea of an abstract structural unity of scientific knowledge [18], against the background of fragmentation of the sciences. Also the last is becoming recognized as a major risk for society, because specialisation prevents the recognition of possible negative side effects in research, education and social institutions in general [19].

Ramadier rises that the notion of unity becomes obsolete in transdisciplinary process, as unity is a state and not a process. For him, the main role of transdisciplinarity lies in the dynamics of the articulation from disciplinary knowledge. As the “whole” is more than the sum of its parts, this is made up of all the articulations between the levels of reality established by disciplinary knowledge. Articulation is what enables coherence within paradoxes, and not unity, as well as putting together the knowledge of each discipline does not mean adopting a transdisciplinary attitude [16].

1.4 Knowledge Generation

Many scientists have been arguing during last few decades, that our relation with a complex world and a complex nature requires complex thought [2]). Considering its

[4] Karl Marx (1818–1883), Max Weber (1864–1920).

[5] Jürgen Habermas argues for three types of scientific rationality related to specific standards in research (Habermas, J., 1987): (1) instrumental rationality of the empirical sciences and their standards of experimental testing, (2) rationality of the historical sciences, which concerns the role of knowledge in creating meaning for life and personal identity in societal contexts, and (3) communicative rationality as communicative action, which are about societal transformations.

[6] Systems theory investigates both the principles and the mathematical models used to describe them of phenomena. Was proposed by Ludwig von Bertalanffy (1901–1972) in biology; and developed by Norbert Wiener (1894–1964) in cybernetics; by John von Neumann (1903–1957) in game theory; by Claude Elwood Shannon (1916–2001) in informa- tion theory; and by Niklas Luhmann (1927–1998) in sociology, among others.

increasing complexity Edgar Morin proposes a radical reform of our organization of knowledge, developing a kind of recursive thinking, capable of establishing feedback loops in terms of concepts such as whole/part, order/disorder, observer/observed, system/ecosystem, in such a way that they remain simultaneously complementary and antagonistic [20]. The bottom principle is not to separate the opposing poles from the many di-polar relations that characterize the behaviour of nature and of social life. It is normal separation, in rational thinking with its linear logic, but actually artificial, since neither nature nor the human society does function in terms of mono-polar relations. Our insistence in artificially and ingeniously simplifying our knowledge about nature and human relations, is the force behind the increasing dysfunctions we are provoking in the systemic interrelations of both eco-systems and the social fabric [2].

Instead of the huge growth of knowledge production that linear logic and reductionism have contributed to, Max Neef says that '*If I were asked to define our times, in few words, I would say that we have reached a point in our evolution as human beings, in which we know very much, but understand very little*'. Knowing is not the same as understanding. While within the realm of knowledge, it makes sense that I (Subject) pose a problem and look for its solution (Object), in the realm of understanding no problems exist, but just transformations that indissolubly integrate Subject and Object [2]. Perhaps the conclusions are that knowing and understanding, belong to different levels of reality[7] [21]. Understanding, more linked to intuition, rules out both method and causality, which are both constructing formal knowledge. Hence, being in different levels of reality, understanding may solve the contradictions that arise in knowledge [2].

From Jantsch it was suggested the idea that knowledge should be organized into hierarchical systems by the coordination of four levels, described in the following way: purposive (meaning values), normative (social systems design), pragmatic (physical technology, natural ecology, social ecology) and empirical (physical inanimate world, physical animate world, human psychological world). The coordination should follow horizontal principles within each level and vertical principles between levels and sub-levels. The ultimate degree of coordination they called transdisciplinarity [10]. Max Neef [2], based on the proposal of Jansch, raised the '*hierarchy disciplinarity pyramid*' (see Fig. 1).

Gaizulosoy and Boyle[8] [22] relate the pyramid of transdisciplinarity with the areas of knowledge generation in the transdisciplinary research process (Fig. 3). It is argued that when the goal of transdisciplinary research is to respond to societal knowledge demands, three kinds of knowledge[9] are required [10] [23]:

[1] Systems knowledge: knowledge of the current status, about the origins and development of problems reduces scientific uncertainty through improved understanding of the causal relations relevant to the problem including their interpretation in the 'life-world' [24]

[7] Two different levels of reality are different if, while passing from one to the other, there is a break in the laws and a break in fundamental concepts like, for example, causality (Nicolescu, 2000)

[8] In his research of an heuristic tool developed to help individual researchers undertaking transdisciplinary projects in systematic structuring and prioritization of the literature review/reporting process.

[9] The terms were coined in 'Research on Sustainability and Global Change – Visions in Science Policy by Swiss Researchers' (ProClim, 1997), with the definition of 'systems knowledge' as knowledge of the current status; of 'target knowledge' as knowledge about a target status; and 'transformation knowledge' as knowledge about how to make the transition from the current to the target status.

[2] Target knowledge: knowledge about the system status required and/or desired to be reached, as needs for change, desired goals and better ways of acting)
[3] Transformation knowledge: knowledge about the means to achieve this transformation, as technical, social, legal, cultural and other means of transforming existing ways of acting in desired directions [7]

These three types of knowledge require each other in order to be generated and influence one another during the research process. The systems knowledge is mainly acquired from the two bottom levels, which provide the empirical information necessary to understand the situation. Target knowledge involves visioning for a new system status, referenced to the normative and the values levels of the pyramid. Transformation knowledge does not directly link to any of the levels of the pyramid since its structure is amorphous and generally specific to the problem being addressed, but is generated through synthesis of knowledge from all four levels of the pyramid.

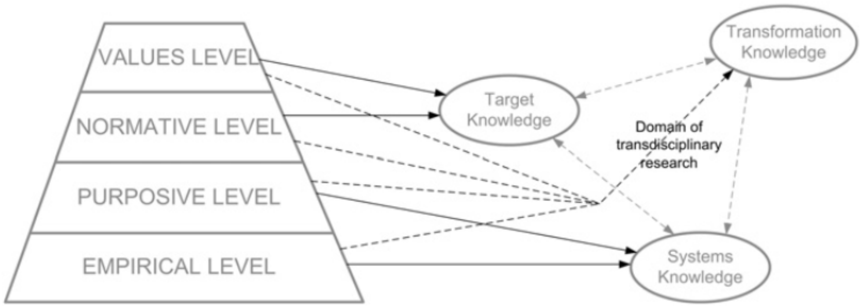

Fig. 3. Relationships between the pyramid of transdisciplinarity and the three types of knowledge of the transdisciplinary research domain where both problem framing and new knowledge generation takes place [22].

These three forms of knowledge remind us of Aristotle's forms of knowledge, namely: science (episteme); life-world action (praxis); production (poiêsis); and prudence (phronêsis), now transformed as goals of transdisciplinary research [10]. Meeting these knowledge demands requires grasping the relevant complexity of the problems, taking into account the diversity of scientific and societal views of the problems, linking abstract scientific reflection with relevant case-specific knowledge, and constituting recursively knowledge with a focus on problem solving for what is perceived to be the common good. The first step for such integration is to acknowledge, to respect and to explore the diversity of perspectives[12]. Even more as Benessia et al. [25] defends, hybridizing sustainability with a variety of knowledges and experiences means engaging with the inherent complexity, indeterminacy of experimentation over socio-ecological systems, promoting a fundamental epistemic and normative shift from searching what to do and to choosing how to do it.

1.5 The different transdisciplinarity approaches

The upper historical perspective points to why transdisciplinarity is a fuzzy and contested concept, shaped by various lines of thinking, heterogeneous conceptions of science and approaches to research, with a variety of terminologies and definitions.

- ***Earlier ideal notions of transdisciplinarity***

The earlier notions predicating transdisciplinarity, being a hyper form of interdisciplinarity, had the aim to develop an overarching framework for similar problems and transform education from 'training' into 'genuine' [23].

After the first international conference on interdisciplinarity, held in France in 1970 and co-sponsored by the Organization for Economic Cooperation and Development (OECD), some participants wanted the term transdisciplinarity to be in the title of the seminar and the post-seminar book. At this time, higher education was being pressed worldwide by calls for reform. Some participants developed the concept further into two interests. Erich Jantsch did with external purpose. He proposed institution education structures based on feedback among three types of units: systems design laboratories, function oriented departments, and discipline oriented departments with a focus on interdisciplinary potential in a hierarchical goal oriented system of science, education, and innovation in purposive levels '*the essential characteristic of a transdisciplinary approach is the coordination of activities at all levels of the education/innovation system towards a common purpose*' [26]. Jean Piaget focused on internal dynamics of science, and recognized about this that "*It's just a dream*" [27].

The philosopher Joseph Kockelmans in a 1979 collection of essays on interdisciplinarity published in the USA, suggests the term '*crossdisciplinary work*' for research which 'is primarily concerned with finding a reasonable solution for the problems that are so investigated, whereas transdisciplinary work is concerned primarily with the development of an overarching framework from which the selected problems and other similar problems should be approached' [28]. He situated transdisciplinarity in the philosophical and educational dimensions of sciences, because he aligned the concept with the work of a group of scientists trying to systematically determining how negative effects of specialisation can be overcome to make both education and research more socially relevant [27]. At this time in the USA, 'transdisciplinary science' connotation arose in the field of to cancer studies and well-being [10].

- ***Towards society and real life problem solving***

By the end of the last century, two currents of definition gained wide attention. Both were drawn notions of transdisciplinarity as a methodology.

On the one hand, there is the need to facilitate a broad scientific and cultural dialogue, informed by the new complexity view [27]. Changes are originated at the first World Congress on transdisciplinarity in Portugal, 1994. The participants endorsed the Charter of Transdisciplinarity. In 1987 Basarab Nicolescu and fellow members of CIRET[10] (the Centre International de Recherches et Etudes

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[10] CIRET is a virtual meeting space for specialists from all domains. It publishes an electronic journal, results of UNESCO-sponsored international colloquia (including the first world congress on transdisciplinarityin Portugal in 1994 and the 1997 congress on the

Transdisciplinaires), began developing a broad-based scientific and cultural approach capable of facilitating long-term dialogue between specialists and educators, from the worldview of complexity in science. Nicolescu identified three pillars of transdisciplinarity[11]:

- Complexity: relativity (not reductional), transcultural, transnational, and encompasses ethics, spirituality, and creativity
- Multiple levels of reality: multidimensionality against to the one-dimensional reality of classical thought
- The logic of the included middle: capable of describing coherence among different levels of reality, inducing an open structure of unity

Nicolescu calls it the science and art of discovering bridges between different areas of knowledge and different beings. Edgar Morin, also a member of CIRET, adds that knowledge of complexity also demands a new dialogue that bridges humanistic and scientific cultures[12] and consequently a new reform of the education [27]. This type of transdisciplinarity requires a personal commitment “challenging that the dignity of the human being is of both planetary and cosmic dimensions” [5]. It means that an openness to different epistemic cultures, experiential contexts, ethics, spirituality, are needed.

On the other hand, there is the need to deal with real-life problems. Jürgen Mittelstraß uses the term in defining ‘*transdisciplinarity as a form of research that transcends disciplinary boundaries to address and solve problems related to the life-world*’ [10]. Scholz refers to as: ‘*Science becomes transdisciplinarity if it reflects on real life problems’ [5]*.

Silvio Funtowicz and Jerome Ravetz deal with the concept of post-normal science, arguing that science must engage in dialogue with all those who have a stake in a decision of high uncertainty [29]. They claimed that ‘*The objective of scientific endeavour in this new context may well be to enhance the process of the social resolution of the problem, including participation and mutual learning among stakeholders, rather than a definitive ‘solution’ or technological implementation*. *This is an important change in the relation between the problem identification and the prospects of science-based solutions*’ [7]. This post-modern type of transdisciplinarity claims that approaching truth from only science in complex contextualized settings, becomes obsolete: science just becomes one voice and vote. It’s imperative the management of irreducible uncertainties in knowledge and in ethics, and the recognition of different legitimate perspectives and ways of knowing [29].

Michael Gibbons and Helga Nowotny claim that a new form of knowledge production has emerged, the so-called mode-2 [30, 31]. 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. 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. Mode-2 knowledge has features such as

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transdisciplinary evolution of the university in Locarno, Switzerland), and reports on projects around the world http://perso.club-internet.fr/nicol/ciret/

[11] In the Manifesto (1996), and the essay ‘‘New Vision of the World’’ at http://perso.club-internet.fr/nicol/ciret/.

[12] E. Morin, Réforme de pensé congress Quelle universite, transdisciplinarité, reforme de l’universite pour demain? Vers une evolution transdisciplinaire de l’universite Locarno. 30 April–2 May1997. CIRET-UNESCO: Evolution transdisciplinaire de l’universite Bulletin Interactif du CIRET, 9–10 (1997) at http://perso.club-internet.fr/nicol/ciret/.

transdisciplinarity, heterogeneity, reflectivity, social accountability, and context- and user-dependency [18].

At the International Transdisciplinarity Conference in Zurich in the year 2000, is featured a latest transdisciplinary approach on real-world problem solving, highlighting the convergence of transdisciplinarity, complexity, and trans-sectorality in a unique set of problems that do not emanate from within science. As result it is defined Zurich 2000 transdisciplinarity as [32]:

> *‘Transdisciplinarity is a new form of learning and problem solving involving cooperation among different parts of society. Transdisciplinarity research starts from tangible, real-word problems. Solutions are devised in collaboration with multiple stakeholders. A practice-oriented approach, transdisciplinarity, is not confined to a close circle of scientific experts, professional journals and academic departments where knowledge is produced. Ideally, everyone who has something to say about a particular problem and is willing to participate, can play a role. Through mutual learning, the knowledge of multiple participants is enhanced, including local knowledge, scientific knowledge and the knowledge of industries, businesses, and NGO’s. The sum of this knowledge will be greater than the knowledge of any single partner. In the process the bias of each perspective will also be minimized.’*

Based on this, transdisciplinarity is a reflexive, integrative, cooperative, method-driven scientific principle aiming at [33]:

a) The **solution or transition of societal relevant problems** and concurrently of related scientific problems, by differentiating knowledge from various scientific and societal bodies of knowledge.
b) Enabling **mutual learning processes** among researchers from different disciplines (from within academia and from other research institutions), as well as actors from outside academia, on equal footing; and
c) Aiming at **creating and integrating knowledge** that is solution-oriented, socially robust[13], and transferable to both the scientific and societal practice, also considering that transdisciplinarity can serve different functions, including capacity building and legitimization [34].

- ***The ‘Southern’ perspective***

In this perspective, principles of integrating research and social change similar to action research have been developed, a radical concept of science in which theory and practice should be mutually beneficial. Near to this, what today is called ‘southern version of transdisciplinarity’ is closely related to the impacts of the writings of the Brazilian authors Paulo Freire and Leonardo Boff, who in the framework of theory of liberation published a specific methodology for working with the people [7]. The pedagogy of Freire understands literacy education not only in terms of reading the word, but also reading the world. This means that the creation of a critical

[13] See Gibbons, 1999.

consciousness becomes an important content of development. Freire develops the practical educational implications of Habermas' conception of communicative action [7]. A basic common element is their shared confidence in 'dialogical and reflexive learning'. These changes have been taking place during the past thirty years in the design of research projects in development cooperation. Where, at the beginning, researchers defined the problems and the solution, now, the affected population's participation is supported in the research process. New approaches and methods, such as rapid rural appraisal (RRA) and participatory rural appraisal (PRA), are being developed to integrate people knowledge.

In the discourse of human rights accountability, new modes of knowledge, discourse, and institutional frameworks were needed across all sectors in both the North and the South. Researchers emphasize that scientific concepts and methods cannot be imposed on indigenous knowledge and complexity. Biophysical and human dimensions must be integrated spatially and temporally in a holistic approach, if it's necessary to identify ways of improving ecosystems and human welfare [35, 36]. Also, social and health scientists began to produce conceptual analyses and empirical findings in the area of transdisciplinary health research, at 1990s, spurred primarily by some innovative work at the University of Newcastle (Australia). Article 14 of the Charter of Transdisciplinarity[14], is relevant here: "*Rigor, openness, and tolerance are the fundamental characteristics of the transdisciplinary attitude and vision (…)*".

2 TRANSDISCIPLINARITY AND SUSTAINABILITY

The concept of transdisciplinarity has become aligned with sustainability in the last discourse of problem solving [37]. The United Nations Conference on Environment and Development in Rio de Janeiro 1992, had the commitment of the statesmen from most nations to sustainable development as a way to conceive the common good as the basic principle of public legislation in a complex world. With sustainability as its normative model, science and scientific activity is demanded to be an 'agent of change', adopting problem-solving approach and innovation for society, not only a resource for integrating scientific knowledge [5].

Sustainability problems are widely recognized as wicked problems[15] [38, 39], beyond the scope of normal, current, industrial-age engineering science. Lots of authors agree that the scientific expertise required to deal with this is in need of reform. Two major views regarding this possible reform have been observed [38]. A more conservative view, suggests that science's ethical, educational, and procedural cultures do not require significant transformation, so science can meet the challenges of sustainability by inventing sustainable technologies that drive innovation. It has been characterized as business-as-usual and systems engineering approaches [38]. From sustainability concerns, they are handicapped due to knowledge resides more and more in narrow specializations [39], leading to new capabilities even though regardless of broader contextual questions.

[14] The Charter of Transdisciplinarity was signed at First World Congress of Transdisciplinarity, Convento da Arrabida, Portugal, November 2– 6, 1994, Article 14. Available at: nicol.club.fr/ciret/english/charten.htm.

[15] Conceptualization attributable to Norton (2005): sustainability problems exhibit typically ten characteristics reduceable to five, also constitutive of wicked problems: difficulties in problem formulation, multiple but incompatible solutions, open-ended timeframes, novelty (or uniqueness), and competing value systems or objectives. Similar concepts were developed earlier by Rittell and Webber 1973, Funtowicz and Ravetz (1993) and Dovers (1996) (Seager et al., 2011).

A more proactive view, so-called sustainable engineering science, proposes shifting orientation towards more integrative approaches to science, education, and technology that [38]: (1) include *macroethics*[16] beyond the usual bounds of professional responsible conduct, (2) approaching risk-based design and management to consider anticipation, adaptability, and *resilience* (3) cultivate *interactional expertise* to facilitate cross-disciplinary exchange.

Macroethics looks at these moral dilemmas that are not traceable and result from the complex and dynamic interaction among many actors (individuals, organizations, professions, industies) (Fig. 4). Consequently, they cannot be resolved without deliberation and collective action harder [38].

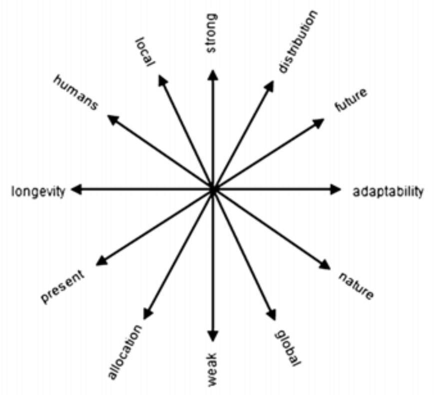

Fig. 4. Sustainability sextant: macro-ethical tool that illustrates several points of ethical tension that define different interpretations of sustainability. [38]

In formulating any problem within the domain of sustainability, scientists must confront each of these axes on a multi-dimensional Sustainability Sextant (Fig. 4). Each dimension is interrelated in the sense that some perspectives suggest or are more consistent with others. Nonetheless, the purpose of the Sextant is to guide individuals from their own points of view to those that may be foreign to them.

On the other hand, taking into account that wicked problems should not be thought of as problems to be solved, but conditions to be governed, designing for resilience, will comprise adaptive strategies based on the ability of a system to respond to stressors without losing basic functionality or structure. So, the sustainability engineering scientist must acquire a macroethical awareness, the deliberation skills necessary to work through macro-ethical issues in concert with others and an anticipatory competence, to be capable of imagining possibilities (as opposed to estimating probabilities) and understanding the potential consequences of adaptive interventions and cultivate interactional expertise [39].

Sustainability research and transdisciplinary research strongly overlap and is considered interchangeably [40]. Also, transdisciplinary aspects of research for sustainability encompass social sciences and humanities as well as the participation of societal actors. When entering transdisciplinarity, engineering researchers enter unfamiliar grounds for scientific knowledge production [7].

[16] Ethical considerations must be considered at the scale of the collective.

Transdisciplinarity research is considered also, a form of action research. Participation and learning circles have to start from the beginning, where the scientist as an “observer of the common learning process” [32]. The concept of linking knowledge to action for sustainability [40] has been reiterated during the last decade [41, 42]. Yet too many scholars still believe that this link will miraculously emerge, it obviously requires a very different type of research and education to generate knowledge that matters to people’s decisions and engages in arenas where power dominates knowledge; and education that enables students to be visionary, creative, and rigorous in developing solutions and that leaves the protected space of the classroom to confront the dynamics and contradictions of the real world [43, 44].

Transdisciplinarity raises the question of not only problem solution but problem choice [27, 5]. However in order to meet the knowledge demands for sustainable development, different approaches are needed depending on the kind of problems to be solved [7, 38]. Since its inception, sustainability science has evolved to become a problem- and solution-oriented field inspired by the post-normal science philosophy that adopts transdisciplinary and participatory research practices [33, 2, 45]. This evolution has bifurcated the field into a descriptive–analytical stream and a transformational stream or, in other words, in ‘*traditional disciplinary-based science for sustainability and the transdisciplinary science of sustainability*’ [46]. In short, sustainability science in its transformational mode seeks broad transdisciplinary participation throughout research and practice focused on solving sustainability problems. Transdisciplinarity, as active collaboration with various stakeholders throughout society must form another critical component of sustainability science[47].

3 TRANSDISCIPLINARITY AND HIGHER EDUCATION

While research and education slowly recognize the importance of shifting their efforts to sustainability challenges and their root causes [44, 46], sustainability scientists lack experience and expertise in contributing to feasible and effective solution options [42]. Principles for higher education have to be developed that are focused on the problem-oriented transdisciplinary approach to provide future researchers with the relevant knowledge and skills [4]. Moreover knowledge of complexity, Edgar Morin exhorts, also demands a new dialogue that bridges humanistic and scientific cultures [27].

Currently, academia is poorly positioned to address sustainability problems because of anachronistic pedagogy, mismatched incentives, insufficient expertise, lack of personal commitment, familiar and comfortable patterns for scholars, and isolated products and communication [39, 47]. Existing education and research training programs are ill-equipped to prepare scientists and engineers to operate effectively in a wicked problems milieu. Advancing sustainable engineering science requires to create new long-term, participatory, solution-oriented projects programs as platforms for the next generation of sustainability scientists and engineers to recognize and engage with the macro-ethical, adaptive, and cross-disciplinary challenges embedded in the cutting-edge problems and approaches in the field their professional issues [38]. As new programs evolve, they can be the proving ground for new pedagogies, incentives, and transdisciplinary collaboration within and beyond the academy.

But education always seems to go after the events. The implementation of academic concepts and methodologies in the practice of sustainability science programs, has not yet been examined in detail, while they have been discussed theoretically in the literature [47]. It is true that the business of education has traditionally been, just the transmission of knowledge, but the future will be more dynamic. The time when young people acquire profesional training up to the age of about 20 or 25, then stay on this activvity to the age of retirement, has passed. Therefore, training in how to work in teams with experts from many different fields, how to learn and adapt quickly and permananntly to ever-changing situations are new imperatives for preparing new professionals [32]. It is also argued that the transience terms of most academic projects do not match the long-term relationship and capacity building required for meaningful participatory engagement and transformational change [25]. In the same way, as editors of Handbook of Transdisciplinary Research[17] noticed, there is a disconnection between local efforts and the abundant information and insights that have emerged in the task: 'What has been learned on the job', they lamented, 'is seldom passed on to others for capacity building' [10]. So, the lack of education might be explainable.

Nevertheless, in spite of any old pattern, the advocation of operationalizing the goals of the field, developing the necessary competencies, and seeking novel partnerships between society and the academy will position academic institutions to make a bigger impact on the transition to sustainability.

- ***Transdisciplinary Skills***

Julie Thompson Klein, who has most revised transdisciplinarity education programs over the world, collected three main statements about the skills needed for transdisciplinary work [10]. The first is the 'quadrangulation' of: disciplinary *depth*, multidisciplinary *breadth*, interdisciplinary *integration*, and transdisciplinary *competencies*. Disciplines provide essential knowledge and remain in transdisciplinary work. Breadth of exposure to multiple disciplines, precise the capacity of articulate specific knowledge and experience gained in the own disciplines. ID precise of the ability to work with pertinent information, to contrast approaches, to clarify differences, and to generate a synthesis, integrative framework. Cultivate transdisciplinarity competencies is related to the last two statements. The second statement is the reconceptualisation of education as a dynamic dialogue of content (principles, approaches, methods, analysis, strategies) and process (how to organize, participate and communicate). The third is the interwined relationship of transdisciplinary competencies.

Derry and Fischer [48] conceptualised a set of overlapping categories of transdisciplinarity competences/skills for graduate STEM (science, technology, engineering, and mathematics) education (applicable beyond STEM domain):
- The ability of productive and reflective participation (understanding of work communities, effective communication)
- Mindset for lifelong learning (critical thinking, on demand and self directed learning);
- The ability of innovative sociotechnical environments, fluent digital media use
- The ability to teach and learn in new knowledge building communities
- Willingness to become an engaged citizen for real world needs

[17] The Handbook of Transdisciplinarity Research emaned from 'td-net' network advisory board, at their first meeting in 2003, but it was edited three years after.

Pohl, van Kerkhoff, Hirsch Hadorn, and Bammer [23] designate some skills needed to lead transdisciplinary and integrative projects:
- Ability to adequately scope issues to apply an integrative approach
- Ability to apply integrative methods and processes (modeling and group facilitation)
- Ability to draw on strengths of different research epistemologies, tailoring them to a common task
- Understanding of policy, practice and product development
- Ability to foster research collaboration

In both the underlying theme is cognitive flexibility, manifested in a willingness to see beyond one's own discipline, and to the integration of knowledge. Of course, authors warn that nobody will be expert in all areas and other members and teams are needed to fill skill gaps. Developing a larger framework for skills and allowing concentration on a subset of them can also provide the core of undergraduate and graduate curricula.

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