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Regards – Focus

Conception and implementation of interdisciplinarity in the Human-Environment Observatories (OHM, CNRS)[☆]

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Abstract – To respond to the complexity of the socioecosystemic crises that increasingly affect an anthropized and globalized planet, since 2007 the author has developed and implemented within the framework of the CNRS Ecology and Environment Institute (INEE) a comprehensive interdisciplinary system known as the Human-Environment Observatories (or OHM, of which there were 13 in 2019), a laureate of the Laboratory for Excellence project (LabEx) as part of the French Government's 'Investing in the future' programme ('*Programme d'investissement d'avenir*', PIA) since 2012. The author presents what interdisciplinarity means in this framework, how it differs from conventionally identified interdisciplinary exchanges, how it is conceived and implemented, from the theoretical to the most practical level. He provides some examples of work and in a discussion, positions this system and its principles with regard to the existing frameworks and systems.

Keywords: environment / sustainable development / human-dominated ecosystems / interdisciplinarity / indisciplinarity

Résumé – Conception et mise en œuvre de l'interdisciplinarité dans les Observatoires hommes-milieux (OHM, CNRS). Les sociétés font face à des crises socioécosystémiques qui affectent de plus en plus une planète anthropisée et globalisée et qui sont un enjeu majeur pour son devenir. Pour répondre à cet enjeu, il faut faire face à la très haute complexité de systèmes très fortement anthropisés dont la compréhension nécessite des interactions entre toutes les sciences de l'environnement (sciences de la Terre, de la vie, de l'homme et de la société – SDE). Dans ce cadre, l'interdisciplinarité n'est pas un choix, mais une contrainte structurelle. L'auteur présente ici un dispositif global d'interdisciplinarité qu'il a conçu et développé dans le cadre du CNRS depuis 2007 dans ce but : les Observatoires hommes-milieux (OHM ; en 2019 treize avaient été créés, répartis en France et dans d'autres pays). Ils ont été organisés dans le cadre du Labex DRIIHM (Dispositif de recherche interdisciplinaire sur les interactions hommes-milieux). Ce Labex, lauréat du PIA1 en 2012 et créé initialement pour 8 ans, vient d'être renouvelé pour 5 ans (2020-2025). Les OHM se dédient à l'étude de sites très anthropisés, marqués par un « événement fondateur » qui vient bouleverser les équilibres écologiques, économiques et sociaux établis depuis des années, entraînant ainsi une crise socioécosystémique majeure (par exemple, un bassin sidérurgique et sa fermeture). Dans cet article, l'auteur énonce les qualités requises pour que cette interdisciplinarité puisse répondre à cet enjeu socioécologique et précise les définitions des démarches de multi-, inter- et transdisciplinarité. Il observe que, dans les OHM, c'est une « disciplinarité éclairée » qui s'est spontanément développée entre les SDE, grâce à cette attitude heuristique d'ouverture d'esprit nommée « indisciplinarité ». Trois exemples de ce fonctionnement sont présentés, qui illustrent la

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souplesse et la simplicité du dispositif ainsi que son efficience pour permettre le développement de liens entre les scientifiques eux-mêmes et avec la société, dans une perspective de développement durable. Le dispositif OHM/DRIIHM est une des possibilités pour répondre à ce défi.

Mots-clés : environnement / développement durable / écosystèmes anthropisés / interdisciplinarité / indisciplinarité

Introduction

Global change is subjecting our planet to a multiplicity of socio-environmental crises, which are often very negative at the local level (company closures, pollution, etc.) and for which society needs knowledge and understanding in order to consider appropriate remedies[1]. These events take place in a specific context, the outcome of two significant realities that profoundly affect this world of ours.

The first is the global population explosion, felt in terms of number and density, a factor in large-scale artificializations (anthropo-constructed systems [Chenorkian, 2014, p. 25-26]). Humans play the main role in all these systems. The second concerns technological developments that have enabled exponential expansion of the transport of goods, people and ideas (Peters *et al.*, 2008), in very large quantities, over very long distances and at very high speeds, even almost instantaneously (from containerization to social media). We can refer to this as the 'great acceleration of the Anthropocene' (Steffen *et al.*, 2015).

The association of these two phenomena has led to the emergence of the 'Anthroposphere', a global planetary network that, in an unpredictable manner, generates interactions between disjointed systems that may be very distant. It thus gives rise to relationships between these systems that are no longer merely hierarchical or panarchical, but also an-archical in the sense that these interactions go beyond all considerations of hierarchy and proximity (Chenorkian, 2014, p. 24), at the erratic frequencies of temporality and of the characteristics of human action. It leads to permanent systemic instability which considerably increases the complexity of these ecosystems, which we then describe as hypercomplex[2].

These circumstances have two major consequences. None of the environmental sciences (earth, life, human and social sciences – provided they are taken into consideration –, or ES) can alone account for this hypercomplexity, and understanding these systems requires (i) a joint and convergent approach to ES that interact, and (ii) a systemic study process i.e. one that takes into consideration the objects involved and their organization, and the nature and dynamics of the interactions they develop between them. The recourse to interdisciplinarity is therefore not a choice, but a structural constraint and an absolute necessity if we are to achieve understanding of these anthropized ecosystems. This fact conditions its characteristics and properties. This interdisciplinarity must be always available (it is a necessity), general in scope (all questions require it), easy to set up (each new question requires several ES), highly functional (it must allow interactions regardless of the ES called on), evolving (capable of changing its geometry and its questioning as understanding of the initial question and its ensuing adjustments progresses), enduring (permanently available without fundamental rearrangement or reconsideration), and resilient (capable of surviving once the initial question has been resolved).

Furthermore, at the local levels[3] that concerns us here in particular, the human factor can no longer be considered either as a forcing variable in a natural ecosystem or as a component of a socioecosystem where an 'anthroposystem' interacts with a natural biophysical 'ecosystem'. It must instead be seen as one of the components of a single ecosystem, in which the anthropic interacts directly with the abiotic and the biotic to form what we refer to as the Single ES[4] (Fig. 1).

[1] The research covered in this text originates from the author's reflections that led to the creation of the Human-Environment Observatories (OHM, 2007) and the Labex DRIIHM (Interdisciplinary Research Facility on Human-Environment Interactions, 2012) within the ESD (Environment and Sustainable Development) department, then the Institute of Ecology and Environment (INEE) of the CNRS. Various aspects of the project have been presented at the Labex DRIIHM annual seminars, and some of them have been addressed in publications (Chenorkian, 2014, 2019; Chenorkian and Abbadie, 2017). However, this is the first time that this thinking has been presented in full, including previously unpublished aspects.

[2] In the sense that Edgar Morin uses this notion to characterize the process of hominization to which it corresponds, term for term (Morin, 1973, p. 130).

[3] At more global levels, the complexity of the systems is such that, given the impossibility of evaluating their consequences, the question loses some of its meaning.

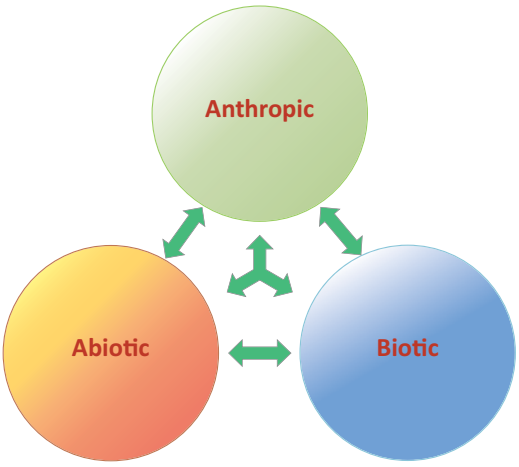


Fig. 1. Single ecosystem (Single ES). In highly anthropized environments, with the preponderance of the Anthroposphere, the anthropic, the biotic and the abiotic form a single ecosystem (source: R. Chenorkian).

Such a reading is heuristically decisive and places global ecology[5] within the very structure of the ecosystem while determining the way it is implemented.

The OHM

In response to this context, the attributes of the systems, the questions asked and society's expectations, we have developed and implemented a specific system within the CNRS Ecology and Environment Institute: the Human-Environment Observatories (or, to give them their French acronym, the OHM). Through the convergence of the environmental sciences, their role is to enable the study of the highly anthropized ecosystems that are most likely to be affected by these socio-ecosystemic crises. They have thus been designed as a means of stimulating, supporting and organizing the interdisciplinary approach required to deal with the very great complexity of these phenomena. Beyond implementation of the fundamental and applied scientific research that underpins them, their approach also implies listening to society's expectations and aims to provide an understanding of the systems in order to advise political or economic decision-makers and social participants as fully as possible when they come to make their choices. In this way, the OHM position researchers within society.

The OHM are the result of three observations: the obligation to apply interdisciplinarity to deal with the complexity of ecosystems, especially highly anthropized ones; the need to involve all ES in order to achieve this; and the permanent and systematic difficulty in achieving such a result.

All the OHM[6] concern an anthropized place. They are built on three elements: a 'social-ecological framework', which is the socioecological context of the place, a 'disrupting event', which disrupts it, and a 'focal object', the product of the first two elements (Chenorkian, 2014 and 2019). The social-ecological framework may be a steelmaking region and the ecological, economic and social consequences of this activity, the disrupting event the closure of the factories, and the focal object the region impacted by this event. All the ES study this focal point, taking a convergent approach known as global ecology. Research in the OHMs is based on an annual call for projects (call for research projects – APR –, doctoral or postdoctoral), seminars (presentation/reporting the research results from each OHM; general, on a specific theme or cross-disciplinary for the DRIIHM) and specific workshops.

The project has now been in place for over twelve years, and was conceived as a fully integrated system, from concept to highly practical implementation. The system and its results, in terms to the required interdisciplinarity, are presented here.

Semantic considerations

There are many terms to describe the relationships between disciplines: pluri-, multi-, poly-, co-, supra-, meta-, inter-, trans-disciplinarity and probably others (e.g. Moineau, 2015; Kleinpeter, 2013; Darbellay, 2011, p. 71; Thompson Klein, 2010; Godard, 1992, p. 352; Apostel *et al.*, 1972, p. 23-24, etc.). The three terms pluri- (or multi-), inter- and trans-disciplinarity, ordered according to the extent of interactions between dis-

[4] Integration has basically been called for since the emergence of the notion of socioecosystem by a great many authors, but never implemented (Chenorkian, 2019, note 3).

[5] Global ecology does not mean 'ecology of the planet' but the understanding of ecosystems through the convergence of all the ES. This is our community's concept, but the underpinning bases were first referred to elsewhere over 15 years ago (cf. Berkes *et al.*, 2003, p. 8: 'A complex social-ecological system cannot be captured using a single perspective. It can be best understood by the use of a multiplicity of perspectives').

[6] There are now 13 OHMs in mainland and overseas France and abroad: Provence coalfield (2007), Oyapock (French Guiana, 2008), Pyrénées – Haut-Vicdessos (2009), Tessékéré (Ferlo, Senegal, 2009), Estarreja (Portugal, 2010), Rhône Valley (2011), French Mediterranean coastal zone (2012), Nunavik (2012), Pima County (Arizona, USA, 2014), Pays de Bitche (2015), Patagonia-Bahia Exploradores (Chile, 2015), and Caribbean coast (Guadeloupe, 2016), Fessenheim (2018).

ciplines, are very widely shared (cf. among many others Piaget, 1972, p. 170; Darbellay, 2018 or 2011) and shall be considered here.

Pluri- or multi-disciplinarity is very generally used to describe the coexistence of disciplines without interaction between them. For Darbellay (2018, p. 2), multidisciplinarity is 'a sequential process in which researchers from different disciplines work, from their own viewpoint, on a roughly shared object of study, independently and juxtaposed' (cf. also Piaget, 1972, p. 166; Darbellay, 2015, p. 165). The 'roughly shared' object is an element that comes close to our approach here, but it does not meet the necessary conditions mentioned above.

The term 'interdisciplinarity' has two main meanings. The first is that several disciplines combine to solve a problem (often through the intermediary of technology, cf. Jollivet, 1992, p. 415 ff; Brown *et al.*, 2015). Most of the time, the combination of disciplines disappears once the problem is solved (see Fig. 2.1). This therefore only partially meets the criteria sought. The second is in fact a process of creating disciplines. Two disciplines combine to form a new one (e.g. bioinformatics[7]; Fig. 2.2). This second meaning is far removed from our needs.

The notion of transdisciplinarity was defined in 1970 by Jean Piaget. It 'would not only cover interactions or reciprocities between specialised research projects, but would place these relationships within a total system without any firm boundaries between disciplines' (Piaget 1972, p. 138). It then developed and diversified from the 1990s onwards (McGregor, 2015; Thompson Klein, 2010). The simplest definition distinguishes between two approaches, one known as 'nicolescuian'[8] and the other the 'Zurich' approach[9] (McGregor, 2015; Max-Neef, 2005, p. 5). The first results in 'a new way of thinking about knowledge and inquiry that has included writing from ethical, metaphysical, and even mystical perspectives' (Bernstein, 2015, p. 6), 'it situates man in the Universe. It postulates that the economy must be at the service of man. It dialogues with all humanist and non-totalitarian ideologies' (Bourguignon, 2014, p. 4). The 'Zurich' approach refers to 'work aimed at designing and implementing tangible solutions to "real world" problems' (Bernstein, 2015, p. 6; Scholz and Steiner, 2015a). 'Transdisciplinarity can be thought of as a method of research that brings political, social and economic actors, as well as ordinary citizens, into the research process itself, in a "problem-solving" perspective' (Darbellay, 2015, p. 166; see also Scholz and Steiner, 2015a, p. 532; McGregor, 2007, p. 490-491), through the creation of 'new knowledge' (McGregor, 2007, p. 487, p. 491-493). All associated knowledge, considered to be of equal importance (Lang *et al.*, 2012, p. 26 ff; Bernstein, 2015, p. 6 ff; Scholz and Steiner, 2015a, p. 529) contributes to resolving the 'wicked problems' it examines: 'justice, sustainability... poverty, war, genocide, hunger, global climate change, the extinction of species, exhaustion of natural resources and the destruction of ecosystems' (Bernstein, 2015, p. 7-11; McGregor, 2011, p. 15; McGregor and Donelly, 2014, p. 165; Fig. 2.3). In both cases, the concepts, approaches and objectives are far removed from what we are looking for here.

Interdisciplinarity in the OHM

What kind of interdisciplinarity applies in the OHM and the DRIIHM after 12 years of practice? This question should be examined from two angles: the nature of this interdisciplinarity and its practice.

'Enlightened disciplinarity'

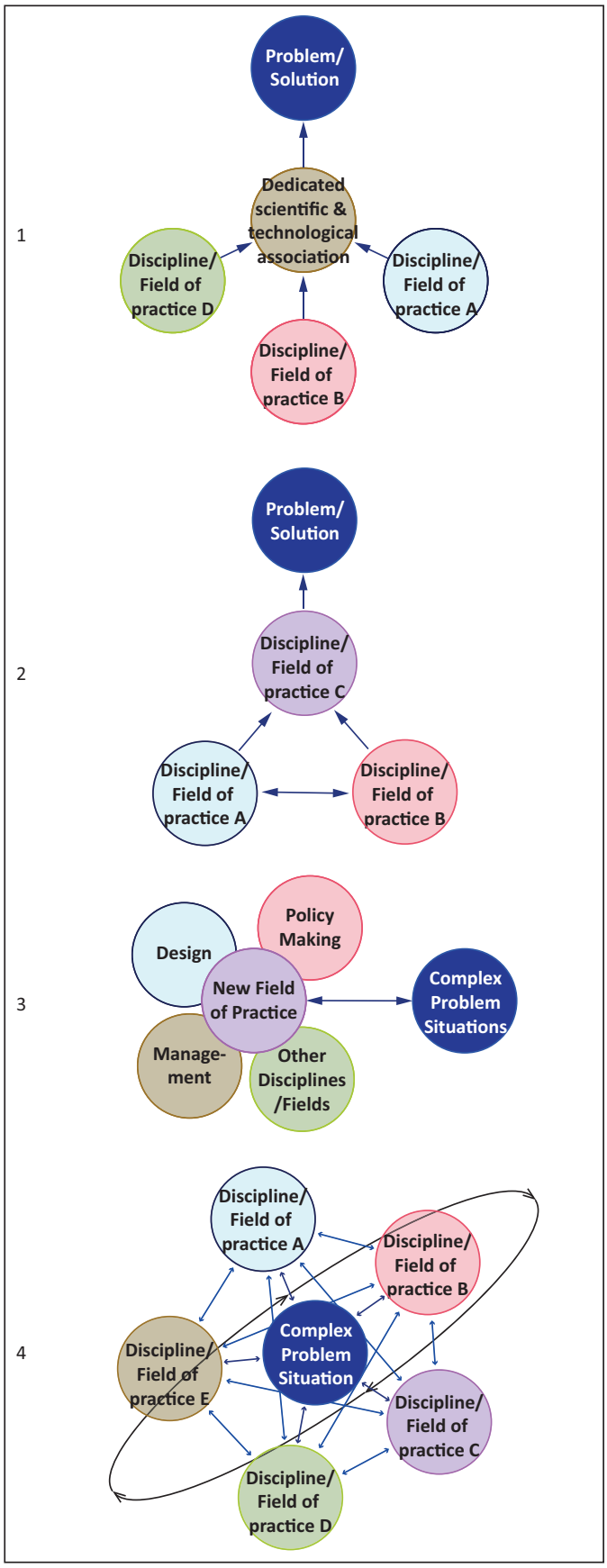
Responses to calls for research projects are mainly disciplinary[10]. Each team works with a disciplinary approach on its own programme but concerning the same (focal) object and with regard to a problematization previously established jointly for the entire OHM. Sharing the object of study within a joint framework from the outset means research can resonate between disciplines, with insights from other points of view bringing out previously unsuspected 'topographies'. For each of the ES, this enlightenment comes from discovering the results of others, properly understanding them, considering how they allow or require a reformulation, reorganization or 'reproblematization' of one's own disciplinary research project, and then either embarking on a new cycle of research/publishing results/restructuring the project, or moving on to the modelling stage and the final synthesis, which will require dialogue between the disciplines and their results to produce a solid and relevant construction that integrates the specifics of each discipline for judicious and timely use, as shown in the examples below. Interdisciplinarity in the sense of a circumstantial combination of disciplines on an issue (meaning 1)

[7] This is basically the North American conception, a direct result of the academic organization and funding methods of higher education and research in the United States (Graff, 2015; *Nature*, special issue, September 2015; Frodeman *et al.*, 2010). See also the excellent illustration in McPhee *et al.* (2018, p. 4), and here, Fig. 2.2.

[8] Named after one of the founders of the CIRET (International Centre for Transdisciplinary Research and Studies), Bassarab Nicolescu.

[9] This name comes from a congress held in Zurich in March 2000 on transdisciplinarity (McGregor, 2015 p. 2).

[10] cf. the awardee research programmes can be seen on the OHM websites, accessible from http://www.driihm.fr/.



may occur, bringing a solution to some very specific cases, but it is very rare. Transdisciplinarity, whatever meaning we give this term, has never been observed.

We describe the practice developed in the OMHs as 'enlightened disciplinarity' (Fig. 2.4). It meets all the requirements set out above. For it to emerge, however, everyone involved must approach it with a spirit of openness, and be willing and able to listen to others to benefit from other knowledge, which is not always a given.

Since the 18th century, disciplines have become separated through differentiation (Moineau, 2015; Bourdieu, 2001). Each disciple thus has an inherent distrust of any mixing that would undermine its identity. Moreover, practically every aspect of the current organization of universities, research organizations, recruitment bodies, research evaluation or its units is based on disciplinary excellence, assessed by peers or experts who are, by nature, supervisory bodies ensuring adherence to the dominant norm of the discipline in question. Thus, although the call for interdisciplinarity is heard everywhere and, it seems, widely agreed upon[11], there are still some very considerable boundaries between disciplines.

Interdisciplinarity is always the outcome of a determined effort that is fundamentally transgressive (Bourdieu, 2001, p. 87; Thompson Klein, 2015, p. 11 ff) and that intrinsically generates negative reactions and consequences. 'Enlightened disciplinarity' and its active and continuous exchanges between disciplines will therefore not emerge spontaneously (Bourdieu, 2001, p. 73).

Fig 2. Types of relationship between disciplines. 1 and 2 – Interdisciplinarity: 1- several disciplines converge to resolve a specific issue; 2- two disciplines hybridize to form a third in a process of disciplinarization. 3- Transdisciplinarity: the research process brings together scientists, politicians, economists, etc., in a single process to build 'new knowledge' in a different kind of relationship. 4- 'Enlightened disciplinarity': all disciplines study the same object, considering and directly integrating the contributions of the others, feeding on these exchanges which may be reiterated as often as necessary, with the aim of putting forward a holistic understanding of the complex system studied (sources: 1 and 4, Chenorkian; 2 and 3, McPhee *et al.*, 2018, p. 4). All illustrations apply the codes of McPhee *et al.*, 2018, p. 4.

[11] This is not necessarily true among English-speaking writers (Jacobs and Frickel, 2009).

To achieve this goal, we decided not to set any prerequisites (no interdisciplinarity required *a priori*, no prior attempt to establish a common language[12]), which all lead to failure, but on the contrary to promote a spirit of openness, applying what is both an attitude and a tool: indisciplinarity.

This term is used relatively frequently in the English-language literature and especially that coming out of North America. The terms indisciplinary and indisciplinarity most often indicate the absence of a discipline (it should therefore be 'a-disciplinary' or even 'de-disciplined', cf. Darbellay, 2015, 2016), as seen in the undergraduate courses in the United States, for example, which are characterized by the lack of disciplinary training (cf. Tribe, 1997; Norman, 2006). For others, it may mean anti-disciplinarity, a proactive attitude against disciplines and in favour of their suppression (Jacobs, 2013, p. 123; Darbellay, 2016, p. 363).

The indisciplinarity we require here is totally different. It is a heuristic posture of openness, designed to facilitate relations between disciplines (Loty, 2005; Catellin and Loty, 2013). It does not malign the disciplines but rather it reviles any watertight construction ('silos', Jacobs, 2013, p. 17), the boundaries that separate disciplinary fields and that it aims to remove. It encourages exchanges for intra- and inter-disciplinary movement. As such, it helps maintain disciplinary approaches that remain open, offering fertile opportunities for movement, dialogue and development. The need to remove the boundaries to enable interdisciplinarity was emphasized by Darbellay in 2011 (p. 84[13]). For us, indisciplinarity thus defined is the key to 'enlightened disciplinarity'. 'Enlightened disciplinarity' and indisciplinarity allow us to implement the interdisciplinarity we need.

We will now look at the implementation of this practice which, as we have seen, has become commonplace in the OHMs.

[12] If such a goal were to be achieved, then the approach would be one of disciplinarization, because a single language means a single discipline.

[13] 'Instead of a unified theory of interdisciplinarity [...]; it would first appear necessary to create a culture of mutual tolerance between disciplines, a form of (inter-)disciplinary empathy in Berthoz's cognitive sense, i.e. the ability to understand the other's viewpoint, to put oneself in the other's shoes, but without giving up one's own identity. The aim is to bring about a shift that allows several complementary viewpoints to be taken on-board when studying humans and society in all their complexity'.

From theory to practice

The solution adopted in the OHMs and the DRIIHM is based on the principles developed by Morin, in *Les idées,* vol. 4 of *La méthode* (1991, p. 39-49) for the weakening of cultural determinisms in order to liberate thought and knowledge through dialogical exchanges, cultural 'warmth' and the development of a 'culture broth' (Fig. 3).

The process begins with the opening of dialogical exchanges, an activity that aims to diminish determinisms and the received and standardized ways of thinking. This opening engenders 'cultural warmth, heat activation [...] exchanges, lively debates, antagonisms. This activation involves [...] a great deal of energy loss and [...] hazards, but [...] provides multiple opportunities for the development of ideas and knowledge' (Morin, 1991, p. 39-49). This leads to transgressive behaviour, opening up scope for freedom for discordant thoughts, enabling cognitive autonomy. This new capacity will allow the expression of deviances which may 'bring about a hybridization or, better still, a creative synthesis between contrary ideas' (Morin, 1991, p. 39-49). This lowering of barriers will foster the emergence of new dialogical exchanges. We have come full circle, a virtuous circle is completed and iterations will occur, one after the other, creating the fertile 'culture broth'.

We have applied this process directly to our question: how do we support the transgressive behaviour of overcoming disciplinary barriers and indeed encourage it by weakening those barriers, thus fostering the eminently subversive capacity to 'unforsee' the expected, in order to recognize the unexpected and to discover the unknown.

On the one hand, the aim is to remove the blocking factors as far as possible. This is probably the most transgressive step because it goes against usual practices and established systems. First of all, it is necessary to do away with anything that 'disciplinarizes', that is an obstacle to 'dialogical exchanges' and blocks new paths. In the first place, this excludes not expertise but the stance of expert, which precludes all debate. Secondly, it means seeing the required excellence not as an opportunity for recognition by a community, but its interest in the work to be done. Thirdly, it means resisting the temptation to systematically seek consensus in the exchange, which neutralizes any individual and collective capacity to transgress.

On the other hand, it means encouraging anything that opens up, decompartmentalizes and provokes open debate. It means developing diversity in all fields, whether in terms of scientific cultures and disciplines, of people in their functions or levels (from students to senior researchers). It means enabling this diversity to

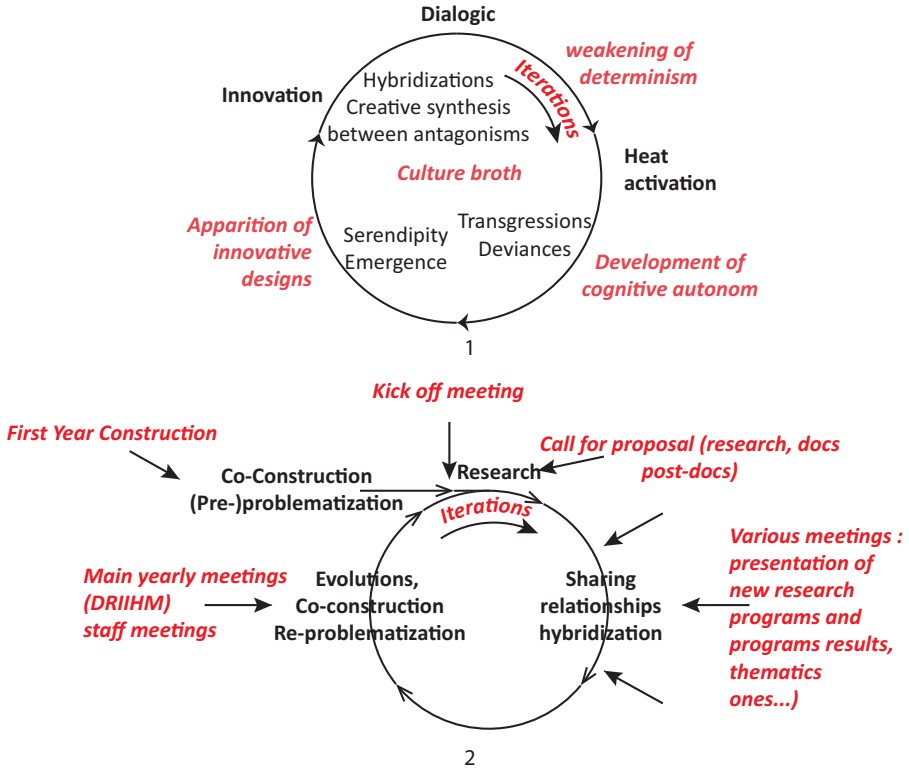


Fig. 3. The culture broth according to Edgar Morin and its composition in the OHMs. 1. Through 'heat activation', the development of dialogical exchanges leads to a weakening of determinisms, which makes transgression and deviance possible. Improbable encounters can then occur, favouring serendipity, emergence and innovation, with the hybridization and synthesis of opposites, eminently dialogical situations, and the like. This conception, which comes straight from *Les Idées*, has been directly applied to the *modus operandi* of the OHMs, term for term (2), with the implementation of the operating modes presented (diversity, specific opportunities to meet, attitudes during interactions, etc.). For the OHMs, the circle is based on annual activities (source: R. Chenorkian).

coexist and co-function and, to that end, creating places and times to meet in line with these principles, so that everyone can/must talk, listen and exchange in both formal and informal settings.

Setting up an OHM is a process of co-construction. Once the three bases have been well established (see above), the first step is to identify the initial themes through which the hypercomplexity of the Single Ecosystem can be approached. This 'pre-problematization' stage is crucial and makes it possible to build a system that will be meaningful for everyone and that everyone will be able to adopt. This calls on the ability to bring the disciplines together around a shared object by developing its potential appeal for 'all' the ES.

The first year of an OHM – the prefiguration or preparatory year – is devoted to this work. Meetings, symposia and workshops are held, some of which are open to the wider community (political, economic, associations, ordinary citizens) to enable them to prepare for the future opportunities for appropriation and exchange. This co-construction with society is also a way of forging links, which will ensure that the subsequent presentation of the work to society is effective. This first year ends with a kick-off seminar where the results of all these thought processes are presented to the communities concerned.

'Enlightened discipline' can then be put into practice over four stages.

Building a receptacle (a 'reactor') and creating the culture broth

This is the Labex DRIIHM and its various components (OHM, kick-off and results seminars, annual Labex seminars, calls for research projects and calls for doctoral and postdoctoral projects, themed workshops, working groups, cross-cutting initiatives). It includes everything that, within the Labex DRIIHM, triggers or facilitates exchanges and builds the community.

The culture broth is everything that leads to mixing and interaction: co-construction, (pre-)problematization and reproblematization, and participation in all seminars. It also means conceiving and organizing the scientific and social mix and the opening of exchanges. Researchers from all the ES are involved in these

co-construction processes. Certain stages must also be open to the wider community so that society's expectations can be taken on-board[14].

Identifying and combining the ingredients

All the ES and all the awardees of a research project are involved when constructing this mix and the ingredients that will feed the opportunities for interaction and exchange. The seminars include all members of the DRIIHM: researchers, practitioners, doctoral and post-doctoral students, master's students, and members of all the system's various committees (CD, CS, COS, CoPil OHM); the opening is extended to all partners: universities, major research bodies, companies, associations, and even individuals.

Bringing and sustaining dynamics

During this stage, everyone involved endeavours to keep down the barriers and maintain open dialogue at all times. The aim is to make sure that the system does not fall back into the deep ruts formed by old habits; that all meetings are held in due form and that participants maintain the right stance; that the diversity is upheld constantly; that rediscipliniarity does not creep back in and there is no trend towards consensus. It is also a matter of accepting the coexistence of order and (partial) disorder, and the time lost but sometimes recovered through fertile acceleration, all of which are natural consequences of the system and the effervescence it is designed to provoke.

Enabling and rekindling exchanges

First and foremost, this stage allows time for seminars (3 days for the DRIIHM yearly seminar) and more informal gatherings. Direct action aimed at establishing interdisciplinarity does not work so it is important to take indirect action to encourage it and allow it to evolve, while remaining highly directive as concerns the framework and principles and ensuring the fluidity of the environment and strong potential for movement. The seminar sessions work if the lack of organization, or even diversion, is accepted locally and where there are free exchanges and thinking, where there is time to let things develop but strictness regarding the timetable. Allowing long breaks in open areas free from constraint encourages unforeseen movements and exchanges.

The balance of an approach that seeks to combine opposites (order and disorder, hierarchy and anarchy, rigour and flexibility) is unstable and can only be attained in movement. A permanent reiteration, an ever-renewed circle that must therefore be maintained. This is the role of the Labex DRIIHM and all its components (OHM, seminars, calls for projects, etc.). This is what builds the community.

[14] NB: this is by no means a question of transdisciplinarity, with the meaning specified above, cf. below, Discussion.

Examples of the 'enlightened disciplinarity' existing in the OHMs

OHM Pyrénées – Haut-Vicdessos: marine mercury in the lakes of the Pyrenees

The Upper Vicdessos Valley (Box 1) has been the site of significant mining activity since ancient times. A series of coring operations was undertaken in the lakes to detect traces of lead pollution. However, what was found was mercury with a marine isotopic signature. Fishing companies have been rearing fish in the lakes for recreational use for decades. Research has been carried out with the fishing companies, fish farms and their archives. The presence of mercury is due to the switch in the 1960s from meal from land animals to fishmeal, made from the by-products of fish caught near big rivers heavily polluted with mercury. The authors hypothesize that approximately one metric tonne per year of marine mercury is now found on land for the whole of France.

Box 1. OHM Pyrénées – Haut-Vicdessos: marine mercury in the lakes of the Pyrenees.

Disciplines involved: paleoenvironment, sedimentology, isotope geochemistry, social surveys, archive work, history

Discipline of publication: geochemistry

To find out more: see the original publication, Hansson S.V., Sonke J., Galop D., Bareille G., Jean S., Le Roux G., 2017. Transfer of marine mercury to mountain lakes, *Scientific Reports,* 7, 12719, https://doi.org/10.1038/s41598-017-13001-2.

Beyond the local level, how can this pollution be stopped, since putting an end to the fish farming activity is neither ecologically nor socially acceptable (it would result in a catastrophic eutrophication of the lakes)?

OHM Mediterranean coastal zone: contamination of beach waters by UV filter inputs in Marseille

This OHM has identified the theme of 'Tourist and recreational use of coastal environments' as one of its two research objectives (Box 2). Research concerns the

'Le Prophète', 'La Lave' and 'La Pointe-Rouge' beaches in Marseille.

Box 2. OHM Mediterranean coastal zone: contamination of bathing water by UV filter inputs in Marseille.

Disciplines involved: geography, sociology, hydrology, geochemistry, environmental chemistry

Communication discipline: geochemistry

A first paper, presented at the Goldschmidt geochemistry conference in Boston in 2018, focused on titanium dioxide ($Ti0_2$) contamination and received extensive media coverage (referred to 72 times by newspapers in different countries).

For more information: see the summary of the paper, Labille J., Slomberg D., Catalano R., Robert S., Boudenne J.-L., Apers-Tremelo M.-L., Masion A., Garidel C., 2018. Evaluation of the environmental exposure to nanoparticulate UV filters used in sunscreens. Paper presented at the *Goldschmidt Boston 2018,* 12-17 August, Boston, https://www.researchgate.net/publication/327974623_Evaluation_of_the_environmental_exposure_to_nanoparticulate_UV-filters_used_in_sunscreens.

Initial geographical-sociological research focused on the uses of beaches (who, when, how, where), which made it possible to contextualize a question on contamination by UV filter inputs involving two actions: chemical dosages of seawater and uses of sun creams (which UV filter – mineral or biological? – frequencies and modes of use, age of users, etc.). This first framework (types of populations, numbers, hours of use, bathing practices) made it possible to take highly relevant geo- and chrono-localized water samples from the outset and to obtain extremely significant results.

Hence, 80% of users bathe. They apply their sunscreen an average 2.7 times per session, as equally often before as after their swim. Peaks in the concentration of UV filter inputs appear at 16:00, 2 m from the shoreline and at a depth of 40 cm. In a first estimate, 68 kg/day of UV filter inputs are released into the waters of Le Prophète beach in the high season, i.e. 5.7 t for the whole season. For TIO_2, the estimate comes to 340 g/day or 71 kg/month.

Beyond the local level, what is the global impact of this contamination? How can we stop a considerable source of coastal pollution through contact or *via* the food webs?

OHM Pyrénées – Haut-Vicdessos: use of the Pyrenean orri, paleoenvironment, biodiversity

The question initially raised concerned the impact of pastoral activities on the floristic diversity of the high altitude areas (Box 3). The reconstruction of palaeovegetation/paleodiversity was obtained through a high time-resolution palynological study of sedimentary records (peat bogs and lakes) dated by carbon-14 or radionuclide (^{137}Cs and ^{210}Pb) dating methods. The difficulty was specifying the weight of pastoral activities over more than a century, in order to potentiate paleoenvironmental reconstructions.

Box 3. OHM Pyrénées – Haut-Vicdessos: use of the Pyrenean *orri*, paleoenvironment, biodiversity.

Disciplines involved: paleoenvironment, sedimentology, isotope geochemistry, archive exploitation, social surveys

Publication discipline: paleoenvironment

To find out more: see the original publication, Galop D., Houet T., Mazier F., Leroux G., Rius D., 2011. Grazing activities and biodiversity history in the Pyrenees: new insights on high altitude ecosystems in the framework of a Human-Environment Observatory, *PAGES (Past Global Changes) News*, 19, 2, 53-55, https://doi.org/10.22498/pages.19.2.53.

During the summer transhumance in the Pyrenees, animals and families move up to the summer areas in the valley, where *orri* – dry-stone family houses – were built. Each family owned several *orri*, which sheltered people and cattle throughout the summer. During the ascent, the forestry administration levied taxes and the customs authorities kept an eye out to prevent smuggling with Spain. As a result, there are extensive archives, which have been thoroughly scrutinized, and we thus now know the number of animals that went up and down with each family each year, and their destination. A survey of the remaining shepherds has established the link between the *orris* and the families in the field. By cross-referencing this information, the fluctuations in pastoral load at the scale of each *orri* or shepherd per year have been accurately compiled; this geo- and chrono-localized information has been compared with the results of paleoenvironmental studies. Most notably, this revealed the existence of a positive relationship between pastoral load and floristic diversity. The results clearly show the decline of the latter, proportionate to the reduction in herds and the reverting to fallow/moorland.

These results point to the value of reviving pastoral activity with extensive systems to maintain biodiversity (through a ripple effect, plants, insects, amphibians, birds, etc.).

Beyond the local level, these results contradict a generally accepted idea that human activity always reduces biodiversity and that a conservation policy can

only be national. It is therefore essential that these results are taken into account for the sound design of biodiversity support measures.

Discussion

The interdisciplinarity illustrated above is obviously in line with the major trend towards a functional rapprochement of disciplines or with the approach that involves partners other than research operators, which has been developing for decades. However, it differs fundamentally from this trend in terms of the needs identified, the way it responds to the complexity of Single Ecosystems, and the way it takes into account society's needs and shares the knowledge acquired on these socioecosystemic crises with society.

The practice of interdisciplinarity in the OHMs might appear closely aligned with the definition of F. Darbellay (2018, p. 2): 'Researchers work together, from – and between – their disciplinary viewpoints, on a common object of study, in a coordinated, interactive and integrative manner'. It differs from this, however, on some key points, mostly related to the organization of work and its temporalities. As we have seen, the researchers work together to co-construct the object of study and its problematization, ready to tackle its complexity very early on in the research projects. In this preliminary stage, in addition to the scientists, people from the wider community may also be involved. However, the research that will be developed will be mostly disciplinary, taking an 'enlightened' approach thanks to a joint problematization beforehand and active indisciplinarity.

In addition, there is no strong coordination at the outset. The calls for research projects cover a clear theme while following the broad lines of the question. Interactions take place on specific occasions (seminars, meetings, etc.) or more or less randomly (simultaneous work on the same subject area inevitably leads to opportunities for exchange, particularly during social events). The focal object does away with the main blocking factors that are responsible for so many failures[15]. It means that the different disciplines are not forced to work together at the start of the research, that close coordination is not necessary, that a common operational framework is not imposed on often discordant temporalities and practices, and there is no need to identify a 'leader' recognized by all from the outset (Scholz and Steiner, 2015a and 2015b). Furthermore, the integrative objective only needs to be set out in a very general way during the project, only required to be precise and functional at the interim seminars and, above all, at the end during the synthesis providing explanations and resulting in modelling.

The examples above very clearly illustrate this. Take, for instance, the issue of marine mercury in the Pyrenean lakes, which took the following research route: geochemistry: determination of trace elements → unexpected result: marine mercury → how to explain this? → what is happening in the lakes: fish farming → study of the characteristics of fish farming (interviews with stakeholders and study of the archives) → identification of the origin of marine mercury → overall explanation and identification of future consequences → formulation of new questions: how can we avoid this contaminant input? what are the consequences of recreational fishing practices? should and can it be stopped? etc.

As for transdisciplinarity, only the 'Zurich' approach – explicitly designed to solve problems materially – might concern us. We have, in fact, many notions in common, but our research practice in the OHMs differs from it on a number of key points, some of which are also related to the organization of work and its temporalities; others are more fundamental concerning, for example, the scale of the research object and the way social actors are involved.

The issues that concern us are not directly the universal 'wicked problems' pointed out by this community (Brown *et al.*, 2015; McGregor and Donelly, 2014). At the outset, we position ourselves at the local level and on specific cases, as these two new examples illustrate. With the OHM Estarreja (Portugal), the chemical complex released significant quantities of metallic and organic pollutants into the open air until the 1990s. What is the current situation in terms of contamination and public health? What can be done to solve the related problems that may be encountered? For the OHM Tessékéré (Senegal), what are the consequences of the construction of the Great Green Wall (GGW), initiated by the African Union to slow down the aridification of the Sahel, on the Single Ecosystem of Tessékéré, in social, ecological, economic and health terms? How can the positive consequences be promoted or supported, or possibly offset or prevent the negative impacts, bearing in mind that, in all events, delivering solutions is not a task for the OHM, but for the people who are socially and politically responsible?

We do not include political, social and economic players and the like in the research process itself because they are not researchers. Experience – that of the 'Zurich' approach, and our own – shows that it is extremely difficult to keep someone involved for the long term if an activity that does not concern their skills or status (many OHMs have tried, particularly on their steering

[15] For a good inventory of the difficulties encountered in implementing transdisciplinarity, cf. Scholz and Steiner, 2015b, Table 1, p. 656-659.

committees). For the Provence coalfield, for example, the focal object worked on by all is the territory concerned by the industrial exploitation of a lignite mine for decades, then affected by its closure and the ensuing social, economic and ecological consequences. During the subsequent co-construction phase, everyone will apply their core expertise to identify the points they consider important with regard to the focal object, and the questions that arise today and may arise tomorrow. Interactions will be organized with non-academic stakeholders in the territory on specific occasions, to gather reflections and questions from the wider community. Translating society's questions into research questions will, however, be the sole responsibility of the researchers. Other interactions will take place to optimize the impact of these mechanisms. Research results will be shared within scientific and societal frameworks. It is not a question of building a single set of 'new knowledge', but of allowing each person to enrich the knowledge of others, as relevant. Within the OHMs, the political, economic and social stakeholders are not included in the research process, but are associated with it, in their relevant capacity and in a timely manner[16].

One of the strengths of the OHMs is that they raise the question of relationships between disciplines upstream of operational research questions, within a framework clearly built around a focal object shared by all and determined locally. It is this preparatory framework that enables simple and easy implementation of 'enlightened disciplinarity' since it removes the need for interdisciplinary co-construction for each research project, doing away with this important but cumbersome and tedious step (Wernli and Darbellay, 2016, p. 14) which is a major blocking factor.

Conclusion

Other systems are dedicated to the study of the environment, ecosystems[17], some of the socioecosystems[18] and the implementation of interdisciplinarity (TERENO critical zones[19] [Bogena *et al.*, 2016] and OZCAR[20]; LTER ecosystems and/or social-ecological systems [Callahan, 1984; Redman *et al.*, 2004], LTSER [Haberl *et al.*, 2006; Ohl *et al.*, 2010]; 'Zones Ateliers' [ZA, Lévêque *et al.*, 2000, 2008]; HERO [MacEachren *et al.*, 2006; Yarnal and Neff, 2007]). The OHMs are fundamentally different due to:

- targeting on highly anthropized objects, defined by exclusively anthropic criteria (crises);
- the consideration that humans form a single ecosystem (Single ES) with the abiotic and the biological;
- their design with a social-ecological framework, a disrupting event and a focal object, and an organization that allows the complexity of systems to be actively considered through the simple implementation of effective and available interdisciplinarity;
- the design and implementation of disciplinary interactions, with indisciplinarity as a basis and 'enlightened disciplinarity' as the outcome, with specific arrangements for interaction between science and society, all of which comprise the characteristic interdisciplinarity of the OHMs;
- the creation of a single system whose components (the OHMs) interact very closely. This is what the DRIIHM allows and represents: a metasystem that lets the whole set-up operate through interaction and feedback in a transcalar, properly ecosystemic manner that is much more powerful and free than a simple network[21].

More than 12 years after the creation of the OHMs and 7 years' existence of the Labex DRIIHM, examples abound to show that the system works, that through the convergence of open disciplinary contributions and by its very design, it removes the main blocking factors to actually achieve an understanding of complex systems through the implementation of global ecology. Equally true is the fact that this characteristic is never definitively acquired, and is the result of continuous action and vigilance. The virtuous circle must be maintained constantly. It is to be hoped that, despite all the individual and structural reticence, this attitude of openness will gradually take root in behaviour. This seems to be progressing within the community of OHM participants, but it still needs to be worked on day after day. The high turnover of participants in calls for research projects constantly brings in new people who are not familiar with these functions and principles. This is also the outcome of the funding methods: small amounts (no more than €10K) but easy to obtain (a brief

[16] This fundamental difference is also clearly expressed by Jacobs (2013, p. 128). A very eloquent illustration of it can be found in Scholz and Steiner (2015a, particularly p. 528-534).
[17] *sensu* Tansley (1935).
[18] *sensu* Gallopin (1991) or Berkes and Folke (1998).
[19] *sensu* National Research Council (2001).
[20] http://ozcar-ri.prod.lamp.cnrs.fr/ozcar/?lang=fr.
[21] With the creation of the first three OHMs, we felt the need to develop relationships between them to leverage the efforts made and the results obtained, which prompted us to identify a network of OHMs (ROHM). We subsequently realized that the way in which the OHMs interacted with one another did not characterize a network at all, but something much more complex, operating in an ecosystemic way, made up of transcalar interaction and feedback, enabled by the DRIIHM. In 2019, we drew the relevant conclusions and completely removed the unsuitable notion of network from the DRIIHM system.

application file and acceptance of risk taking), so as to lay the foundations on which to build much more ambitious projects to be submitted to other sources of funding. To ensure these practices take root among participants, we encourage any approach that enables this assimilation (multi-year projects, organization of multiple opportunities for exchanges), calling widely on master's level interns (with participation in all seminars). We also plan to coordinate more closely with certain universities to help the principles of our interdisciplinary operation filter into the curricula. In sum, the challenge is to create a receptive and seasoned community.

Finally, throughout these years of operation, the organization of research in a disciplinary system has never been felt as a disadvantage, as long as everyone adopts an open attitude and keeps in mind that a global understanding of the system under study cannot be achieved on the basis of their discipline alone, solely because of the complexity and importance of the interactions/feedback that develop within it. The very pragmatic position we take exempts us from any positioning on post-disciplinarity. Never has a 'desire to end disciplines' (Darbellay, 2016, p. 363) been felt. Our experience simply testifies to the fact that, for us, the problems do not arise from disciplinarity but more from the absence of indisciplinarity.

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