

# Cross-disciplinary Science and the Structure of Scientific Perspectives

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Cross-disciplinary use of science is needed to solve complex, real-world problems, since disciplinary knowledge is insufficient. But carrying out scientific research with multiple very different disciplines is in itself a non-trivial problem because there are fundamental problems of cross-disciplinary communication, and because the present organization of science for cross-disciplinary work is inadequate. Perspectives matter. In this paper we carry out a philosophical analysis of the perspectival nature of science, focusing on the synchronic structure of scientific perspectives across disciplines and not on the diachronic, historical structure of shifting perspectives within single disciplines that has been widely discussed since Kuhn and Feyerabend. We show what kinds of cross-disciplinary disagreement to expect due to the perspectival structure of science, suggest how to handle different scientific perspectives in cross-disciplinary work through perspectives of a second order, and discuss some fundamental epistemic differences between different types of science.

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*Key words: Interdisciplinary science; communication; disagreement; scientific perspectives; perspectivism*

## 1. INTRODUCTION

*Perspective is one of the component parts of reality. Far from being a disturbance of its fabric, it is its organizing element. ... Every life is a point of view directed upon the universe. Strictly speaking, what one life sees no other can. ... Reality happens to be, like a landscape, possessed of an infinite number of perspectives, all equally veracious and authentic. The sole false perspective is that which claims to be the only one there is. (José Ortega y Gasset 1961 [1923], 90f)*

The complexity of the world is rapidly increasing, as is the complexity of science, and there is a continuing differentiation of functions and perspectives. Over time, science has differentiated from the unspecialized natural philosophy of the past into specialized fields of observation like biology, sociology and psychology (Stichweh 1992, 1996, Luhmann 1990, 446ff). The established disciplines are further differentiating into specialized sub-disciplines and new disciplines are still being formed based on functional professions in society like nursing and physiotherapy, and new technologies like information technology. Often there are also crucial differentiations within disciplines between different 'schools of thought' such as the different socioeconomic perspectives on globalization and sustainable development (Byrne and Glover 2002).

The differentiation of science is both an answer to the growing complexity of the world and in itself a source of new complexity. And the growing differentiation and complexity of science is a challenge to the use of science in society. When society is faced with a complex problem like climate change, environmental pollution, sustainable food production or life style diseases, there is a need to draw on a range of different disciplines from physics, chemistry and physiology to anthropology, sociology, economics, political science and ethics, spanning natural, social and human sciences. But these disciplines do not agree on solutions to the problem or even on what the problem is. They have no shared theoretical framework, and often they disagree on essential questions such as what is scientific and what is good science.

Therefore, there is a rising call for cross-, multi-, inter- or transdisciplinary science as a tool to address the combined problem of the differentiation of science and the increasing complexity of the systemic challenges to modern societies (e.g. Pennington 2008, Hirsch Hadorn et al. 2008, Pohl and Hirsch Hadorn 2008). The promise is that helpful solutions can be gained from the (multidisciplinary) use of several disciplines on the same problem, from the (interdisciplinary) development of a shared framework for cooperation between the disciplines, or from a (transdisciplinary) integration proper of the involved disciplinary and stakeholder perspectives. In this paper we use the term cross-disciplinary science<sup>1</sup> as a general term for multi-, inter- and transdisciplinary science, in order to be able to speak of the general problematics of cross-disciplinary work without being caught up in the specifics of the established categories.

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<sup>1</sup> We use this term to designate (truly) cross-disciplinary research where different disciplines study the same research object, not including the more trivial instrumental use of other disciplines as tools within a discipline.

In the scientific literature there is a growing recognition that truly cross-disciplinary cooperation to solve complex real-world problems, which includes disciplines and schools across the traditional divisions between natural, social and human sciences, is very difficult to perform successfully. This confirms our own experiences. In spite of good wills and many ambitions to the contrary, there are fundamental problems in communicating and mediating between the different scientific perspectives, in particular where there is no common theoretical framework, and often the cooperation is constrained by the hegemony of one perspective at the cost of the others (e.g. Dewulf et al. 2007, Evely et al. 2008, Miller et al. 2008, Bracken and Oughton 2006, Harrison et al. 2008, Pennington 2008). The more ambitious the collaboration is, in terms of using and integrating very different scientific perspectives in solving real, complex problems, the more difficult the task. This raises fundamental questions on the role of scientific knowledge, communication and organization in front of complex problems. Disciplinary knowledge is insufficient, yet there is no established cross-disciplinary knowledge to fill this gap. In this situation effective cross-disciplinary communication is essential to gain the most from disciplinary knowledge, but, as stated above, there are fundamental problems of cross-disciplinary communication. Consequently, there is a need to re-evaluate the present organization of science towards complex problems.

In line with the promise of transdisciplinarity, a range of different approaches to in some way (re-)integrate very different scientific perspectives to address complex real-world problems have been suggested, such as systems theory, complex modeling and various holistic frameworks. These efforts are commendable, but we don't think any of them provide a general approach to solve the fundamental problems that arise when very different kinds of science are to be used in an integrated way in complex problem solving. The problems of disintegration are either ignored in a reductionist and hegemonic way, or a new so-called holistic perspective is introduced, which ignores the specialized perspectives and therefore in itself is a kind of reductionism. For instance, Pohl and Hirsch Hadorn (2008) consider 'systems thinking' a constituting conceptual basis of the transdisciplinary research perspective. But the choice of systems framework is not innocent – each system theory has its own perspective on complexity that observes certain types of problems, and the different system theories will leave different imprints on the answers gained.

The differentiation of science, the growing complexity of the problems science is expected to solve, and the ensuing problems in carrying out cross-disciplinary science is not only a challenge to science and the use of science in society, but also a challenge to philosophy of science. Most work within the discipline of philosophy of science has so far been concerned with single disciplines, such as physics or biology. In many cases physics is used as a model for all of science. And even when the focus is on the heterogeneity of scientific disciplines, there is rarely any focus on the interplay of different disciplines (e.g. Knorr Cetina 1999, Giere 2002, Kellert et al. 2006). However, there is an emerging awareness of the challenge of cross-disciplinary science. Recently, in a discussion of the optimality approach to modeling and its dependence on other approaches, Potochnik (2010) concluded that there is a widely felt tension in science between the explanatory independence of scientific fields, subfields, approaches and research programs, and the broad, epistemic interdependence between them because of the inherent limitations of each approach –

causal complexity makes the divide-and-conquer approach to science effective for practical reasons; yet there is a need for collaboration: “Evidential interrelationships do not respect field boundaries; they require cross-disciplinary evidence-gathering” (Potochnik 2010: 230). In this paper we take up this challenge.

We argue that the perceived problems of cross-disciplinary science are not exceptions, but symptoms of a fundamental structural problem in cross-disciplinary science, which can be analyzed philosophically by gaining a deeper understanding of the perspectival nature of science. The first step in the analysis is to investigate the cognitive aspects of science as a systemic learning process and look at the ‘instruments of observation,’ broadly construed. The differentiation of science is not only a differentiation of social systems, but also a cognitive and epistemic differentiation and specialization of scientific perspectives. Differentiation increases the complexity that science can handle overall, by reducing the observational complexity that each perspective must handle, through selection and delimitation. This makes differentiation a very powerful mechanism in science; and this is the reason why a genuine reintegration that ‘undifferentiates’ scientific perspectives, in general, is neither possible nor desirable – the strength of independent scientific perspectives is needed. There are of course many examples of theoretical syntheses in science, like the neodarwinian synthesis and relativity theory, but such local syntheses do not negate the general processes of differentiation and the overall disunity of science (Kitcher 1999). Indeed, the limited reducibility of theories leads to a pluralistic epistemology of science with complementing truths on different cognitive levels (Rorhlich 1988). The differentiation of science is the reason why truly cross-disciplinary science is a non-trivial problem. And irrespective of metaphysical beliefs, the heterogeneity of science is an empirical fact for contemporary philosophy of science to address.

In this paper we explore how philosophical analysis of the structure of scientific perspectives can help us understand the persistent problems in cross-disciplinary science. We want to expose the perspectival causes of communication failures and disagreements in cross-disciplinary science and sketch out a framework to understand and handle different scientific perspectives (see further in Alrøe and Noe 2014). We will start out by removing the road-block for cross-disciplinary work that some types of science are by necessity more scientific than others. Then we will introduce the concept of perspectives from a cognitive and semiotic understanding, because this contains strong implications for how we think about scientific knowledge and scientific disagreement. Next, we outline the connection between the perspectival structures of science and the types of scientific disagreement that they entail. Finally, we suggest how the problems that arise in cross-disciplinary science due to the perspectival nature of science can be handled through second order perspectives, and outline a perspectivist typology of science to better understand disagreements between scientific perspectives.

In doing this we hope to arouse a wider interest in the philosophy of cross-disciplinary science. Furthermore, the practical aspiration is that this pluralist and perspectivist, but not relativist, framework can serve as a helpful basis for future cross-disciplinary research and for the cross-disciplinary use of science in society.

## 2. PERSPECTIVES, VALUES AND ‘GOOD SCIENCE’

Before we turn to the perspectival structures of science, we need to remove a potential road-block for cross-disciplinary work and for the present analysis: the idea that some types of science are *by necessity* more scientific than others, and the associated idea that the supposedly more scientific types of science are to be preferred to other types. A deeper analysis of this issue is beyond the scope of this paper, but the perspectivist understanding of science contains certain ideas about scientific quality that provide a more level playing field for different types of science, and which we will briefly outline here.

The complex cross-disciplinary research processes that aim to address complex real-world problems are interwoven with values. Some, more traditionally inclined philosophers of science might therefore maintain that the problems of performing cross-disciplinary research are examples of a science infested with normative issues, which should have been kept outside, and refuse that this is at all a problem for philosophy of science. However, it is important to underline that this is not a question of protecting science from outside interests and ‘social norms.’ The scientific perspectives that are involved in complex, social problem solving stand square across the normative and the empirical, across research instruments, values and social relations (e.g. Longino 1990).

In the planning of such research, decisions must be made on what problems to investigate; what methods of observation and intervention to apply; which theoretical framework to utilize; which key concepts to use in hypothesis forming and in what sense; and what assumptions to lay down as a basis for model construction. Some and maybe most of these decisions are determined by existing research structures, traditions, policies, habits, and contingencies, but they are still research choices that jointly determine the specific perspective that is taken in the research process, and which could be different. And in a complex problem solving context, all these decisions harbour implicitly or explicitly value-laden choices.

The realization that values are deeply embedded in the practices of sciences that address complex, real world problems, has important implications for how the scientific ideal of objectivity is construed. In the research field of sustainable food production, as an example, value-laden concepts such as food quality, soil quality, sustainability, animal welfare, justice, health, and welfare enter as key elements in most research projects. At the same time, there are diverging conceptions of what soil quality, animal welfare, sustainability, etc. means, both within the scientific community and in society at large (e.g. Schjønning et al. 2004, Fraser 1995, Byrne and Glover 2002). In such truly complex research fields, which include reflexive, social and semiotic aspects as well as causal aspects, an important requirement for doing good science is to establish clarity concerning how (not whether, but how) values enter into the key value-laden concepts that are used and how this influences methodological choices. Apart from determining scientific quality, this is important for determining the relevance of the research.

That science is value-laden does not mean that it is necessarily subjective and bad science. On the contrary, the deliberate, reflexive handling of the values that are (by necessity) entailed in the research perspective is a precondition for doing good science. To be objective is not to be context-free, but to be open and clear about the context and perspective from which something is stated. In the words of Niels Bohr, objectivity simply means giving an *unambiguous description* of what has been experienced in research, and this unambiguity can only be obtained by including the context of observation (Favrholdt 1999: xlix, 88–90). Bohr thus recommended “to use the word phenomenon only to refer to observations obtained under specified circumstances” (Favrholdt 1999: 89) – phenomena are attached to perspectives. This is different from van Fraassen’s definition of phenomena as ‘observable entities’ in contrast to appearances as the (perspectival) outcomes of given observation or measurement set-ups, and both phenomena and appearances being distinct from the theoretically postulated, underlying reality (van Fraassen 2008: 283–290). We think a more fruitful distinction between the phenomenal and the real object can be gained from semiotics – see the next section.

Being scientific in this sense can be expressed with the term ‘reflexive objectivity’ in line with other work towards a standpoint, perspectival, situated or naturalized account of objectivity (e.g. Kukla 2008, Barad 2007, Rouse 2002). As a criterion of good science, reflexive objectivity requires that the communication of scientific results must include a description of the cognitive context that the results spring from (Alrøe and Kristensen 2002). This is in accordance with the long tradition in scientific publication practices to require a description of the research method, and it furthermore includes other parts of the cognitive context, which are not always put forward in scientific publications, namely the intentional context (explicit values and problems) and the social context (financing and affiliations). But reflexive objectivity also points to a deeper concern for the cognitive context that is ‘built-into’ the scientific perspective and often not made explicit. Tacit values, knowledge, practices and instruments that, together with those that are made explicit in scientific communication, make up a scientific perspective, and they are tacit precisely because this is part of what makes a scientific perspective effective. In order to explore these tacit cognitive and perspectival structures, we need to observe scientific perspectives as perspectives and not as abstract theories or social groups of scientists.

### 3. A COGNITIVE AND SEMIOTIC UNDERSTANDING OF SCIENTIFIC PERSPECTIVES

There is a growing recognition that the context established by scientific disciplines, schools and methodological approaches is decisive for the focus and the kind of observations that can be made by science. This contextual and pluralist conception of science has been nurtured by the ideas about the incommensurability of successive scientific theories launched by Paul Feyerabend and Thomas Kuhn. In recent years there has been a rising interest in cognitive approaches within philosophy of science, where the focus is on scientific models and representation rather than theories and truth (e.g. Giere 1988, 1994, 2004, Cartwright 1999, van Fraassen 2008). And lately, Ronald Giere (2006a, 2006b) has developed this cognitive understanding of science into a ‘scientific perspectivism’ proper. Perspectivism has had a long but marginal presence in

philosophy with roots in Kant and Nietzsche (e.g. Palmquist 1993, Anderson 1998). And there have been narrower, specific perspectivist approaches within philosophy of science, such as Rueger's (2005) model-theoretical analysis of perspectives within the formalism of a theory. But Giere was the first to develop a fully perspectival philosophy of science. While Giere has mainly developed the perspectivist approach in the context of natural science, we here explore it as a general approach to science in its wider continental sense, which includes natural, social and human sciences.

The perspectivist view of science is quite radical compared a conventional realist view of science, but it can be characterized plainly in a few sentences: There is no outside perspective on the world. All knowledge comes from a certain perspective. All learning happens in concrete perspectives on the world, which are part of the world, and which can themselves be made objects of observation. This fairly banal insight contains strong implications for how we think about scientific expertise, scientific disagreement and the role of science in society, as well as for our ideas about scientific norms.

A scientific discipline is a specialized perspective for observation of a field with specific instruments, concepts, logics and examples. The perspective is reproduced and refined through internal processes. It delimits and focuses the field of observation, and makes possible the observation of certain phenomena and aspects. This view of science implies that there are many scientific truths about any complex problem, and that the question for philosophy of science is not how to select the correct one, but how to appreciate and use the nonunifiable plurality of partial knowledges (Longino 2006). All ontological claims are interwoven with the epistemological conditions for observation that apply in the perspective where it is grounded.

However, this does not imply that any truth can be as good as any other, or that there is no difference between expertise and taste. The distinct, collective character of science is manifest in the foundational methodological ideas, open inquiry, systematic observation and testable truths, which establish its excellence in the production of knowledge.

The perspectivist approach described here (which in this respect goes beyond the scientific perspectivism in Giere 2006a, 2006b) builds on a thoroughly semiotic understanding of a scientific perspective. A key element in this approach is the distinction between phenomena and noumena that Kant established in modern philosophy. Phenomena are things-for-us, things as they appear to us. Our knowledge is of phenomena and our objects reside in our phenomenal world. Noumena are the unknowable things-in-themselves. Scholars have long disagreed on this distinction between phenomena and noumena, but as Palmquist (1993, App. VIII) argues, Kant's distinction between the noumenal and the phenomenal realms is properly regarded as a *perspectival* distinction. The noumenal is not found as an object of experience, but only by its possible effect.

In Charles S. Peirce's semiotics we find the same distinction in an elaborated theory of representation and interpretation, which is readily applied in a perspectivist view of science.

According to Peirce: “A sign, or representamen, is something which stands to somebody for something in some respect or capacity” (Nöth 1990: 42, CP: 2.228 [1897]). In his later works he stresses the semiotic relation between the immediate object that is represented in the sign and the reality of the object:

*“I define a Sign as anything which on the one hand is so determined by an Object and on the other hand so determines an idea in a person’s mind<sup>2</sup>, that this latter determination, which I term the Interpretant of the Sign is thereby mediately determined by that Object. A Sign therefore has a triadic relation to its Object and to its Interpretant. But it is necessary to distinguish the Immediate Object, or the Object as the Sign represents it, from the Dynamical Object, or really efficient but not immediately present Object.”*  
(Peirce 1998: 482, CP: 8.343 [1908])

Peirce’s theory of semiotics is very rich, but here it suffices to point out that three analytically distinctive but practically connected operations are performed within a semiotic process. One is the selection of an immediate object from the redundancy of possibilities pertaining to the dynamical object; the second is the assigning of a sign to the immediate object, which represents the object in an iconic (similarity), indexical (direct connection) or symbolic (conventional) way; and the third is the linking of the quality of the immediate object (regarding its reference to the dynamical object) with its pragmatic use in the interpretation.

It is important to stress that, in Peirce’s sense, there is no position from where we can observe the dynamical object as such; every perspective only adds to the number of immediate objects that refer to the dynamical object. This is of course very different from a traditional realist conception which takes the thing in itself as the immediately present object. Furthermore, there is no ontological commitment to objects in favour of relations implied in the term “object”.

Figure 1 illustrates the fundamental elements of scientific observation in form of a semiotic model of the cognitive aspects of a scientific perspective, which builds on Peirce’s theory of semiotics and the semiotic approach to cognition as a coupling of interaction and reference in the biosemiotic tradition (e.g. Uexküll 1982, Hoffmeyer 1997), and in this way follows Kukla’s (1992) definition of a cognitive system as an interpreter; and on Niels Bohr’s epistemological lesson from quantum physics, which he stated in many places, here from a letter to Pascual Jordan in 1931: “Not only, of course, have we learnt that every observation involves a disturbance of the phenomena; we have furthermore realized that the whole concept of observation requires a separation between the object and the means of observation” (Favrholdt 1999: 521), and which has later been taken up by Barad (2007: e.g. 148) and Rouse (2002: 272ff).

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<sup>2</sup> This is a pedagogical presentation. Peirce did in fact not restrict interpretants to persons (Peirce 1998: 478).



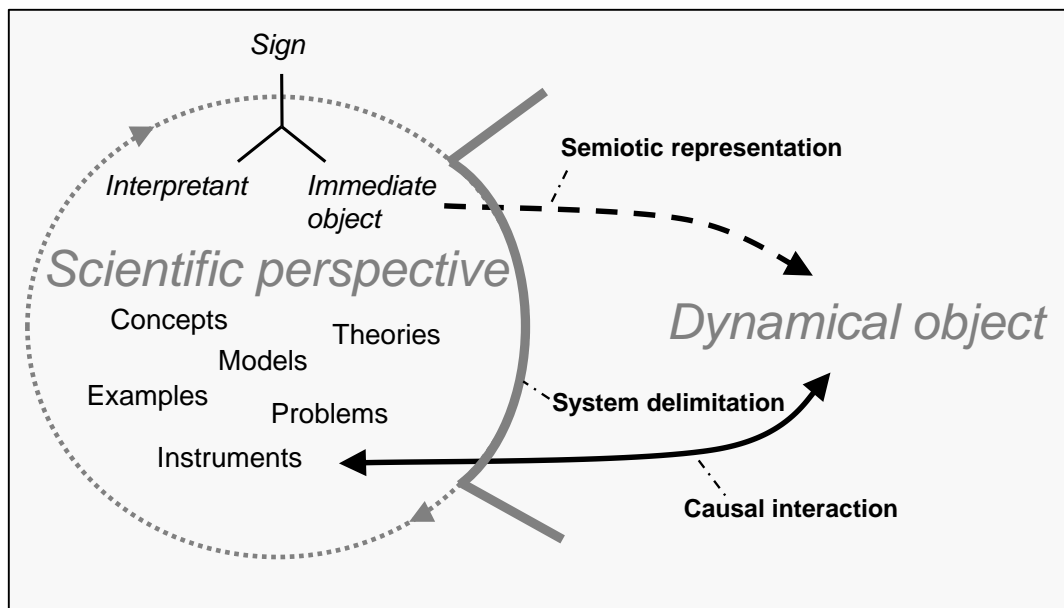


Figure 1: A semiotic model of the cognitive aspects of a scientific perspective observing a dynamical object, which is represented by an immediate object within the perspective, and the three key conditions for observation: delimitation, representation and interaction.

The model shows the three key conditions for observation. *System delimitation*: the very idea of observation requires a delimitation of the cognitive system, which separates the observer and the observed. *Semiotic representation*: the cognitive complexity of the observing system enables, and delimits, the complexity of the ‘observer world.’ *Causal interaction*: observation requires an interaction between the observer and the observed that can irritate the representation, and which connects the observer and the observed in a shared reference frame. A scientific observation is always done from a certain perspective with certain concepts, theories, models, examples, problems and instruments that establish the three conditions for observation. The communicative aspects of the scientific perspective are not shown explicitly in the figure but the semiotic model shows the sign as a link to the deeper cognitive basis for scientific communication – the sign is “a Medium for the communication of a Form”, as Peirce puts it<sup>3</sup>.

As a simple example of the three conditions for observation, consider a blind man with a stick. Holding the stick firmly, the man is able to observe the floor in front of him by moving the stick around, but he cannot observe the stick – the stick is part of the observing system. Holding the stick loosely, the man can observe the form of the stick in his hand, but not the floor in front of him – the stick is now part of what he observes. He can delimit his observing system to his hand or he can include the stick, but he cannot do both at the same time; he needs to make a separation between the observing and the observed to observe at all. If there is no interaction, if the stick just waves around in empty space, there can be no observation. But if the stick hits something, a dynamical object, this causal interaction is an irritation that will enable him to start making a semiotic representation of the space around him. Both the interaction and the representation are necessary for his process of observation. At first the representation may be crude and not very

<sup>3</sup> Undated manuscript “On Signs”, <http://www.commens.org/dictionary/term/sign> accessed 21/11-2014.

helpful, but with continued interaction it may be refined and become more useful, so that he can use his observations to act in his environment.

The representations of science refer to or point at dynamical objects, and the representations are tested when we establish observational situations (systematic observations, interventions, experiments) where the dynamical objects may 'kick back' in the causal interactions that are an essential part of observations (cf. Figure 1), but the dynamical objects can never be fully captured in the immediate objects of science. A dynamical object has a surplus of possibilities for observation, and the representation in form of an immediate object present in any observation is, by necessity, a reduction based on a certain perspective.

When two different observations of the same dynamical object mutually exclude each other, we end up with 'complementary phenomena' in Bohr's sense (Favrholdt 1999: 88–90). Quantum physical complementarity arises where the necessary interaction with the observed object (cf. Figure 1) cannot be disregarded, because the observed objects are sufficiently small that the quantum of action becomes significant. Popularly speaking, the position of a particle cannot be observed without the radiation involved in the observation influencing the momentum or the particle, and therefore measuring the position will make the momentum indeterminate or ill defined, and vice versa. Some twenty years after Bohr first presented his complementarity view, he emphasized "the impossibility of any sharp separation between the behaviour of atomic objects and the interaction with the measuring instruments which serve to define the conditions under which the phenomena appear. ... Consequently, evidence obtained under different experimental conditions cannot be comprehended within a single picture, but must be regarded as complementary in the sense that only the totality of the phenomena exhausts the possible information about the objects" (Bohr 1949). This nicely sums up the analogy between quantum physical complementarity and the potentially complementary relations between different scientific perspectives in cross-disciplinary science.

By definition, it is a condition for cross-disciplinary science proper that the different perspectives observe the same thing, so to say, and here the model in Figure 1 points to a two-layered problem of communication across scientific perspectives. There is a need to point directly at some 'real' dynamical object to be shared in cross-disciplinary work, but we can only communicate signs (names, models, etc.).<sup>4</sup> The specialized languages of scientific disciplines and schools are not generally shared. Some perspectives are closely connected and share methods, models, theories or worldviews, others are very different and closed to each other. The 'rock bottom' basis for cross-perspectival communication is the 'common, ordinary language' (in Bohr's sense, see

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<sup>4</sup> According to Weisberg's (2007) argument that modeling is the analysis of real-world phenomena by way of analysing a model, these two signs, names and models, would be quite different forms of signs, a name being an abstract direct representation and a model being an indirect representation. Translating this understanding into the Peircean semiotic terminology, a model is a dynamical object that is constructed to represent another (real-world) dynamical object. Hence, whereas a name is a (quite complex) iconic sign in itself, we would more often communicate signs based on observations of that sign, or descriptions of models, in Weisberg's words.

Favrholdt 1999: xxxvii), though this is still conditioned on common daily lives and therefore prone to cultural differences.

To take a simple example, the common name 'a cow' can be generally shared but reveals fairly little of the dynamical object referred to. More specialized, perspectival names such as dairy cow (for production), year cow (for accounting), prize animal (for cattle shows), livestock unit (risk of eutrophication) and grazing pressure (for landscape conservation) point to different aspects of the dynamical object of a cow. In order to successfully communicate the immediate objects represented by these names across perspectives, a shared interpretation of the sign has to be established. Communicating across perspectives is not a trivial thing.

The second layer of the problem is that the same dynamical object can be observed and represented in different ways in different perspectives, but none of these immediate objects is the same as the dynamical object in itself, and it is not possible a priori to determine whether different scientific perspectives observe the same dynamical object in cross-disciplinary work, even though this is the presumed. In language terms, when one perspective speaks of 'sustainable development,' 'soil quality,' 'farm,' or 'cow,' it does not necessarily mean the same as when another perspective uses the same term. The communicative paradox of cross-disciplinary science is that the common language is not sufficiently precise to handle the immediate objects of specialized perspectives, but more precise and specialized communication moves us away from the common language with which we can communicate across perspectives. This is a lesson to be learned from Peirce's semiotics, and an idea that has been radicalized by Niklas Luhmann (1995, 143, emphasis in original): "The fact that understanding is an indispensable feature in how communication comes about has far-reaching significance for comprehending communication. One consequence is that communication *is possible only as a self-referential process.*" Communication across perspectives depends on structural couplings being established, and the differentiation and specialization of scientific perspectives reinforces this key condition.

We may be able to interact with the dynamical object through experiments, which create particular observation conditions, and through practical experiences, and in this way we can attempt to establish whether our representations 'correspond' to reality. But built into the observation conditions provided by different scientific perspectives, there is a linkage between ways of interacting with the world and ways of representing the world that makes it difficult, and in principle impossible, to share a common reference to a dynamical object across perspectives. Obviously, this does not mean that one cannot perform cross-disciplinary work, but it does mean that cross-disciplinary work is not a trivial matter. In the following sections we will explore the perspectival structure of cross-disciplinary science and offer some perspectivist analyses and tools to facilitate cross-disciplinary communication and cooperation.

## 4. THE PERSPECTIVAL STRUCTURE OF CROSS-DISCIPLINARY SCIENCE

The perspectivist conception of science presents a fruitful route to a better understanding of the problems and potential of cross-disciplinary work. A key step is to give an outline of the connection between perspectival structures of science and the types of scientific disagreement that they entail. Scientific disagreement is a good thing. It is through disagreements that scientific knowledge is tested and developed. But the confusion of different kinds of scientific disagreement is not productive. By creating a better overview of what kinds of disagreement can be *expected* between different scientific perspectives, due to their perspectival differences, we can establish a better basis for assessing and handling other forms of scientific disagreement, which are due to scientific dishonesty, political spin, disciplinary hegemony, bad science, etc., and point out a route to overcome some of the pitfalls of cross-disciplinary research.

The differences between types of scientific knowledge, disagreement and learning that appear in a perspectivist understanding of science are shown in Table 1. The table shows different types of knowledge, disagreement and learning (columns) in relation to the perspectival structure of science (rows indicating 'within a perspective', 'between perspectives', etc.). The kinds of disagreement to expect within a perspective are the normal, converging disagreements (Table 1, row 1) and the diverging disagreements that transgress the perspective and which may transform or split up the perspective (Table 1, row 2), whereas forms of unconnected 'blind' disagreements and communication failures are to expected between different perspectives (Table 1: row 3). Most elements in the perspectivist understanding of science shown in Table 1 have been treated in other contexts, without a comprehensive perspectival framework, and the table shows a few well known philosophical and sociological approaches, such as the boundary-work of Thomas Gieryn, the scientific revolutions of Thomas Kuhn, and Harry Collins' interactional expertise.

	Type of knowledge and expertise		Type of disagreement	Type of system learning process
1. Within a perspective	Embodied and tacit knowledge, Paradigm,	Orthodox knowledge	Converging disagreement	Socializing, Reproducing and refining, Normal science
2. Transgressing a perspective	Contributory expertise	Heterodox knowledge	Diverging disagreement	Differentiation of science, Scientific revolution
3. Between perspectives (of first order)	Acontextual knowledge, Interactional expertise		Unconnected 'blind' disagreement, Communication failure	'Learning the language,' Hegemony, Boundary-work
4. In a second order perspective	Contextualised knowledge, Reflexive expertise		Perspectival disagreement	Second order polyocular communication

Table 1. Types of knowledge, disagreement and learning in relation to the perspectival structure of science.

Gieryn (1983) investigates the actual delimitations of science from non-science that specific sciences use in the pursuit of their professional goals. As discussed in a previous section, such boundary-work can be a problem in cross-disciplinary work, because some scientific perspectives are marginalized as non-scientific by other, more esteemed and powerful perspectives. See e.g. Hinrichs (2008) for a discussion of boundary work in agrifood studies.

Kuhn's paradigms are examples of perspectives in our understanding. Kuhn (1996 [1969]), in his Postscript to *The Structure of Scientific Revolutions*, suggests the term 'disciplinary matrix' as a more precise term for 'paradigm,' the term used in his highly influential book from 1962. The disciplinary matrix includes symbolic generalizations (theories and laws), metaphysical paradigms (models, analogies, and metaphors), values, and exemplars (concrete problem-solutions). The elements of Kuhn's disciplinary matrix are similar to the elements of what we have termed the cognitive context of a scientific perspective. However, Kuhn and the rich tradition following Kuhn have a historical, diachronic focus, where the paradigms of normal science are interrupted by scientific revolutions or paradigm shifts within a certain scientific field, whereas we in this paper focus on the synchronic disagreements between different perspectives and the consequences of the historical differentiation of science into different fields, disciplines and schools, in line with Maruyama (1974). The Kuhnian tradition in general focuses on theories and language, though there are some who take a more cognitive approach (Chen 1997, Andersen et al. 2006). Our approach here differs from the main tradition in having an explicit cognitive focus on what can broadly be called 'the observational apparatus.' Kuhn's views on the incommensurability between consecutive paradigms correspond to the problems in integrating and communicating across perspectives in cross-disciplinary work that we have described in this paper. But where Kuhn uses a language metaphor, talking of the untranslatability between different paradigms (Chen 1997), our approach points out that is in principle impossible and in practice more or less difficult to communicate across perspectives because each observational perspective has its own phenomenal world - its own representation of the world entailed in theories, models, concepts and examples, which is tied into the specific observational apparatus and the specific forms of interaction provided by it. Despite the common features, our more general (not only diachronic, but also synchronic) and explicitly perspectivist approach leads to other questions and other answers than Kuhn's.

Collins and following him a number of other researchers have investigated what the scientific practice means for expertise, and what scientific disagreement means for the role that expertise has in society (e.g. Collins 2004, Collins and Evans 2007). However, this work concerns in particular the opportunities for individual researchers to obtain expertise in a different field than their own, and not the general perspectival structures that are in focus here. Collins distinguishes between *contributory expertise*, possessed by those who participate in everyday activities and development of the field, and *interactional expertise*, which is characteristic of those who can communicate fully with the field, but are not able to contribute. The general interactional expertise of scientists (especially within the natural sciences) helps make the, in principle impossible, cross-disciplinary cooperation merely difficult. But in general, it takes a long time to obtain interactional expertise on a new field, and due to the differentiation and specialization of science it is hardly

possible today to become a 'modern renaissance man' with interactional expertise in a range of widely different fields. Interactional expertise therefore cannot be considered a general solution to the cross-disciplinary conundrum. The 'trading zones' of Galison (1997: 803ff) refer to scientific communities and not individuals, but still, the focus is on language and not on scientific perspectives as a whole.

The perspectivist understanding provides a common framework for discussing these different approaches to handling knowledge, disagreement and learning across scientific perspectives, and this linkage may be helpful in itself. But the really novel in the perspectivist approach is that it points to structures beyond these existing approaches. It is only in a thoroughly perspectivist understanding of science that the possibility of a fourth, multi-perspectival form of knowledge, disagreement and learning shows up, building on the idea of second order cybernetics (Foerster 1984). Perspectival disagreement and reflexive expertise are based on the handling of contextual knowledge from first order perspectives in a second order learning process, which we call polyocular communication (Table 1: row 4). . This involves a second order perspective that observes the observations of first order perspectives.

In the next two sections we first describe how second order perspectives can be used concretely to handle cross-disciplinary science and then outline some general cognitive and epistemic structures of scientific perspectives that can help facilitate such processes.

## 5. SECOND ORDER OBSERVATION OF SCIENTIFIC PERSPECTIVES IN CROSS-DISCIPLINARY SCIENCE

Building on the ideas in the previous section, we suggest that the problems that arise in cross-disciplinary science due to the perspectival nature of science need to be handled through perspectives of a second order. Using a term first used by Magoroh Maruyama (1974, 1978, 2004) in cross-cultural and organization studies, we characterize such second order learning processes as polyocular communication based on second order observations. That is, a second order perspective does not directly observe the research object; it performs second order observations of the first order scientific perspectives observing the object, and in this sense it manifests one multi-perspectival or polyocular view of the object (see Figure 2 for an example).

The need for second order perspectives and polyocular communication is a reaction to the difficulties of communicating directly across different perspectives with, possibly, different immediate objects in form of theories, models, taxonomies and entities, different delimitations of the shared (dynamical) research object, different understandings of common concepts, different logics and rationales, different criteria of science and different societal and intentional contexts in form of values and interests. The subject matter of the polyocular communication is thus contextualised observations and representations that expose the perspectives and conditions they stem from, and contextualised notions of knowledge and expertise in general. The second order perspective that is home to polyocular communication is on the one hand a scientific perspective like any other, residing in a research group or a wider research community, but different in

operating at a meta-level compared to first order scientific perspectives on the research object. As such it is a different form of organization of the research process, a research process that includes two levels of observation to enable a new form of knowledge production based on polyocular communication.

In the (obviously simplified) example in Figure 2, agronomy is concerned with food production and observes yields on the farm, biology is concerned with nature and observes biodiversity in and off the fields, economy is concerned with markets and observes commodities from the enterprise, and sociology is concerned with culture and observes human interactions in and around the farm. In a concrete cross-disciplinary investigation of, say, nature quality in a farmed landscape, these disciplinary perspectives represent different interests in nature quality with very different ideas about what nature quality means, they have different methods for how nature quality is best investigated, different geographical and conceptual boundaries of farms and landscapes, and in the end they draw different conclusions based on different rationales. A common geographical research area therefore cannot ensure that the different perspectives observe the same dynamical object, and a common pool of data cannot ensure integration across disciplines, since data are always observations from a certain scientific perspective.

It is sometimes stated as a goal that the scientific disciplines that are applied in cross-disciplinary research should undergo a disciplinary integration proper, often using the term transdisciplinary science (e.g. Pohl and Hirsch Hadorn 2008). This may be a relevant target if the objective is, for instance, to create an integrated perspective on a technological field such as nanotechnology (Johnson 2009). If the integration succeeds, a new, separate perspective is established, where specific theories, models, values, logic and exemplars are selected and the research field determined. There are strong internal mechanisms in science that favour the formation of specialized perspectives, which offer consistent, effective and accurate knowledge in the context of their particular, delimited research world and refined tools of observation.

On the other hand, the idea of transdisciplinarity of a first order, without the selections and delimitations inherent in the formation of a single scientific perspective, is incongruous. The specialized disciplines are generally not able to both reproduce and refine their own perspective and carry out second order observations of the different perspectives (including their own) that are employed in cross-disciplinary work. It is fine to utilize and extend the interactional expertise, in Collins' sense, that each researcher bring into the work, but while such individual cross-cutting expertise is helpful, it is not enough to underpin cross-disciplinary work. There is a need for formalized procedures to observe and communicate about the scientific perspectives involved, and there is a need for separate resources to perform such second order learning processes in scientific practice, as illustrated in Figure 2. Concretely, this could for instance be organized in form of a separate work package in a cross-disciplinary research project, with its own funding and human resources, but also involving researchers from the different disciplinary perspectives, with the aim to establish a reflexive, polyocular communication based on observations of the observations of different disciplinary perspectives and their cognitive context.

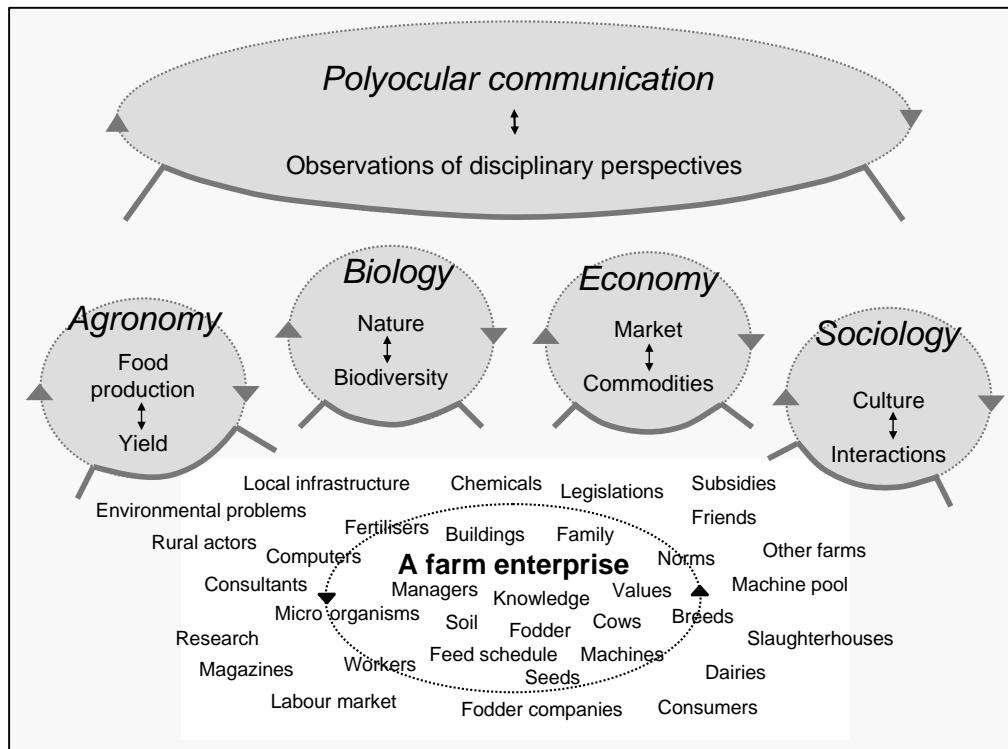


Figure 2: An example of polyocular communication based on second order observations of specialized disciplinary perspectives on a farm enterprise.

In conclusion, the polyocular approach to cross-disciplinary work that we have outlined here is neither a dis-integrated multidisciplinary approach, even though it does not seek to integrate the different disciplines involved, nor a formation of a new, integrated scientific perspective as an independent approach or discipline, even though it does bring a form of integration. This is not to say that polyocular observation and communication cannot lead to new and more integrated models of the research object, or that the involved scientific perspectives cannot learn from the process and transform their own approach accordingly. And indeed, such second order learning processes are bound to promote interactional expertise among the involved researchers. But the successful application of a polyocular approach does not depend on such changes. In fact, the approach depends on clear and distinct perspectives where the conditions for observation can be unambiguously described; and we must expect it to sometimes bring forth mutually excluding representations of the research object from different perspectives, or complementary phenomena in Bohr's sense.

Broadening the scope, we think there is a need for such second order observations, polyocular learning processes and reflexive expertise on cross-disciplinary work not only to handle the internal problems of the practice of cross-disciplinary research, but wherever different strands of science are used together to help solve complex problems and whenever different specialized scientific perspectives are brought in as expertise in democratic debates and societal decisions.



## 6. FUNDAMENTAL EPISTEMIC DIFFERENCES BETWEEN SCIENTIFIC PERSPECTIVES

Establishing second order perspectives on cross-disciplinary science is a necessary but not a sufficient condition for a productive understanding of perspectival disagreements. There is a need for an overview of how different scientific perspectives differ in epistemically relevant ways and what this means for their function. There are many possible ways to structure and categorize different types of science, and many have been suggested over time, but the perspectivist view of science that we apply here implies a different typology of science than the conventional.

Traditionally, science has been seen as divided into two or three main types, with the natural sciences on one side and the social and human sciences on the other, based on an ontological distinction between human and nature as that which is 'not human'. We don't think these traditional divisions, which are widely embedded in university structures and public perceptions, reflect the really fundamental differences between scientific perspectives very well. From a perspectivist viewpoint, differences that are based on the epistemological and methodological relation between the scientific perspective and its research world are more fundamental, and a better 'map' of these fundamental structures will provide a better basis for multiperspectival communication and cooperation. Below we briefly describe three basic distinctions between types of scientific perspectives (see also Alrøe and Kristensen 2002).

The first really fundamental distinction, following Habermas (1972, 302–310) is between different *cognitive interests* of science and the associated methodological differences. We do not follow Habermas' original triadic distinction, which somewhat mimics the traditional distinction between natural, human and social sciences. We distinguish between an *empirical* interest that produces descriptive and predictive knowledge referring to how the world is and probably will be and a *normative* interest that produces prescriptive knowledge on how the world should be and ideas about the good. The methodological distinctions based on cognitive interests carve the world of science differently than the traditional divisions: typical empirical sciences are physics, biology and most social sciences, typical normative sciences are logics, aesthetics and ethics. Following Peirce (1998: 51, 259), a third form of science is the hypothetical sciences, with a *hypothetical* interest in producing possible world structures. The hypothetical sciences include mathematics (the archetype of this form of science), counterfactual history, counterfactual modeling, scenario analysis, etc. Empirical, normative and hypothetical perspectives are all crucial and equally qualified ingredients in cross-disciplinary science targeted at complex real-world problems and social development.

The second fundamental methodological distinction is between *reductive science* focusing on parts and processes and *systems science* focusing on whole systems. This is the difference, in degree, between scientific perspectives with less reduced, real-world-like research worlds and perspectives with more reduced, laboratory-like research worlds (see Rouse 1987, 101). It generally distinguishes physics from ecology and social science, but the methodological distinction does not follow traditional disciplinary borders since there are more or less reductive perspectives within

physics, ecology and social science. Both reductive science and systems science relies on idealization in their theory building, but reductive science furthermore relies on the practical construction of observationally delimiting experiments (or thought experiments) and theoretical abstraction from complex system contexts.

There are great scientific advantages of working with highly reduced research worlds in terms of possibilities for experimental control and replication of results and accompanying powers of precision and generalization. This has often led to the, more or less explicit, conception that the systems sciences are necessarily less scientific than reductive sciences. But there are both benefits and costs of reduction: the powers of generalization come at the cost of impotence outside the constraining presumptions of the reduced research world. Faced with social phenomena, the laws of physics have only a limited power of explanation. One form of hegemony in cross-disciplinary science is thus the presumed superiority of reductive science over systems science, leading to the neglect of 'systems effects', 'emergent properties', 'the management factor', 'the role of motivation', etc. Conversely, there are methodological limits to systems science due to the heterogeneity of the more complex research entities, resulting in limited predictive powers. Furthermore there are ethical concerns due to the direct involvement in complex social and ecological systems, which the more reductive sciences are able to bracket out (but not avoid).

The third and last fundamental methodological distinction that we emphasize here is between *detached and involved sciences*. This is the less advertised difference between two positions of science in relation to its research world, the detached, observational and descriptive stance and the involved, experimental and intervening stance, in line with a pragmatist view of science. Some sciences, like astronomy, cosmology and the museum-based natural history of the past, are almost fully detached from their research object (this distinction does not concern the relation of science to its immediate objects, representations or models, but the relation to the dynamical research object). But most modern sciences are 'systemic sciences' that, in some way or another, influence the object that they study - if not directly through their scientific practices, then through the larger circles of research use. High energy physics constructs its elementary particles in giant colliders, chemistry invents new fancy molecules, conservation science conserves fragile ecosystems, health science cures diseases, anthropology brings new ideas into hitherto isolated cultures, and psychology changes the way people think about themselves. The mix and sequence of detached and involved stances is a key element in all scientific practice, in reductive as well as systems sciences. The detachment from the research object is a hallmark of science, as indicated by the importance of the conventional concept of objectivity, but this is only a conditional independence - conditional on the choices and actions needed to establish a detached stance.

The three fundamental distinctions can be used as dimensions to 'map' different kinds of scientific perspectives into a new typology of science. In the empirical sciences the map will include classificatory (detached, reductive), experimental (involved, reductive), historical (detached, systems), and developmental sciences (involved, systems). The classificatory and experimental approaches in the reductive sciences are closely connected, such as for instance the particle classifications and experiments of high energy physics, whereas the historical and developmental

perspectives in systems sciences are as different from each other as they are from very reductive sciences. We have experienced this marked but often unacknowledged difference between a detached, descriptive systems perspective and an involved, systems perspective that is oriented towards instigating change and transition, as a source of frustrating and unexplained disagreements in cross-disciplinary research.

A typology of science that is based on fundamental epistemic differences can facilitate the initiation and planning of cross-disciplinary research projects by offering recognition of very different types of science as equals, and by providing a place and function for different types of scientific perspectives. The specific differences can also be of help in the polyocular communication processes that we suggested above for cross-disciplinary science. For instance, logic may be recognized as a normative science that in this respect resembles aesthetics and ethics more than it does the hypothetical science of pure mathematics or the empirical science of physics; economics may be recognized as a relatively reductive science, which in this respect resembles physics more than it resembles other, less reductive social sciences; and conservation biology may be recognized as an involved science that resembles social management sciences more than the detached, descriptive science of natural history.

## 7. CONCLUSION

Science is differentiated and heterogeneous, and there is a need for different kinds of science to come together to help solve the complex problems of modern society. But cross-disciplinary science is not a trivial matter, and often the scientific communication across disciplines proves difficult and inadequate. This is not, in general, due to some kinds of science being more scientific than others. Empirical and normative research, reductive and systems research, involved and detached research can all be equally good science in a sufficiently general conception of science. We have argued that an increased awareness of the perspectival structure of science can facilitate scientific progress in the cross-disciplinary practice and use of science. To this end, we have pointed out the need for a new form of organizing science that includes separate, second order research processes that allow for polyocular observation and communication of specialized scientific perspectives, and sketched out how they can be realized. Making clear what perspectival disagreements to expect in cross-disciplinary science can help distinguish sound and productive scientific disagreements from disagreements due to bad science, dishonesty, spin and disciplinary hegemony, and thus help enable a new perspectivist approach to scientific knowledge. This paper is only onestep towards a philosophically and practically satisfying perspectivist framework for cross-disciplinary science, but we hope that it may lead to more philosophical, scientific and practical interest in the differences between scientific perspectives and what this means for the ability of science to investigate and help solve complex, real-world problems.

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