STRUCTURAL-EPISTEMIC INTERDISCIPLINARITY AND THE NATURE OF INTERDISCIPLINARY CHALLENGES

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ABSTRACT: Research on interdisciplinarity has been concentrated on the methodological and educational aspects of this complex phenomenon and less on its theoretical nature. Within a theoretical framework specific to the philosophy of science, I propose a structural scheme of how interdisciplinary processes go, focusing on the concepts of availability of the methods, concept linking, and theoretical modeling. In this model, the challenges interdisciplinarity is claimed to pose to its practitioners are of the same *nature* as the challenges scientists encounter within the evolution of their own disciplines.

KEYWORDS: interdisciplinarity, transdisciplinarity, disciplinarity, structure of knowledge, theoretical modelling

Introduction

In the last few decades, the concept of interdisciplinarity has become central for the metascientific analyses of both scientific practice and higher education in the sciences. Researchers have focused on these two aspects – methodological and educational – as determinant and in many views exhaustive for the nature of interdisciplinarity. Motivations and goals of interdisciplinary practice have also been associated with these two aspects and as such have been reduced to solving complex problems and enhancing education.

How have we referred to interdisciplinarity since it was acknowledged? We have observed and participated in the *phenomenon* of interdisciplinarity in scientific practice, and we have emphasized the good track record of its results. Such recognition has encouraged us to search for and practice interdisciplinarity whenever possible, despite the various theoretical and methodological problems it certainly poses. The phenomenon gained such importance that within scientometry, various formulas have been proposed for indicators measuring the interdisciplinary approach and content of journals.[1] Labeling with the attribute of 'interdisciplinary'

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[1] See for instance (Leydesdorff & Rafols 2011) for a comparative analysis of the indicators used to measure interdisciplinarity of the journals.

has become almost a “fashion trend:” researchers are claiming their proposed projects as interdisciplinary, organizations are advertising that they hire interdisciplinary teams, and candidates are presenting themselves in their résumés as interdisciplinary-oriented. Of course, there is nothing wrong in that, since interdisciplinarity is a real phenomenon, and searching for interdisciplinarity is entirely justified epistemologically. But is interdisciplinarity really a virtue “higher” than the virtues of the scientific practice performed within one discipline, or of a special nature? The virtue of interdisciplinarity that made us “advertise” it with such persistence and shape it as the new orthodoxy of current scientific practice is actually established by the complex challenges it poses to its practitioners. If scientists overcame these special challenges regarding special problems (and as such, contributed to the good track record of the practice), we were justified in claiming this special status of interdisciplinarity. However, inquiring deeper into the nature of interdisciplinarity, we may find that the answer to the question of “higher virtue” is not straightforward.

Literature on interdisciplinarity has presented it as an ongoing, growing phenomenon focusing more on the problems, barriers, and challenges it poses from methodological, educational, and research-community-related perspectives, and less on its theoretical nature. The research has not yet reached a crystallized theory of interdisciplinarity by which to account theoretically for those problems, to provide criteria of adequacy and norms of optimization for the practice of interdisciplinarity, and to make predictions for the developments of the disciplines themselves, as well as to provide norms for the interdisciplinary education. At most, research is in the stage of constituting a conceptual framework for such theory, still concentrating on typologies, and revealing so *many* apparently independent aspects of interdisciplinarity as phenomenon, that prospects of establishing such a framework are dim. If this is the case, we put the cart before the horse when focusing on practical problems and developing programs of management rather than clarifying the nature of interdisciplinarity? Overall, what discipline or disciplines would be entitled to deal with such a theory – philosophy of science, cognitive sciences, educational sciences, or another? Note that all these disciplines are already interdisciplinary, and if we propose that one or all of them contribute, we have an interdisciplinary methodology for investigating interdisciplinarity, which poses an issue of epistemic circularity.

A definition of interdisciplinarity which reflects all its essential aspects has not yet been provided. In the attempts toward a definition, key constituent concepts of interdisciplinarity have been assigned names reflecting in ordinary language concepts of an overly broad generality. These attempts offer good dictionary definitions, but that generality prevents the use of such a definition within a theoretical framework. Brewer's (1999, 328) definition is a relevant example in this respect:

> Interdisciplinarity generally refers to the *appropriate combination of knowledge* from many *different specialties* – especially as a *means* to shed *new* light on an actual *problem*.[2]

The aspect of complexity, methodological effort and inquiry, motivation of the unsolved problems, and novelty of the results are reflected (through the italicized words above) in this dictionary definition, and other definitions within literature are usually more or less descriptive versions of this one.

What is clear – and all researchers agree – is that interdisciplinarity is an *epistemic* phenomenon. Since epistemology provides a kind of generality and primary foundation transcending typologies and boundaries specific to the concept of a particular discipline, this is where we should start in pursuing a theory of interdisciplinarity: the epistemic nature of interdisciplinarity.

In this paper, I argue that a third (neglected) aspect of interdisciplinarity is essential for clarifying its nature and for accounting further for the problems and challenges interdisciplinary does pose. This aspect is the epistemic outcome of the ongoing process of practicing interdisciplinarity, a theoretical entity of a structural nature developed through interdisciplinarity, which is grounded on the content of the disciplines as bodies of knowledge. This concept stems from the epistemic motivations of interdisciplinarity, among which the *theoretical* advancement of a discipline should also be included.

By analyzing these motivations in relation with the nature of the structures developed through interdisciplinarity, we can argue that the challenges interdisciplinarity is claimed to pose are of *the same* nature as the more or less special challenges scientists encounter within the evolution of their own disciplines. Hence, presenting interdisciplinarity as a special virtue of scientific practice is somehow exacerbated to the extent that that virtue is "as special as" the virtue of dealing successfully with the complexity of the disciplines themselves. My arguments run within a theoretical framework specific to the philosophy of science as well as the classical structural view on scientific theories.

The main aim of this paper is to clarify the nature of interdisciplinarity, by revealing its theoretical side in close relation to its motivations and dynamics. For this clarification to be possible, a primary conceptual clarification is needed and will be pursued.

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[2] My emphasis on the words.

In the first section, I will try to clarify the criteria of specificity that we should follow in characterizing disciplines, because interdisciplinarity and its investigation have been seen as tightly dependent upon disciplinarity. Then I will argue for both weakening some distinctions and sharpening others for the purpose of this paper. In the second section, I will argue that interdisciplinarity does not mean or imply non-disciplinarity. I propose a structural scheme of how interdisciplinary processes go, focusing on the concepts of availability of the methods, concept linking, and theoretical modeling, and I conclude that the concepts of the disciplines in process of interdisciplinary interaction stand in certain *kinds* of relations, of a logical-epistemic-cognitive nature. These relations on one hand render interdisciplinarity amenable to a theoretical account, and on the other hand, the properties of these relations account for the dynamics of the phenomenon of interdisciplinarity. In the last section I draw conclusions.

1. Discipline – Defining, Delimiting, or Just Distinguishing?

In the study of interdisciplinarity, the focus has been on the essential concept of 'discipline'. With the attempts to provide a complete definition for 'discipline' and the adequate placement of the concept into the framework of investigations, various main aspects of the concept were stressed: social, historical, semantic, epistemic, and scientific. Within these main aspects, the typology is enlarged by every facet of such aspects: educational, expertise, authoritative (within the social aspect), distinction, reference (within the semantic), epistemic content, the truths, the normative, organization, regimentation and institutionalizing of knowledge (within the epistemic), resistance and evolution (within the historical), epistemic virtues and methodology (within the scientific aspect). The mutual dependence of these unfolded aspects makes difficult any attempt toward a descriptive definition by which to ensure a non-contextual stable use of the term, consistency with the disciplinary social practice, and eventually embedding in a conceptual framework within which to investigate interdisciplinarity theoretically.

1.1. Defining

The difficulty of stating an adequate definition comes first with the attempt to separate its use in ordinary discourse (including educational contexts) from that in a theoretical-scientific context. Regarding the former type of discourse, we have gotten used to the term 'discipline' to distinguish between and delimit what we were taught in primary through secondary schools and have associated the discipline with its teacher. Now, searching for a "meta-disciplinary" definition seems to be influenced by this habit, not to mention the Latin etymology of the word, based on the root *discere* (to learn): *disciplinis* (disciplines) and the derived *disciplulus* (disciples); per this origin of the term, a *discipline* is a matter of knowledge or skills that can be taught by a teacher to his or her disciples (Alvagonzáles 2011). The latter type of discourse poses a particular kind of problem: Observe that sciences (or disciplines) dealing with (or at least referring to) the concept of discipline span a broad range, from philosophy of science and epistemology to social sciences (educational, policy, psychology, management, and so on), and thus it is difficult for a definition to fit all the conceptual and theoretical frameworks of these sciences or disciplines. For instance, the theoretical-philosophy disciplines are more concerned with the discipline's body of knowledge as a theoretical unit than with its social dimension, while social sciences are more inclined toward its aspects of education, interpersonal relationships, and social implications. The problem arises when trying to define interdisciplinarity through disciplinarity – since *all* the disciplines should be related to the concept of interdisciplinarity, *the same* definition should be employed in a metatheoretical/metascientific investigation of interdisciplinarity.

Definitions or descriptions for the concept of *discipline* that have been provided represent various ways of combining and weighting the aspects listed at the beginning of this section. Some researchers emphasize the educational-social dimension while others focus on the epistemological-theoretical one. This is not the place to review them or make a classification of these definitions.[3] I will just note that the previously mentioned double tendency reflects two distinguishable views on the concept of disciplinarity: one takes the discipline to be a body of knowledge with a certain epistemic autonomy and authority (the former delimits it and the latter makes it teachable), and thus the *content* of the discipline is taken to be more relevant for a definition than its relations to the society – call it the *internalist* view; the other sees the discipline as both its content and *social relations* (including academic, educational, and organizational-institutional) under the principle that content is in fact dependent on these social relations – call it the *externalist* view.[4]

The externalist view seems to be dominant, and this is explicable through the prevalence of the social sciences among the disciplines dealing with interdisciplinarity. The externalist views range from admitting the content as characterizing disciplines to radical ones, giving exclusivity to the social dimension; for instance, Apostel (1972), for whom sciences and disciplines do not exist, but only persons or groups practicing them. The structuralist approach of the content and dynamics of science, originating in the conceptual and methodological framework

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[3] A well-organized review can be found in Chettiparamb 2007, 2-5.

[4] The terms for this typology and the typology itself are not original; they have been used in the literature, for instance in (Klein 2002).

initiated by J. D. Sneed and W. Stegmüller in the 1970s allowed the access of analytical philosophy into the scientific domains, as well as interdisciplinary communication between philosophers, scientists, and historians of science (Kuhn 1977, 289-291). In the view of T. Kuhn (1970, 182-187), the disciplines, which are seen as related to the concept of paradigm, are characterized by four elements – symbolic generalizations, models, values, and exemplars. For Kuhn, these structural elements shape the scientific communities and define problems and solutions, and not vice versa. In what follows I will adopt an internalist view.

1.2. Delimiting

Now it is time to adopt a simplifying position regarding definitions. The main reason we struggled to find an adequate definition for 'discipline' is that in order to investigate interdisciplinarity, we have to engage the concept of 'disciplinarity,' tightly related to *inter*disciplinarity. Disciplinarity is a *general* practice or principle of practice, regardless of the particular discipline to which it may refer in a particular context. Despite the various dimensions 'disciplinarity' may have, it means and should be used in the current context as "staying/remaining within the boundaries" of a discipline in the course of a scientific endeavor, having as a goal either problem solving or theoretical advance. The related concepts 'staying within' and 'boundaries' can make sense only as relating to the content, structure, and/or internal "affairs" of a discipline (including methodology and all its epistemic production and values) organized or structured so as to allow "the bounding" in some sense. This conceptual dependence imposes an internalist view for the concept of discipline in the context of interdisciplinarity (while not rejecting the externalist one). It is the *content* of a discipline that makes us able to 'stay within' it as investigators and not its social extension, even though that content is humanly produced, managed, and bounded.

The concept of boundary (of a discipline) may have a double sense: one related to the (bounded) content and the other semantic and related to the criteria of naming disciplines. Indeed, one can refer to boundary as the criterion of distinguishing between disciplines in order to have a consistent usage of their names in various discourses.

However, these criteria should not be merely conventional; naming a discipline should be as rigorous as the constitution of the discipline is. For the former sense, the concept of boundary does pose a serious problem: A discipline is not a static construct, but rather, has a certain dynamic concerning both its content and social implication. That dynamic is time dependent and human dependent. As such, how should we understand 'boundary,' so that 'staying within' it will make sense despite these dependencies? How is this problem related to interdisciplinarity? We shall return to this point later.

1.3. Distinguishing

In the attempts to define 'discipline,' the goal of distinguishing objectively between disciplines has been followed, and this goal again has put forward the internalist view. The distinction aspect has led to structural definitions regarding the internal content of a discipline. Almost all such definitions have taken its objects of investigation and its methodology to be the two main constituents of the content of a discipline. For the former, their nature and ontology is expressed differently across the definitions; for instance, Boisot (1972, 90) takes "observable and/or formalized objects," but also "phenomena that are materialization of the interaction between these objects" to be the objects of study of a discipline. Heckhausen (1972, 83-84) distinguishes between the "material field" as "a set of objects" and the "subject matter" as "the point of view from which a discipline looks upon the material field." Squires (1992, 202) adopts a simple semantic stance by naming 'object' "what they are about." The latter element – methodology – expressed through "laws" (Boisot 1972, 90), "operations" (Squires 1992, 202) or "methods"/"analytic tools" (Heckhausen 1972 and many others) is what actually constitutes the structure of the content, as operating upon, linking, and making connections between the objects of study and the various concepts, theories, and truths of a discipline. I may add 'procedures,' 'techniques,' 'principles,' 'rules,' 'norms' and so on and note that methods have their own degree of rationality, generality, or epistemic authority. They may range from primary functions of human reason (like perception, association, or primary induction) to methods that are discipline-specific. Regarding this latter type, Bauer (1990, 106) transforms it into a second-order epistemic criterion of distinction adding to the content distinction through objects and methodology, by noting that

> Disciplines differ in epistemology, in what is viewed as knowledge, and in opinion over what sort of knowledge is possible. They differ over what is interesting and what is valuable.

Methodology and its mode of validation and evaluation is also what distinguishes scientific from non-scientific disciplines. This distinction based on methodology has been stressed by several authors who investigated interdisciplinarity; however, for our structural approach under the internalist view, the distinction is of little relevance, as we shall see further. The distinction is however of high relevance for the externalist views, especially in what concerns the historical and educational aspects of a discipline.

1.3.1. Distinguishing Through Concepts

We shall keep the two main constituents of the content of a discipline for the purpose of distinction – the objects of investigation and methods – in their broad sense; that is, the objects irrespective of a specific ontology or ontological commitment, and the methods with no epistemic distinction, hierarchy, or categorical taxonomy. At this point, let us note that distinction based on these two constituents does not work everywhere. There are distinct disciplines sharing both their objects of investigation and their methodology. To take an immediate example, consider astronomy, (physical) cosmology, and astrophysics. Their common objects of investigation are celestial bodies and phenomena, and they all use the same observational methods, as well as theoretical methods of physics (from various branches) and mathematics. What then essentially differentiates them? (Of course there are the historical criteria of delimitation, the amount or degree in which a specific method is used, and the placement of the methods in one branch or another of mathematics or physics.) The answer is: the stance towards their object of investigation, the primary concepts they developed about these objects, and the primary conceptual framework developed around them. Astronomy considers its objects of interest in their origin and evolution, being more focused on local celestial structures and systems, and interested in typologies, patterns of regularity, and the prediction of the dynamics of such systems. Astrophysics is more concerned with the physical nature of the celestial bodies and less with their positions and motion, while cosmology treats the objects within the largest-scale structures and dynamics of the Universe as a whole, being also concerned with fundamental questions about its origin, nature, structure, evolution, and fate. Other examples can be easily found in well delimited sub-disciplines of the same big discipline (for instance, atmospheric physics and meteorology within Earth science, or cognitive psychology and neuropsychology within psychology). Of course, the relevance of such examples is sensitive to various contextual factors, including historical and semantic; however, the conceptual aspect of the objects of investigation is related to methods not only in what concerns distinction between disciplines, but also in the effective way in which methods of a discipline do work. Indeed, the rational methods of investigation are not applied to any object in its material nature, nor as an abstract linguistic entity as referent, but to *concepts about* that object, even if this reverts in some trivial instances to the mere sense perception of the objects. Even an empirical method of research (say, collecting responses to a survey over a population sample, or participant observation in a community within some social sciences) is not applied directly to the material world, but to what our mind shapes through concepts as an image of it (through data in previous examples); this is also true for empirical, experimental, or engineering disciplines. This view, in which we can only infer from what is thought traces back to Frege (1951/1892) and is based on the predicative nature of concept, which is fundamental for traditional logic and for some primary notions of mathematics (such as that of set, set membership, infinite sets, etc.). We should adopt it just because the content of a discipline (even non-scientific) as an epistemic unit has to submit to traditional logic.

Conceptualizing the objects of investigation before employing them in judgments, inferences, rules, and theories within a discipline means both adopting a view – however radical – on the inner nature of these objects and placing them within larger systems or structures of knowledge. The conceptual stance may differ dramatically for the same object of investigation across disciplines. For example, empirical concepts embeddable in a certain physical structure or having certain properties, describable in ordinary language of an empirical discipline, can be abstract mathematical concepts – identified through mathematical definitions – for applied mathematics or for mathematical physics. If they were not mathematical concepts, mathematical methods could not be applied to them. A population for a psychological discipline is a group of people with different psychological profiles, while for mathematical (statistical) psychology, it is a set of elementary events belonging to a probability field. If this were not so, statistical research or inference would not be possible within psychology. Therefore: 1. The nature and properties of the concepts are essential for a method to *be able to* be applied to them, just as a (mathematical) function can make sense only for its domain of definition. 2. Across disciplines, it is precisely the *difference* between those concepts about the same objects that makes interdisciplinarity possible, for if the concepts were similar, the methods of the same discipline would be operating on them (now or in the future). In the next section, we shall also see how concepts of different natures are linked across disciplines from a structural point of view.

Summing up as motivations the additional criterion of distinction between disciplines and the constitutive fundamental role conceptualizing does have for the methodology of a discipline, I will take *the concepts* to be the third essential element of the content of a discipline. These include the primary concepts about the objects of investigation, but also other concepts developed through theoretical advancement; along with the relations between them, they all form the conceptual framework of that discipline. Concepts have already been considered as part of an internalist definition of a discipline. In the previous examples, they are mentioned in the definition of Squires (1972, 202) as "their [disciplines'] stance toward that object [of investigation]"[5] and Heckhausen (1972, 84) as "the point of view from

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[5] My insertions in brackets.

which a discipline looks upon the material field." What I want to emphasize is the epistemic relationships concepts do have with the objects of investigation, with each other, and with the methods operating on them: Concepts are about the objects of investigation – this is a semantic relation, but not merely conventional; the correspondence is made on the rational criteria of placing the concept into existing frameworks of the universe of knowledge about the respective topic, while not breaking any well-established systematic coherence with this correspondence.[6]

1.3.1.1. The Relationships between Concepts

Concepts stand in various types of relations to each other in the course of defining, making judgments, inferences, applications, and statements. As with the methods, concepts stand on one hand in an identity relation (a method would not be what it is without those concepts to or upon which it is applied), and on the other hand, it is a means of linking concepts epistemically. For instance, the method of basic induction links a data set associated with the evolution of a phenomenon to a predicted event. Two or more concepts linked through a rational method belong to the same epistemic structure. Note that the method linking two or more concepts is not only the "engine" creating that connection, but it also gives the *kind* of connection those concepts share, so that a relation can be defined (and not only conventionally denoted) as the class of the connections of a certain kind. In our previous example, basic induction put the concepts from the observational base and the prediction in a sort of inferential connection. A similar kind of connection is created between a set of hypotheses and the conclusion obtained by using the basic principles of logical inference or the usual deductive methods of science. Including a concept in a new definition creates a constitutive (or identity, if you prefer) connection between the newly defined concept and the one(s) included, while concepts linked through the application of a theory into another or in a specific context stand in an applicative kind of connection. The connection between the particulars and their corresponding generals is another kind, and so on. I will come back to the point of epistemic kinds of connection later.

1.4. The Nature and Epistemic Status of the Methods

Finally, for the methods, let us note that placing them within the content of a discipline does pose a sensible problem. Even though disciplines share methods as well as concepts, and even though there exist discipline-specific methods among

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[6] Of course, such breaks occur sometimes, culminating with scientific revolutions. Within a chronology of the processes of constitution of a discipline, first correspondences always exist.

which are methods developed internally by a discipline, a method remains something that is *used*. This usage has linking concepts as its immediate goal, and it must be epistemically *justified* if we talk about a rational practice. However, that justification about usage cannot be attained within the discipline itself using the method, but beyond it and beyond any other, within a general epistemology of the rational methods. This is true not only for the primary methods available for *any* discipline (such as abstraction from experience, logical principles, induction, theoretical modeling, and so on), but also for discipline-specific ones. For instance, the method of statistical inference used in social sciences is not epistemically justified within those sciences, but at another level of reasoning. First, the mathematical nature of the concept brings a justification based on the epistemic value of the mathematical-logical necessity that we all accept regardless of our profession. Second, the empirical confirmation and the good track record of the inferred results are not concepts originally specific to the science using that method, but of all sciences using it, as well as to our common rationale in daily life. Even if we accept Bauer's (1990, 106) position on validating methods as being discipline-specific, I claim that that internal validation is just decisional – thus normative – and reduced to choose and select; the criteria of these two actions may be discipline-specific and may be justified for the objectives of a discipline, but the core epistemic validity of the methods lies in the *availability* of the method, which is beyond the discipline (say, transdisciplinary) and dictated directly from a level of discipline-free rationality. In other words, the distinct epistemology of each discipline in Bauer's terms (at least in what concerns methods) is subject to a second-order primary epistemology of reasoning.

From this perspective, it seems that the nature of *any* method is intrinsically transdisciplinary, in the current usage of the term.[7] On the other hand, taking the method as belonging to the epistemic content of a discipline is fairly justified: the method is the means of creating connections, which account for the internal systematic coherence of the content and the intelligibility of the system, but the method also accounts for the kinds of connections it makes between concepts, and this latter contributes to the *understanding* of that connection and also accounts for the *relevance* of a connection to be included in the epistemic content of a discipline.

Now, if we mentioned semantical and syntactical relations, definitions, statements, and theories as related to the content of a discipline, and – leaving for a moment the internalist view – taking into account that the content of a discipline

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[7] This conclusion is in the vein of Lakatos's (1968) view on methodological unity of sciences, and opposed to the views of Cartwright (1999), Galison (1996) or Shapere (1984), who argue for a methodological differentiation depending on the nature of the disciplines.

should be communicated and taught, shouldn't we introduce *language* as the fourth element of content? Language contributes to the specificity of a discipline, especially in what concerns vocabulary. It is very likely that there are not disciplines sharing the same objects of investigation, concepts, and methods, and so perhaps language is not necessary as a new criterion of distinction. However, language certainly is present in the content. It suffices to mention the linguistic nature of conceptualizing, of definition, of predicative logic, and of scientific theories to see that language serves as both a tool and a method for creating and linking concepts (not to mention its role in communication). The options are either to include it in methodology as a primary method (function of the brain) or to take it as the fourth distinct element of content. The observation that methods are also expressible in language, just as concepts are, inclines the balance toward the former option. The observation that all the development and results of a discipline can be expressed in a body of statements formed in a language (what is to be communicated and taught in a curricular way) inclines it toward the latter option. Also bear in mind that our aim here is to investigate interdisciplinarity through disciplinarity and – for the sake of simplicity in such a complex context – we must employ only those concepts directly related to the two we mentioned, namely "boundary" and "staying within (the boundaries)." It seems that language does not submit to this attribute, except in the semantic criteria of naming disciplines, which we proposed to avoid. Indeed, language (either ordinary or scientific) – by its nature – is cross-bordering, flexible, and with a high degree of freedom in its semantics and domain of description. It suffices to mention mathematical language, which has exported predications and vocabulary into the ordinary language and into the languages of several disciplines. As such, the linguistic element is one that facilitates cross-bordering, and not bounding. This process goes in fact in a double sense, being so specific to interdisciplinarity: once language accesses the new discipline, it feeds back the language of the original discipline and so a new language is formed.[8] Given all these considerations and that we are talking here about the *epistemic* content of a discipline, not only the linguistic one, I will take language as an element of the content associated to all three previously included, but not independent or distinctive in its own right.

Summing up, in my internalist view, the content of a discipline would consist of these three components:

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[8] The concept of interlanguage through interdisciplinarity and transdisciplinarity traces back to the works of Piaget (1972) and Lichnerowicz (1972), as well as to early structural approaches of unity of science.

- the objects/subjects that discipline investigates
- the conceptual framework that discipline uses in its investigation of the objects/subjects, development, or any of its objectives
- the methods which that discipline uses for advancement and accomplishing its tasks and objectives.

With this primary organization of the epistemic content of a discipline – not presuming it as exhaustive nor standing for a rigorous definition – we can take the next step in analyzing interdisciplinarity structurally and epistemically within a conceptual framework developed around the concepts of 'boundary' and 'staying within (the boundaries).'

2. Non-disciplinarity and Interdisciplinarity

In this section, I will argue that, at least under an internalist view, interdisciplinarity, transdisciplinarity, cross-disciplinarity, or multidisciplinarity does not mean or imply non-disciplinarity.

If disciplinarity is understood as relative to the concept of (a kind of) boundary for the epistemic content of the disciplines, then all these prefixed versions of '-disciplinarity' should mean crossing or passing through or breaking or even violating these boundaries. An immediate reflection on this supposed epistemic action would observe a. that those boundaries (if any) must be by their nature trespassable; b. that trespassing is justified and allowed at a certain level of meta-methodology; c. that trespassing (which is not quite justified as an adequate term given b.) occurs by means of one or more epistemic methods the disciplines usually use in their practice; d. the methods with which the boundary is crossed should belong[9] to the epistemic content of the discipline within which the epistemic action was initiated (where the problem was posed or the theoretical goal was designed, etc.).[10]

Now it is time to take a new action toward simplifying all that we described as the epistemic content of a discipline. As a necessary parenthesis to clarify the abstract concepts introduced when discussing methods in the previous section, I will describe in structural terms what the epistemic structure of a discipline would mean in order to represent boundary crossing.

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[9] In the sense of "used" (see the view on methods in the previous section).

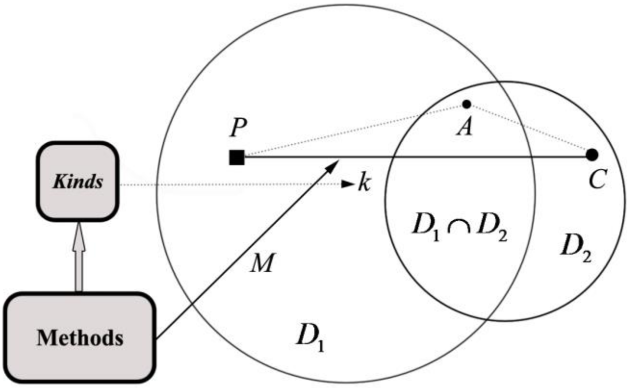
[10] The apparently distinct case in which a method is *imported* from another discipline for a particular endeavour can be cancelled in the view that once used, a method has linked concepts belonging now to the epistemic content of that discipline, and the method should belong as well, even if no longer used in the future (the argument has been detailed in the previous section).

2.1. Disciplinary Epistemic Structures, Dynamics and Bounding

In our framework, the crossing of the boundary works by the following simplified scheme:

Let D_1 be the original discipline within which a problem P (either practical or theoretical) is posed and addressed. P is formulated in the conceptual framework of D_1. We can see P as a concept or a group of concepts related to each other. For the sake of simplification, we take the former case, since a structure of concepts is itself a well identified concept. As an initial case, consider the aim to connect P to a concept C not belonging to D_1, but to a different discipline D_2 (the same simplification applies to C) in a way that will ultimately enrich our knowledge of P expressed in D_1. The general case is to connect more than two concepts, but for simplification we shall consider only binary relations, as they suffice to reflect our point on disciplinarity. Assume we found a method M that made that connection. The aim has been attained and the whole action is called interdisciplinary because a boundary of D_1 was crossed, at least in what concerns concepts.

1a. The inquiry stage



1b. The integration stage

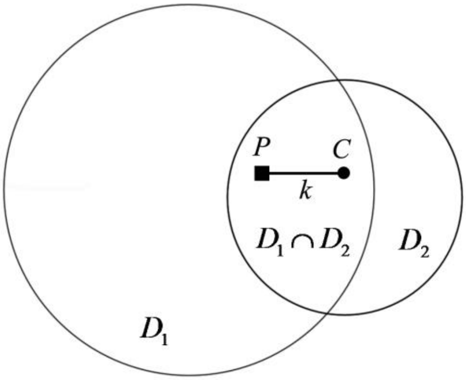


Figure 1. Linking concepts between different disciplines

The method M could be either one already used by D_1, developed within D_1 just for the current purpose, or "imported" from another discipline. Given my transdisciplinary view on the nature of methods expressed in the previous section, I will not in this context take the latter case as one of interdisciplinarity. Once used, a method is validated for that use (for the concepts it links), and it can be considered as belonging to D_1 in the sense that at any time it can be used again where it is adequate. Now let us take an insight into the nature of these actions and their outcome.

First, we should accept that concepts P and C were already somehow *connected* before the method M was applied. This connection may be made visible if we break the concepts down to constitutive concepts until reaching their primary concepts of constitution, among which one (A in the figure) or more is common to the two disciplines. Any concepts – regardless their nature, category, or regimentation – are connected to each other in the *network* of knowledge, as neither concept is developed *ex nihilo*, but from existing concepts; this is clear for the mathematical concepts and happens in any area of knowledge. As such, any two disciplines share common concepts (not necessarily about their objects of investigation), so the intersection $D_1 \cap D_2$ is never empty.[11] However, having P connected with A and A with C does not cancel the endeavor of linking P to C, because those primary connections may not be relevant for our purpose – that is, we might not gain any new knowledge about P. For instance, if A is a concept constitutive to both P and C, we can say nothing about how P and C stand in a relation or in what kind of relation they do stand. Or, if A implies P and A implies C, we cannot say that C or P implies the other, since this does not reflect the transitivity of the implication. In other words, we need a connection between P and C that is epistemically *relevant* for the objective we propose. This is where the distinction between network of knowledge and structure of knowledge is essential. P and C are connected in the former; however, a connection between them in the latter is acquired only when it has the status of (belongs to) a *relation*. But what constitutes that relevance? In mathematical terms, a network is a graph connecting atomic nodes through paths, while a structure is a set of atomic nodes (objects/positions) together with a family of relations between them, that is, a set of sets of connections (n-uples of nodes of various arities). A relation represents a class of connections, and this class can be constituted either conventionally or by criteria of relevance of the representation that that structure does. As such, even though the nodes are atomic and lack any content or epistemology in the abstract structure, grouping the connections between them as relations grants the nodes a minimal epistemology given by the criteria of grouping. However, this epistemology is the one of that particular structure and particularity comes from that grouping; therefore, the conventional nature of the relations remains. In mathematics, any structure (in the sense of Bourbaki (1950)) is reducible to a set-theoretic structure, but any relation (as a class of connections) is *defined* mathematically. This does not happen for other non-mathematical representations of various systems such as classical structures, where the relational arrangement is conventional (that is, we just name or interpret the relations, but not define them). However, for a structure representing knowledge through linked concepts, we can acquire an epistemology of the structure from *outside* it, by assigning the connections what I call epistemic *kinds*. For instance, consequential (inferential), constitutive, applicative, predicative (characterizing or assigning properties), and negation are kinds of connections between concepts, constituting any rational system of knowledge. Their nature is both logical and cognitive, and they represent the rational processes of thought. If two or more concepts connected in the structure exhibit a connection of a certain

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[11] I am using abusively the set-theoretic notation, just for illustration. If we consider the epistemic side of the content of a discipline (including methods), the notion of intersection is different from that applying to sets of objects.

epistemic kind, the relation holding that connection (and other connections of the same arity and type) acquires the same epistemic kind. This is what we require as relevant for the aimed connection between P and C in our context: an epistemic kind k, given by method M. Let us call a classical structure with connections having assigned epistemic kinds an *epistemic structure*.

Such a structure is usually a second-order structure because relations between relations may also hold. Think of *properties* of concepts, which are both second-order concepts and relations between first-order concepts. For example, in mathematics, the property of 'being divisible to' connecting integers is related to the property of primeness of a number, and the connection is of a constitutive kind, since primeness is defined through divisibility.

Not only do epistemic kinds ensure the relevance of the relations between concepts within the interdisciplinary action in context, and not only do they ensure understanding and logical coherence of the constructed systems of knowledge, but that relevance is included in the criteria for delimiting the content of a discipline by external authorities. As such, it is clear that the "boundable" content cannot consist only of concepts, but of the entire structure linking them through connections of certain epistemic kinds.

Now let us take an epistemologist-observer position for what we have just represented structurally as discipline boundary crossing. Once the (P, C) connection is realized with epistemic kind k, concepts P and C along with their connection come to belong to the same epistemic structure. This structural extending "moves" both concepts P and C into the common zone $D_1 \cap D_2$, since the connection is epistemically relevant. However, P was assumed to belong exclusively to the original discipline D_1, for if it also belonged to D_2 we wouldn't have any interdisciplinary action. One may argue that there are two stages of this process separated on a timeline – one of inquiry and application of method M, and one of integration – and only in the latter is the new connection assimilated into the existing structure; as such, in the first stage – the one of interdisciplinarity – the two concepts remain in separated domains (the two stages are pictured in Figure 1a and 1b along with all the denotations used above). My counterargument invokes the same concept of epistemic kind, which is not disciplinary. The relevance of the connection (P, C) is – at the moment of obtaining – acknowledged through k, which is not specific to either of the two disciplines or their boundaries or intersection. For the investigator, once the connection is obtained, the epistemic structure of D_1 is extended regardless of the conventional (and perhaps relevant) disciplinary bounding of that moment. Since it is the investigator alone (or team of investigators) that actually perform(s) the interdisciplinary action and only their results are validated externally, we have an instance of interdisciplinarity (as crossing content boundaries) with no actual crossing (staying within the epistemic structure of the original discipline).

Indeed, the stage of integration does exist and is socially driven. The integration will apply not only to the two concepts linked, but will engage all the concepts with relevant connections to those two from both disciplines; therefore $D_1 \cap D_2$ extends itself with more than one connection and two concepts. The structural integration is selfaccelerated, and this represents the process of merging disciplines. It is the classic case of physics and biology; biology and chemistry; sociology and anthropology and many other pairs. Domains of disciplines are also in process of merging through structural concept linking. This is how sociobiology, quantum information science, cognitive neuroscience, and other relatively new disciplines were established.

Crossing discipline boundary (if a valid notion) is not done only through accessing concepts from another discipline. There is also the case when the aim is to connect P with a concept C also from D_1, through a method by which we access content from D_2. This case is illustrated in Figure 2 and described in structural terms as what we traditionally mean by theoretical modeling: We identify/observe a structure of concepts from D_2 that is homo- or isomorphic with a structure of concepts from D_1 that includes P and C (call S_2 and S_1 the two structures). This correspondence is not made arbitrarily or conventionally (although it may be made as such), but by following criteria of relevance as well as convenience. Among the former, the correspondence should preserve in both domains the systematic coherence of other structures involving concepts from those placed in correspondence. The validity of the model is tested against this coherence, and it might at any time be invalidated when advancing outside in the superstructure, including through empirical observation. Assume the corresponding concepts of P and C in D_2 are A and B [$f(P) = A$, $f(C) = D$, where f is the structural morphism]. By using the system of knowledge or theory from D_2 we infer or observe that A and B do stand in a certain relation in S_2 and – by means of the homo/ isomorphic feature of f – we infer that P and C do stand in a certain relation in S_1. Note that this inference is actually an *interpretation* back in S_1 of the known relation between A and B, that is it is described in the terms of D_1. Thus, we obtained the connection (P, C) through a double inference: one is within S_2, and the other between or across

S_2 and S_1, via f and its properties.[12] We may now fairly assume that if connection (A, B) is of the epistemic kind k, the inferred connection (P, A) is of the same kind; otherwise the systematic coherence would be broken in D_2.

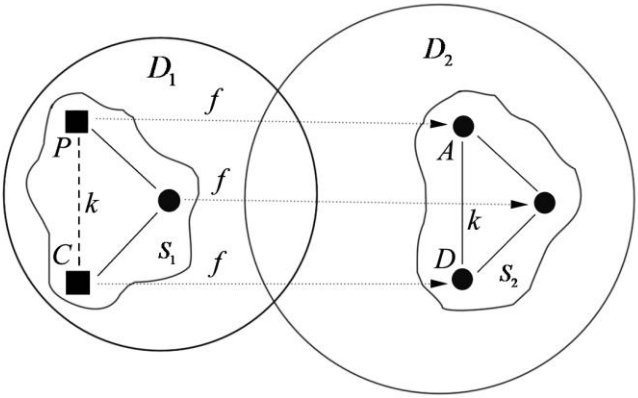

Figure 2. Linking concepts through theoretical modeling

Now, take again the observer position. Where or how was the boundary of D_1 crossed? It seems to have occurred nowhere. Concepts from D_2 were not accessed through f, as in the previous case, but put in a formal correspondence with those from D_1, then interpreted back in D_1 along with their connection. It is like a semantic relation – we can talk about something without seeing or touching it. No relation has been established between the concepts of the two disciplines. What we brought in D_1 is a truth of D_2, which we adapted to D_1 so as to have an epistemic kind for the connection (P, C). The method M through which we did this (theoretical modeling) is not discipline-specific, but universal. Is this import of truth through M a boundary crossing? The content of D_1 was not enriched with new concepts, nor with new relations, but with a new connection (as the imported truth interpreted) for an existing relation. Given that the inferred connection is relevant for D_1, the epistemic content of this discipline is actually the same as before the

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[12] In the traditional terms of structural-theoretical modeling, the former inference is said to take place within the 'governing theory' of the model, while the latter is the interpretation step (when a new function is applied from one structure to another, not necessarily the inverse of f).

interdisciplinary action. Then, the only option remaining is to qualify the truth import as boundary crossing from D_2 to D_1. However, this import is actually the method we used in the action and does not belong to any discipline. Theoretical modeling, which is at its core a primary cognitive method, namely that of reasoning through analogy, just sheds light on a structural equivalence that we uses to advance knowledge in the target (original) discipline. But *observation* is in turn a primary cognitive method and cannot be granted any boundary crossing – we can observe from distance. Think also of metaphors as an example, which in language have the role of easing understanding or describing through syntactical analogy. Metaphors are based on the same structural morphism as theoretical models.[13] A metaphor with fictional subjects will never alter or cross into the non-fictional reality. If this is still seen as bringing something (new) to something from something separated, the entity that is brought seems not to cross any boundary of any sort. Overall, as in case 1, we have boundary crossing with no crossing for the epistemic content.

The universal method of theoretical modeling used in case number two is one of a special power. It can link structures from various domains and concepts of different natures and do transfer of truths from one domain to another. However, its results are subject to further confirmation. At some point in the evolution of the system of knowledge of the target domain, one result may be invalidated by observation, experience, or theoretical inconsistency with other substructures. If such a problem occurs, it is not the method which should be invalidated, but the model developed for its application – that is, the structures, their relations, and their interpretations. Regarding the latter, language of the target discipline plays again a major role here, being actually part of the model. This is why there is always a fine-grained competition of models in the advancement of rational disciplines.

Models are used not only between disciplines, but also between domains or theories within one discipline. The paradigmatic example is that of pure mathematics, for which the set-theoretic foundation allows various theories to be linked through structural morphisms and mathematical structures. Physics also uses its own models to advance. For instance, the model of colliding balls from Newtonian mechanics is used in the kinetic theory of gases (interpreting gas molecules as elastic balls); the gas model was used in applications in nanotechnology, energy research, and biology (Lizhang 2012); the gas model also found applications in recently developed theories on stars and galaxy formation (Binney & Tremaine

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[13] Nonetheless, their validation against the external systematic coherence is more limited than in the case of theoretical models.

2008). Any discipline advances through theoretical modeling, by applying its established truths to new contexts if a structural similarity is found.

Theoretical modeling is what we usually call an *application* of one theory into a target domain – in fact, a non-trivial case of application, as an application mediated by a model. Thus, we can roughly say that D_2 was applied to D_1, and such application contributed content for D_1, but this is not content from D_2. The new content was a connection between concepts from D_1 "suggested" by the governing theory from D_2 and there isn't any integration stage as in case one in which the new content is assimilated in a common zone.

Traditional disciplines have evolved sufficiently through theoretical modeling to have "zones" called interdisciplinary, double-named and considered as a new academic discipline such as mathematical physics, mathematical biology, mathematical economics, mathematical neuroscience, and so on (having mathematics in the role of D_2); but also bioinformatics, bioeconomics, behavioral economics, socioeconomics, psychometrics, biopsychology, and so on. A discipline named in such prefixed forms 'D_2 (-"ized") D_1' refers to a "zone" of D_1 whose content (as statements, truths, and theories) is constituted by using models (and thus imported truths) from D_2. Whether teaching 'D_2 (-"ized") D_1' include also *how* those truths were reached in D_2 is an arbitrary choice; teachers must take seriously into account their expertise in D_2 in all its dimensions. In what concerns the epistemic content, I have argued above that the truths of the applied discipline are not imported as new content for the target discipline.

Mathematics is obviously the most frequently present discipline in such modeling processes, and this is not surprising at all if we think of its special status as a discipline. Specific features of mathematics and applied mathematics, like the nature of their structures, the mathematical language, the predicative logic and set-theoretic foundation account for its descriptive power and all the roles it plays in the constitution and advancement of the sciences, either natural or social. The descriptive power of mathematics is structural. The fact that the laws of physics are best formulated in mathematical language and mathematical descriptions of the empirical phenomena are possible (with a certain degree of idealization) within any scientific discipline, receives structural explanations. One widely accepted explanation is related to the richness in structures of pure mathematics compared with the structural needs of scientists (Maddy 2007, 341-343). This richness is self-generated through the structural apparatus of mathematics, where self-application follows the same model based on structural morphisms. This structural richness and fertility is also externally influenced in a metabolic manner. Mathematics feeds from the problems of sciences, develops new theories just for addressing those problems, and puts their results at the disposal of the sciences, which access them through mathematical modeling. This perpetual process has now reached a stage in which the border between pure and applied mathematics is very diffuse. We have a mathematics of anything, however complex the thing may be, and as such we have a mathematics of any discipline dealing with that thing as its object of investigation. "Mathematics of" is simultaneously a model, a method, a description, a field of both pure and applied mathematics, and – sometimes – a new discipline, if named as such. We also have a physics of something, a biology of something, or sociology of something and it is just the evolution through models that makes us see an interdisciplinary zone around the investigated object, which we call "D_1 of D_2".

The method of mathematical modeling is not epistemically justified within mathematics and does not belong to mathematics; it is a particular case of theoretical (structural) modeling. In fact, the general applicability of mathematics has never received a satisfactory explanation at a metatheoretical level and thus raises philosophical questions. These questions developed around what in philosophy of science is called 'Wigner's puzzle:' *Why* is mathematics applicable in the sciences and physical reality, *how* do we rationally justify the use of mathematical models in the investigation of physical phenomena, and *how* do we explain their high rate of success, given the extreme difference in nature, ontology, epistemology, and logical category between the source (mathematical) and the target (physical-empirical) domains and also some special features of the mathematical practice?[14] For instance, some mathematical concepts and theories created and developed independently of any empirical contexts prove to apply to certain empirical contexts (Wigner 1960, 3, 7), perhaps after decades.

Among the criteria we follow in granting mathematics a special status among disciplines, one quite marginal might be that mathematics has never received a definition to reflect its nature and specificity, and this may account for our inquiry into defining or not defining disciplines. As a discipline, science, method, formal language, or whatever it is, mathematics has provided common conceptual frameworks for wide domains of most of the natural sciences, and methods of investigation and advancement of the disciplines; in this way, it has proved to be one of the main "engines" of what we call interdisciplinarity, by merging, unifying, and

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[14] These questions developed around the influential paper of physicist Eugene Wigner (1960), the author of the syntagma "the unreasonable effectiveness of mathematics" and shaped a new domain within philosophy of science, namely philosophy of applicability of mathematics.

providing a common conceptual language. As a discipline, it has a content in which structures are auto-expandable, and the epistemic kinds of the connections are logical kinds. In addition, it seems that its applicative feature influences the development of this content. Given these, can we delimit such content – and how?

The epistemic-structural model is not quite a reductionist model for interdisciplinarity in the internalist view. Employing the concept of epistemic kinds in the constitution and qualification of the relations of the structure grants the set-theoretic structure a special epistemology which has both a logical and a cognitive dimension. Relating the methods to this structure as generators of the epistemic kinds increases the power of representation of the model, which is able to reflect the dynamics of the processes and is open to further refinement to reflect also the users' interventions in these processes. The nature of the main concepts employed (relations, connections, sets, kinds, structural analogy) is not discipline-specific,[15] but directly related to cognition, so our concern about epistemic circularity expressed in the introduction vanishes. There is no specific discipline dealing with this model, just our inner structural setup of reasoning.

Conclusions

Now is the time to take stock of what we have argued. We started from the common conception that we must study interdisciplinarity through disciplinarity, as being a kind of practice that combines knowledge from two separate disciplines, and this combination assumes crossing some boundaries of the combined disciplines; as such, disciplinarity is assumed to mean staying within those boundaries. Because interdisciplinary actions operate on the content of the disciplines and the concepts of 'boundaries' and 'staying within' (them) are relative to a (boundable) content (as a body of knowledge), it is adequate to have an internalist view on the discipline and consider the content in its epistemic-structural nature. In our structural framework, structures are seen as relations between concepts of certain epistemic kinds, and these kinds are assigned through the rational methods linking concepts which thus exhibit a transdisciplinary nature. Therefore, we have represented the interdisciplinary boundary crossing in two possible ways: linking concepts from different disciplines and linking concepts from the same discipline by using theoretical models sourced in another discipline. For both, I have argued that the

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[15] The view that primary mathematical notions like sets and functions are not mathematical, but specific to our primary cognition, is still debatable within philosophy of mathematics. Relatively recent advancements in perceptual mathematics or protomathematics, among which is worth mentioning the works of Teissier (2005), Ye (2009), and Mujumdar & Singh (2016), may have important implications for this debate, favoring the view.

epistemic content of the original discipline is actually not passed, and as such we have interdisciplinarity with no boundary crossing. Interdisciplinarity (or any of the prefixed versions of '-disciplinarity') – in the common meaning – cannot be equated with and does not imply non-disciplinarity. The conclusion we ought to draw from this contradiction is that the two concepts we started from ('boundary' and 'staying within') were not adequately represented. What then are the options for changing that? How can we delimit a structurally represented content in a way other than *selecting* substructures? Choosing a type of closeness to certain operations instead of the mere set-theoretic delimitation does not work either, since the only possible operations are still over the concepts and represented as relations. If the methods themselves are the operators instead of assigning epistemic kinds – and thus make them discipline-specific in nature – the closeness through methods would assume that interdisciplinarity requires the development of brand *new* (crossing) methods different from discipline-specific ones, which is not the case in the real practice. Overall, it seems that any kind of set-theoretic- or topological-like bounding is inadequate for the epistemic content of a discipline. This is also in the vein of Nicolescu's (2014) view on boundaries. If this is the case, we have to draw a radical conclusion: From an epistemic-structural perspective, interdisciplinarity cannot coexist with disciplinarity, because delimiting is not possible.

The formalism of the model I have sketched can be integrated in both the framework of the general systems theory and Piaget's (1972) cognitive structuralist model of advancement of knowledge, where the key concepts are assimilation and adaptation. This is not the place to develop this unifying design, but it deserves further research. I will limit myself to mentioning that the cognitive origin of Piaget's concepts would benefit nowadays by the pioneering results of the mathematized neurosciences, so that the abstract nature of the structures of knowledge may find biological models. The epistemic structural model of (inter)disciplinarity supports this prediction if we consider the properties that epistemic kinds do exhibit at a first glance: all such relations are antisymmetrical, some of them are transitive, and structures are extended through the transitive ones. It would not be very surprising if these properties are found to be related to the neurophysiology of the brain, where the flow of electrical impulses over neural paths do have properties of sense and direction related to cognitive achievements.

Coming back to interdisciplinarity, the answer to the title question of section two is this: Finding a complete definition for the concept of 'discipline' is of no relevance for the investigation of interdisciplinarity in its common meaning, since disciplinarity and interdisciplinarity are not opposite each other, just as finding the complete definition of mathematics would never account for a metatheoretical justification for its universal applicability nor change the way mathematical methods are applied in other disciplines. Delimiting a discipline in its content is possible set-theoretically in either its objects of investigation, its concepts, or its methods alone, but not all together; considering all three together with their natures and relationships requires a structural representation of the epistemic relevance and coherence of a cognitive system which cannot be bounded. Finally, distinguishing between various disciplines is possible, meaningful, and useful, as it ensures the semantic stability of the discourse on the topic, regiments the curricular side of the disciplines, and allows shortcuts for content access in discourse, education, and research. However, there is also a weak aspect of distinctiveness: Making sharp distinctions influences the conceptual stance we take for interdisciplinarity in many directions, for instance when we address the issue of problems and challenges of interdisciplinary practice.

In our epistemic structural framework, the two-case structural scheme of crossing boundaries is not only a counterexample for an inadequate conceptualization, but also a minimal structural representation of the actual interdisciplinary practice and advancement, through either direct concept linking or theoretical modeling. In this representation, there is no difference between how advancements are made within a certain structure named as a specific discipline for the purpose of distinction and reference, and across different such structures. The same kind of structural advancement is made in both situations, and the immediate goal of each action is to make relevant connections between concepts, including concepts of different natures, by assigning them the same[16] epistemic kinds everywhere. Viewing the methods of advancement as universal in the sense of epistemic availability and discipline-independent justification supports this equating.

Observe also that under this model, there is not much distinction between interdisciplinarity, cross-disciplinarity, multidisciplinarity, transdisciplinarity and other recently prefixed versions. This is not a weakness of any reductionist stance, but an effect of the combination of logical-epistemic-structural-cognitive components for the nature of the model.

In conclusion, the problems and challenges associated with interdisciplinary practice and so greatly stressed within the research of the phenomenon are the same *in nature* as those that investigators and experts encounter within their own discipline. These problems are not associated with crossing any boundary of content, but with the *complexity,* and the management of this complexity; it amounts to the potential breadth of knowledge in every domain paired with the anthropocentric

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[16] In the sense of the finitude of those available or validated.

features of the investigators: possessing a driving curiosity, reaching proposed aims, and making new discoveries, all against the limited resources of reason and brain. Interdisciplinarity was *ab initio* associated with the concept of complexity, at least in what concerns education (Klein 2001; 2004), but a kind of complexity of combining knowledge rather than the complexity of the knowledge itself.

These challenges with respect to content complexity depend on historical contexts and evolution for every discipline. Take as two opposite examples Christian theology and mathematics. The former has not expanded much in content for the last century, as no influential new concepts have been developed or accessed (Pelikan 1989, vii-ix). The latter, mathematics, is the most fertile discipline, developing at an incredible rate new concepts and theories stemming from auto-application and difficult problems, including the problems of the sciences. There were brand new theories developed just for solving an "annoying" conjecture, which ultimately found other applications in other fields.[17]

Considering further the example of mathematics, imagine a mathematician graduating in this discipline 20-30 years ago and working now on a mathematical project requiring application of a mathematical theory developed recently. The problem or challenge this mathematician encounters is that of recreating the entire structural linkage between the new theory and the traditional concepts and theories taught in university. This is not an easy task and may be impossible in some circumstances. An option would be to collaborate with another more recently degreed expert in that theory, who is able to prepare relevant by-passes in the epistemic structure to ensure the understanding of the relations, saving time and other resources for the older colleague. Now imagine the same mathematician working on an applied-mathematics project in, say, medical imaging of the brain. In order to develop mathematical models and correspondences with the concepts of the target domain, the applied mathematician must become familiar (in some degree of reduction and convenience) with the anatomy of the brain and other medical concepts regarding medical images. This familiarity is required for the applied mathematician to make the relevant links with the mathematical concepts and theories. Is this challenge different from the former? Both assume effort, both have the option of collaborating, and in both, the mathematician struggles to connect concepts previously unconnected – of the same nature in the former case, of a

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[17] Just to provide one illustrative example, think of Poincaré's conjecture, whose solution was provided 98 years after its statement in 1904. The solution belongs to the early history of algebraic topology. Generalizations of the conjecture to higher dimensions links to the concept of deformation in Riemannian geometry, with implications and applications for gravitation and cosmology.

different nature in the latter. The struggle is first with the complexity and not (or second) with interdisciplinarity.

The management of the complexity of knowledge has a strong social aspect despite the freedom of the investigators. Even if interdisciplinarity does not exist structurally, the phenomenon of interdisciplinarity does exist in this social aspect. It starts with the curricula conditioned by academic and governmental authorities and assignation of official expertise, and it continues with all interpersonal relationships developed around the interdisciplinary projects, including team management. In this social realm, boundaries are of a different nature and can be kept or crossed through different criteria. As such, we have interdisciplinarity through boundary crossing and a multitude of challenges that may be addressed by appropriate social sciences. Leaving the internalist view but retaining the conclusions from above, still accepting interdisciplinarity as a valid notion, maybe the right characterization for the concept of discipline would be the normative-authoritative "to get disciplined" (in the sense of Turner (2000, 47) or Parker (2002, 374), cited in Chettiparamb 2007). Another promising concept reflecting social boundaries is that of interdisciplinarity as a culture (Bauer, 1990).

The epistemic-structural model of disciplinary advancement, by reducing the processes to a limited number of kinds may suggest first reducing or collapsing the excessive typologies developed around this topic, and second, that a theory of interdisciplinarity can only be a *social*-science theory; other structural theories on this phenomenon may qualify only as general theories of knowledge. A third suggestion would be that within such theory, we must carefully discern between the challenges and problems of interdiciplinarity as formulated by the researchers, as some of them may be just semantic in nature and thus ingenuine.

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