The paradox of scientific expertise
A perspectivist approach to knowledge asymmetries[1]

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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.

(Ortega y Gasset 1961 [1923]: 90f)

Abstract Modern societies depend on a growing production of scientific knowledge, which is based on the functional differentiation of science into still more specialised scientific disciplines and subdisciplines. This is the basis for the paradox of scientific expertise: The growth of science leads to a fragmentation of scientific expertise. To resolve this paradox, the present paper investigates three hypotheses: 1) All scientific knowledge is perspectival. 2) The perspectival structure of science leads to specific forms of knowledge asymmetries. 3) Such perspectival knowledge asymmetries must be handled through second order perspectives. We substantiate these hypotheses on the basis of a perspectivist philosophy of science grounded in Peircean semiotics and autopoietic systems theory. Perspectival knowledge asymmetries are an unavoidable and necessary part of the growth of scientific knowledge, and more awareness of this fact can help avoid blind and futile struggles between scientific perspectives, and direct efforts toward more appropriate ways of handling these fundamental knowledge asymmetries. Concretely, we show how different kinds of scientific knowledge, expertise, disagreement and learning can be correlated to the perspectival structure of science, and propose how polyocular communication based on (second order) observations of the observations made by specialised perspectives can be used to handle such perspectival knowledge asymmetries. This can help overcome the observed problems in carrying out cross-disciplinary research and in the collective use of different kinds of scientific expertise, and thereby make society better able to solve complex, real-world problems.

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1 Introduction

The ever-increasing production and usage of specialised knowledge is an indispensable condition for a knowledge society, but the mere production of specialised knowledge will not bring society to thrive and prosper; specialised knowledge needs to be communicated in such a way that it can be utilized, enter into democratic processes and decisions, and create societal value (Kastberg 2007). Kastberg states that “knowledge asymmetries” tend to emerge at a rate corresponding to the growth of knowledge, and that asymmetries “are no longer limited to the prototypical ones between social classes, between institutionalized social roles such as expert and ‘layman’ or political institutions of power such as ‘authority’ and ‘subject’. They also emerge within institutions themselves, between ‘experts’ with different agendas or of different persuasion, political or otherwise.” Furthermore, Kastberg suggests that knowledge asymmetries are an indicator that the knowledge potential of society is not synthesized and exploited as well as it could (ideally) have been, and that this is probably *the* issue for a knowledge society.

This is where the present paper takes its starting point. In Kastberg’s list of knowledge asymmetries there are not only different asymmetries, but different forms of asymmetries, which lead to different types of problems for society (though we do not presume that knowledge asymmetries are always problematic). The first type is ordinary *problems* of knowledge asymmetries, such as the differences between experts and laymen that are well known in the context of knowledge transfer (e.g. Ko et al. 2005). These problems may be difficult, but can be solved by the same measures that lead to the asymmetry: the layman must gain more knowledge to ‘catch up’ with the expert. The second type is *dilemmas,* asymmetries between authority and subject such as the power asymmetries between principals and agents in business exchanges (Sharma 1997). These problems cannot be resolved only by the measures of knowledge transfer or ‘learning what the other knows’, since this leads to the other horn of the dilemma, increasing the conflict that is involved. The third type of problems is *paradoxes*, which are connected with the burgeoning number of asymmetries between experts with different focus and different agendas that Kastberg (2007) pointed out. The paradox of this form of knowledge asymmetries is that the growth of knowledge in modern societies necessarily leads to fragmentation of knowledge. One cannot solve this kind of problems by way of the means and distinctions that constitute them, this will only reinforce the paradox; generating more knowledge will only increase the fragmentation of knowledge and create more asymmetries. To resolve a paradox you need to transgress the framework in which the paradox exists.

Based on pragmatic philosophy, we suggest that knowledge cannot, and should not, be separated from its basis in learning, cognition and inquiry (e.g. Dewey 1991 [1938], Alrøe 2000). The task for the present paper is therefore to analyse the cognitive and perspectival structure of scientific learning, as a basis for investigating *the paradox of scientific expertise*: that the growth of scientific knowledge leads to a fragmentation of scientific knowledge. We explore how the differentiation and specialisation of science and expertise leads to what we call *perspectival knowledge asymmetries*, and what this means for the communication of scientific knowledge, and we provide a framework to understand and handle such perspectival asymmetries and the resulting communication failures and scientific disagreements. The practical aspiration is that this pluralist and perspectivist (but not relativist) framework can serve as a helpful basis for working across disciplinary perspectives in science and for using different kinds of scientific expertise in society.

2 Background: The differentiation of scientific knowledge

According to the German sociologist Niklas Luhmann modern society is differentiated into independent, communicative function systems, such as the economic system, the political system, the legal system, the scientific system and the religious system. (Luhmann 1995, 1997: 707ff). The functionally differentiated systems are autopoietic and operationally closed through self-referential processes, and each system functions as a media for communication and forms a distinct perspective for observation in society. Parallel to the functional differentiation of society, there has been a differentiation of scientific disciplines (Stichweh 1992, Luhmann 1990, 446ff). Over time, science has differentiated from the unspecialised natural philosophy of the past into specialised disciplines like physics, biology, psychology, economics and sociology, and the disciplines are continuously differentiating into more specialised sub-disciplines or different ‘schools of thought.’ Furthermore, new disciplines are still being formed based on the academisation of professions in society like nursing, and the emergence of new technologies like biotechnology.

The differentiation of science is both an answer to the growing complexity of society and a source of new complexity that poses a challenge to the use of science and expertise 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 spanning the conventional distinctions between natural, social and human sciences. There has therefore been a rising call for cross-, multi-, inter- or transdisciplinary science as a tool to solve complex real-world problems, and increasing attention to the combined problem of the differentiation of science and the increasing complexity of the systemic challenges to modern societies (e.g. Pennington 2008, Pohl and Hirsch Hadorn 2008).

However, in the scientific literature there is also a growing recognition that cross-disciplinary cooperation is very difficult to perform successfully, in particular when the disciplines focus on very different aspects of the problem such as causal mechanics, flow processes, signs, values and social relations, or have very different agendas. This confirms our own experiences. The different disciplines involved do not agree on solutions to the problem, or even on what the problem is, and often they disagree on essential questions such as what is scientific and what is good science. In spite of good wills and many ambitions to the contrary, there are fundamental problems in communicating and mediating between different scientific disciplines, in particular where there is no common theoretical framework, and often the cooperation is constrained by the hegemony of one discipline at the cost of the others (e.g. 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.

Differentiation increases the complexity that science can handle overall, by reducing the observational complexity that each perspective must handle. This marginalisation of complexity makes differentiation a very powerful mechanism in science; the specialised perspectives offer consistent, effective and accurate knowledge in the context of their particular, delimited research world and refined tools of observation. This is the reason why a genuine reintegration that 'un-differentiates' scientific perspectives is, in general, 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).

On this background we claim that perspectival knowledge asymmetries are an unavoidable and necessary effect of the growth of scientific knowledge. And we suggest that the issue of perspectival knowledge asymmetries can be analyzed philosophically by investigating the perspectival nature of science. In the following three sections we will pose three hypotheses on the relation between scientific knowledge and perspectives, explain what they mean, and examine whether and how they can be substantiated.

The three hypotheses are:

1. All scientific knowledge is perspectival.
2. The perspectival structure of science leads to specific forms of knowledge asymmetries.
3. Such perspectival knowledge asymmetries must be handled through second order perspectives.

3 The perspectivist approach to science and cognition

The first hypothesis is that all scientific knowledge is perspectival. This means that scientific knowledge is always created in perspectives, and that a perspective is not only a means of observation, but also an 'apparatus for learning'. The differentiation of science is not only a differentiation of social systems, but also a cognitive or epistemic differentiation into specialised scientific perspectives, and the first step in our examination of this hypothesis is to investigate the science as an observation and learning process (cf. Alrøe 2000).

3.1 The cognitive and perspectivist view of science

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, Hales and Welshon 2000). 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 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, and for our ideas about scientific norms.

A discipline, or more often a subsystem or 'school' within a discipline, is an example of a scientific perspective. A scientific perspective harbours certain concepts, theories, classifications, instruments, problems, etc. that delimit and focus the observational field, and make possible the observation of certain phenomena and aspects (Figure 1). The defining characteristic is that a scientific perspective is an autopoietic system that is reproduced and refined through internal processes (Alrøe 2000). Tacit knowledge in form of implicit values, embodied knowledge and practices are part of what makes up a scientific perspective (cf. Collins 2010), 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.

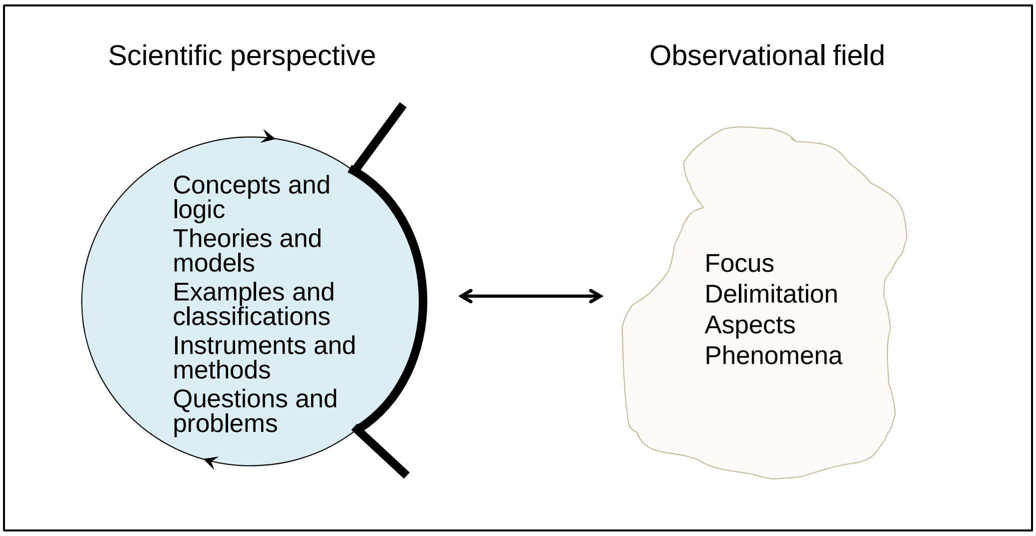

Figure 1. A scientific perspective is characterised by specific concepts, instruments, problems, etc., which delimit and focus the observational field.

The perspectivist view of science implies that there are many scientific truths about any complex problem, and from a philosophy of science point of view the question is not how to select the correct one, but how to appreciate and use the non-unifiable plurality of partial knowledges (Longino 2006). All ontological claims are interwoven with the epistemological conditions for observation and the built-in values and norms that apply in the perspective where it is grounded (Alrøe and Kristensen 2002). Truths are perspectival, but 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-learning character of science is manifest in the foundational methodological ideas, open inquiry, systematic observation and critical approach, which establish the excellence of science in the production of knowledge.

3.2 The semiotic understanding of scientific perspectives

The perspectivist approach described here builds on a thoroughly semiotic understanding of a scientific perspective (and in this respect it goes beyond Giere's scientific perspectivism). 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 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 is something that stands to somebody, the interpretant, for something, the object, in some respect or capacity. And in his later works he stresses the semiotic relation between the *immediate object* as the sign represents it and the *dynamical object* or really efficient object that the immediate object refers to (e.g. Peirce 1998 [1908]: 482, CP: 8.343).

Figure 2 illustrates the fundamental elements of scientific observation in form of a semiotic model of a scientific perspective observing (what it calls) a dairy cow. The model builds on Peirce's theory of semiotics, the later development within biosemiotics (e.g. Uexküll 1982, Hoffmeyer 1997), and Niels Bohr's epistemological lesson from quantum physics: "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." (Bohr 1931, cited in Favrholdt 1999: 521).

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 or point at 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. The representations of science can be tested by establishing observational situations (systematic observations, interventions, experiments) where the dynamical objects may 'kick back' (cf. the causal interactions in Figure 2). But a dynamical object has a surplus of possibilities for observation, and any immediate object is, by necessity, a reduction based on a certain perspective.

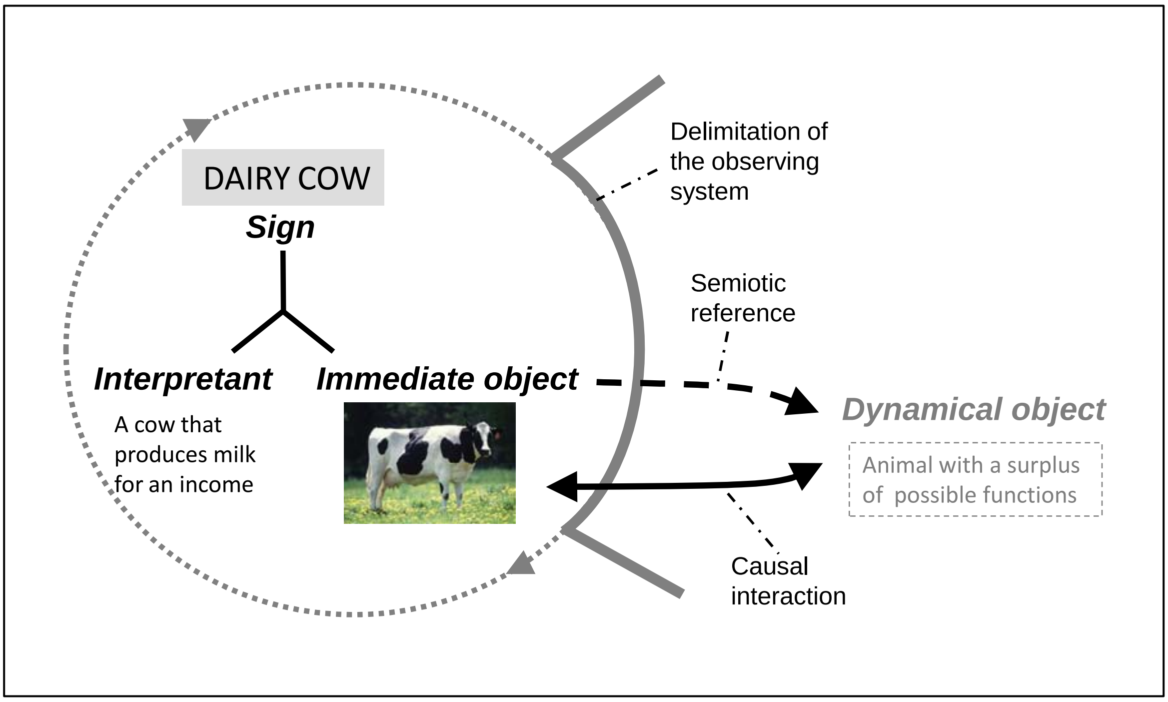

Figure 2. A semiotic model of a scientific perspective observing (what it calls) a dairy cow, showing the distinction between immediate and dynamical object and three key conditions for observation: the separation of the observer from the observed, the semiotic reference to the dynamical object, and the causal interaction with the dynamical object (modified from Alrøe 2000).

3.3 Communication across scientific perspectives

By definition, it is a condition for cross-disciplinary science that the different perspectives observe the same thing, so to say, and the model in Figure 2 therefore 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, categories, models, etc.).

The first layer is thus that the specialised languages of scientific disciplines and schools are not generally shared. Some perspectives are closely connected and share methods, models, theories and classifications, others are widely different and closed to each other. 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. 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 specialised, 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.

The 'rock bottom' basis for cross-perspectival communication is the 'common, everyday language' (though this is still conditioned on common daily lives and therefore prone to cultural differences). *The communicative paradox of cross-disciplinary science* is thus that the common language is not sufficiently precise to handle the immediate objects of specialised perspectives, but more precise and specialised 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 specialisation of scientific perspectives reinforces this key condition.

The second layer of the problem is that since the same dynamical object will be observed and represented in different ways in different perspectives, it is not possible a priori to determine whether different scientific perspectives observe the same dynamical object, even though this is the presumed. Built into the conditions for observation there is a linkage between ways of interacting with the world and ways of representing the world, which makes it difficult, and in principle impossible, to share a common reference to a dynamical object across perspectives.

Obviously, these deep-seated problems of communication do not mean that one cannot perform cross-disciplinary work, but they do mean that cross-disciplinary research is not a trivial matter.

4 The perspectival structure of scientific knowledge and disagreement

In the previous section we elaborated a fundamentally perspectival model of scientific observation and cognition that substantiated the hypothesis that all scientific knowledge is perspectival. The second hypothesis in this paper is that the perspectival structure of science leads to specific forms of knowledge asymmetries. This means that we are to expect different types of scientific knowledge, expertise, disagreement, and learning depending on how they relate to the perspectival structure.

Scientific disagreements are productive knowledge asymmetries, because they contribute to testing and developing scientific ideas. 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.

In the following section we look at a few well known philosophical and sociological approaches to scientific disagreement and expertise, which we suggest can be understood as elements in a perspectivist understanding of science.

4.1 Some well-known approaches to asymmetries in scientific knowledge and expertise

Thomas Kuhn (1996 [1969]), in his Postscript to The Structure of Scientific Revolutions, suggests the term 'disciplinary matrix' as a more precise term for 'paradigm' as it is used in his highly influential book. In this sense, Kuhn's paradigms are examples of perspectives in our understanding. The disciplinary matrix includes symbolic generalizations (theories and laws), metaphysical paradigms (models, analogies, and metaphors), values, and exemplars (concrete problem-solutions), and these are similar to the elements of a scientific perspective that we have outlined. 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 single scientific field, whereas we in this paper focus on the synchronic disagreements and knowledge asymmetries across disciplines and perspectives in line with Maruyama (1974). The Kuhnian tradition generally 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 the reason why it is in principle impossible and in practice more or less difficult to communicate across perspectives, is because each observational perspective has its own phenomenal world – its own representation of the world entailed in theories, models, concepts, classifications and examples. This is a deeper reason than language, tied into the specific observational apparatus and the specific forms of interaction provided by it. Despite the common features, our synchronic and explicitly perspectivist approach leads to other questions and other answers than Kuhn's.

Harry 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 in the present paper. Collins distinguishes between *contributory expertise*, possessed by those who participate in everyday activities and development of the field (and who therefore possess the necessary tacit knowledge to contribute, cf. Collins 2010), and *interactional expertise*, which is characteristic of those who can communicate fully with the field, based solely on explicit knowledge, but who are not able to actually take part in and contribute to the field. There is in general some degree of interactional expertise among scientists (especially within each of the main areas of science), which helps make the cross-disciplinary cooperation not impossible, but merely difficult. But in general, it takes a long time to obtain interactional expertise in a new field, and due to the differentiation and specialisation 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. Neither can the 'trading zones' of Galison (1997: 803ff), which refer to scientific communities and not individuals, because the focus here is on language and not on scientific perspectives as a whole.

Thomas Gieryn (1983) investigates the actual delimitations of science from non-science that specific sciences use in the pursuit of their professional goals. 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.

4.2 A perspectivist framework for types of knowledge, expertise, disagreement and learning

The perspectivist understanding of science provides a common framework for discussing the existing approaches to handling different forms of asymmetries in knowledge and learning.

In Table 1 (line 1-3) the paradigms and scientific revolutions of Kuhn, Collins' contributory and interactional expertise, and the boundary-work of Gieryn are placed in a perspectival framework together with a number of other differences between types of scientific knowledge, disagreement and learning. For example, the kinds of disagreement to expect within a perspective are the normal converging disagreements of science (line 1); when a perspective is being transgressed, we expect to see diverging disagreements that may transform or split up the perspective (line 2); whereas forms of unconnected ‘blind’ disagreements and communication failures are to expected between different perspectives (line 3).

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

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

This linkage of existing approaches to a comprehensive perspectivist framework may be helpful in itself, and it substantiates the hypothesis that the perspectival structure of science leads to specific forms of knowledge asymmetries. 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 form of knowledge, disagreement and learning shows up: second order perspectives based on observation of observation (Table 1: line 4); an idea that builds on constructivist and perspectivist approaches in second order cybernetics and social systems theory (Foerster 1984, Luhmann 1993). A second order perspective can potentially transcend the incommensurability of perspectives that are blind to each other (bearing in mind, however, the significance of tacit knowledge). Perspectival disagreement and reflexive expertise are thus based on the handling of contextual knowledge from first order perspectives in a second order learning process, which we call polyocular communication. In the next section we describe how second order perspectives can be used to handle perspectival knowledge asymmetries.

5 Second order observation and polyocular communication

The third and final hypothesis in this paper is that the perspectival asymmetries in Table 1, line 3 and the ensuing problems in the communication of scientific knowledge must be handled through second order perspectives. This means that there is a need for new forms of scientific perspectives and learning processes that aim to observe the world by observing the observations of a range of specialised perspectives. A key question is then how these second order perspectives may look like, where they can be realised, and how they may be applied to the problems of knowledge asymmetry. In the following we will show how the hypothesis can be implemented in cross-disciplinary research and discuss the broader implications for the paradox of scientific expertise.

5.1 The case of cross-disciplinary research

In the first part of this paper we indicated the problems of carrying out crossdisciplinary research due to problems with asymmetries in communicating across different scientific perspectives with different immediate objects in form of theories, models, taxonomies and entities; uncertainties as to whether those immediate objects actually refer to a shared (dynamical) research object; and, possibly, 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.

Figure 3 shows an example of such a problematic crossdisciplinary research project with four different specialised disciplinary perspectives on a farm enterprise (ignoring the second order perspective for now). In this (obviously simplified) example, 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 way to try to ensure the co-ordination of such crossdisciplinary research projects is to require that all the disciplines work on the same geographical study area. But a shared study area cannot ensure that the different perspectives observe the same dynamical object. Each discipline has its own immediate objects, and one cannot force a disciplinary perspective to observe what it is not able to observe. In the example above, the biological perspective will look for nature quality in the small biotopes in hedges and ditches, where biodiversity in form of rare and threatened species may be found, and the agronomic perspective will look in the fields, where biodiversity in form of robust and plentiful species may support soil fertility and crop growth (cf. Tybirk et al. 2004).

Another way to ensure co-ordination is to require that the disciplines establish a common pool of data, but this is a misguided method, since data are always observations from a certain scientific perspective. Treating data as context-free observations is therefore prone to generate misunderstandings and loss of insight; for instance all data may be interpreted from the perspective of one hegemonic discipline.

A range of different approaches have been suggested to, in some more fundamental way, re-unite science or (re-)integrate scientific disciplines in cross-disciplinary work, such as systems theory, complex modelling and various holistic frameworks. These efforts are often commendable, but we don't think any of them provide a general approach to solve the fundamental problems of using very different kinds of science in an integrated way to solve complex real-world problems. Some approaches ignore the power of differentiation and pluralism in science, and seek to re-unite science by promoting selected specialised perspectives as fundamental and sufficient in themselves, in a reductionist and hegemonic way. Others introduce a new holistic perspective, which ignores the specialised perspectives and the possibility of other holistic perspectives, and therefore is itself a kind of reductionism. For instance, Pohl and Hirsch Hadorn (2008) consider 'systems thinking' a constituting conceptual basis of an overall transdisciplinary research perspective. But there are a range of different systems frameworks; 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 (see e.g. Ramage and Shipp 2009, Midgley 2003). The choice of systems framework is not innocent.

A disciplinary integration proper may be a relevant target in specific cases where the objective is to create an integrated perspective on a technological field such as nanotechnology (Johnson 2009). Here, a new, separate perspective is established, where specific theories, models, values, logic and exemplars are selected and the research field determined. However, the idea of transdisciplinary integration of a first order, without the selections and delimitations inherent in the formation of a new specialised scientific perspective, is incongruous. As a general solution, first order (re-)integration of specialised scientific disciplines is neither possible, nor desirable. In order to establish a general framework for solving real-world problems through crossdisciplinary research, we need to look at second order perspectives and how they may be implemented.

5.2 Separate, second order perspectives for polyocular communication

But where, then, may such second order perspectives be placed, what do they look like, and what is their function? First of all, we argue that there is a need for a separate, second order research process which observes the first order observations in their perspectival context (as illustrated in Figure 3). The specialised disciplines are generally not able to both reproduce and refine their own perspective **and** carry out second order observations of the different perspectives that are employed in cross-disciplinary work (including their own). It is fine to utilize and extend the interactional expertise, in Collins' sense, that each researcher brings into the work, but while such individual cross-cutting expertise is helpful, it is not enough to underpin cross-disciplinary work.

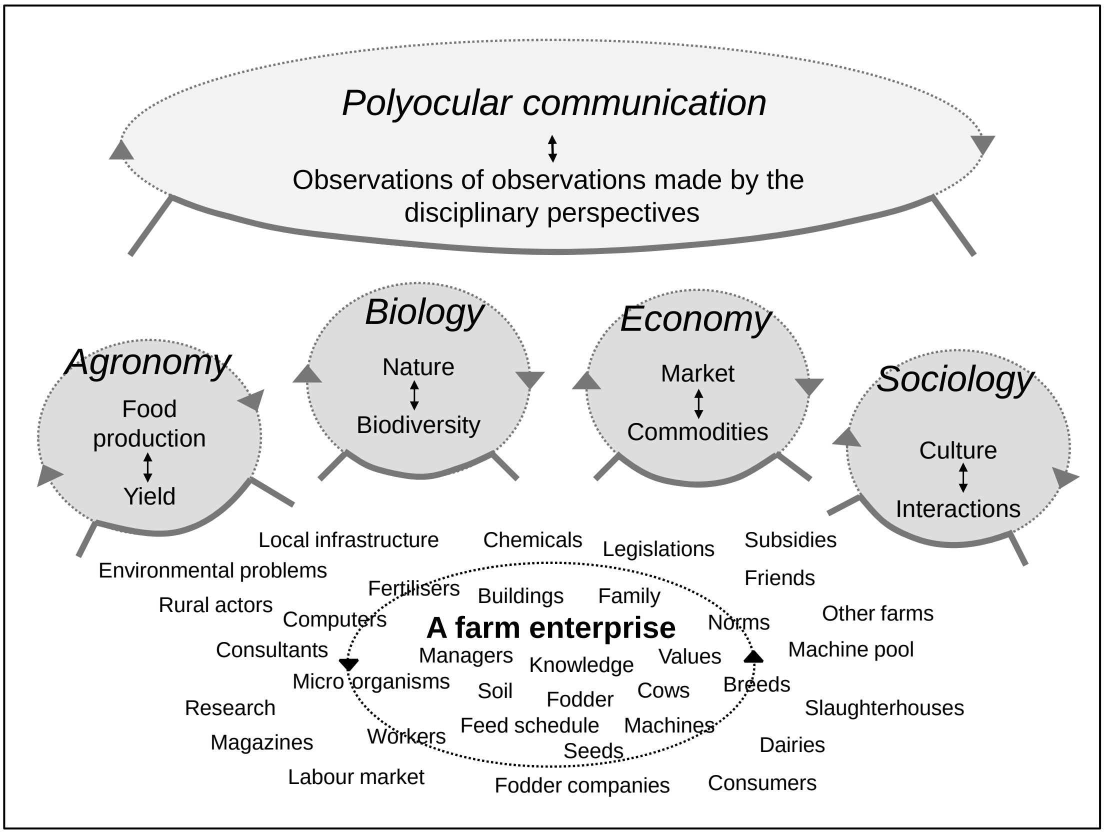

Figure 3. An example of a second order perspective on a farm enterprise based on (second order) observations of the observations of specialised disciplinary perspectives, and thus providing a basis for polyocular communication and learning (modified from Noe et al. 2008).

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*. That is, a second order perspective does not directly observe the research object; it performs second order observations of observations made by the different first order scientific perspectives involved, and in this sense it manifests a multi-perspectival or polyocular view of the object, which can unfold a multidimensional space of understanding. The key activities in the second order research process is thus to 1) illuminate the involved perspectives and their conditions for observation, communication and learning, in order to 2) enable a contextualised communication of observations and analyses, which exposes how they are influenced by their perspectival and cognitive context and thus helps overcome perspectival knowledge asymmetries, and thereby 3) provide for a polyocular communication of the research results. The second order perspective is on the one hand a scientific perspective like any other, residing in a research group or a wider research community, but on the other hand it operates at a meta-level compared to first order scientific perspectives, and does not directly observe the research object.

There is a need for separate resources to perform such second order research processes in practice. 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. This does not mean that this process would necessarily be carried out by other researchers. It may well involve researchers from the different disciplinary perspectives, with the aim to utilize their intimate experience with their own perspective and to increase their awareness of the imprint that their perspective leaves on their observations, analyses and conclusions.

6 Conclusions and prospects

In conclusion, we need to resolve the fundamental paradox that the growth of science leads to a fragmentation of scientific expertise and growing knowledge asymmetries, in order to be able to establish a general framework for solving real-world problems through crossdisciplinary research; and to resolve the paradox we need to transgress the first order structure of scientific perspectives and incorporate second order perspectives.

Scientific knowledge is perspectival, and scientific perspectives can provide consistent, effective and precise knowledge, but only on the basis of differentiation and specialisation. Perspectival knowledge asymmetries are therefore an unavoidable and necessary part of the growth of scientific knowledge. More awareness of this fact can help avoid futile struggles between scientific perspectives, and direct efforts toward more appropriate ways of handling these fundamental knowledge asymmetries, such as the second order, polyocular approach to cross-disciplinary research that we have outlined here. This goes beyond the typical non-integrated multidisciplinary approach, but it does not seek to integrate the different disciplines involved, nor form a new, integrated scientific perspective, even though it does bring some kind of integration in form of polyocular communication.

This is not to say that polyocular 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 context of observation can be unambiguously described (taking due account of tacit knowledge). At the same time, polyocular communication can only happen with reference to a shared dynamic object that, it is agreed, can be observed in different ways; and we must expect it to sometimes bring forth mutually excluding representations of the research object (complementary phenomena in Niels Bohr’s sense).

Second order perspectives in some form can be of use not only in crossdisciplinary science, but wherever very different strands of scientific knowledge are used to help solve complex problems in society, and whenever different types of scientific expertise are used in education, business development, democratic debate and political decisions. Polyocular learning processes could help us overcome the paradox of scientific expertise by enabling us to handle perspectival knowledge asymmetries, and thus contribute to a more reflexive expertise and a less fragmented basis for democratic processes and societal decisions.

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