Second-Order Science of Interdisciplinary Research

A Polyocular Framework for Wicked Problems

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> Context • The problems that are most in need of interdisciplinary collaboration are "wicked problems," such as food crises, climate change mitigation, and sustainable development, with many relevant aspects, disagreement on what the problem is, and contradicting solutions. Such complex problems both require and challenge interdisciplinarity. **> Problem** • The conventional methods of interdisciplinary research fall short in the case of wicked problems because they remain first-order science. Our aim is to present workable methods and research designs for doing second-order science in domains where there are many different scientific knowledges on any complex problem. **> Method** • We synthesize and elaborate a framework for second-order science in interdisciplinary research based on a number of earlier publications, experiences from large interdisciplinary research projects, and a perspectivist theory of science. **> Results** • The second-order polyocular framework for interdisciplinary research is characterized by five principles. Second-order science of interdisciplinary research must: 1. draw on the observations of first-order perspectives, 2. address a shared dynamical object, 3. establish a shared problem, 4. rely on first-order perspectives to see themselves as perspectives, and 5. be based on other rules than first-order research. **> Implications** • The perspectivist insights of second-order science provide a new way of understanding interdisciplinary research that leads to new polyocular methods and research designs. It also points to more reflexive ways of dealing with scientific expertise in democratic processes. The main challenge is that this is a paradigmatic shift, which demands that the involved disciplines, at least to some degree, subscribe to a perspectivist view. **> Constructivist content** • Our perspectivist approach to science is based on the second-order cybernetics and systems theories of von Foerster, Maruyama, Maturana & Varela, and Luhmann, coupled with embodied theories of cognition and semiotics as a general theory of meaning from von Uexküll and Peirce. **> Key words** • **Perspectivism, semiotics, complex phenomena, social systems theory, differentiation of science, perspectival knowledge asymmetries.**

"Perspective is one of the component parts of reality. Far from being a disturbance of its fabric, it is its organizing element." (Ortega y Gasset 1961: 90)

"…a scientific perspectivism does not degenerate into a silly relativism." (Giere 2006a: 13)

Introduction

« 1 » The science of sustainable agriculture is an example of a science that does not have its own scientific perspective. It depends on interdisciplinary collaboration between many different specialized disciplines such as plant physiology, organic chemistry, soil physics, environmental science, ecology, engineering, statistics, business economics, and sociology; and it must always be prepared to include new perspectives (recently, e.g., climate change, marketing, and social systems) due to the influence of a large variety of stakeholders and the structural and semantic developments within agriculture, food, the environment, and society at large.

« 2 » The problems that are most in need of interdisciplinary cooperation are "wicked problems" such as food crises, climate change mitigation, and other resilience and sustainability problems (Klein 2004). Wicked problems are complex problems where there is disagreement on what the problem actually is, there are different interests and different perspectives involved that frame the problem differently, and proposed solutions often contradict each other (Rittel & Webber 1973).

« 3 » Bryan Norton emphasizes that with respect to wicked problems we face an analytic void:

> "For those frustrated with the lack of progress in many areas of environmental protection, Rittel & Webber's work suggested a powerful explanatory hypothesis: Complex environmental problems cannot be comprehended within any of the accepted disciplinary models available in the academy or in discourses on public interest and policy. This failure is not a matter of inadequate practice, but a matter of principle." (Norton 2012: 449)

« 4 » This means that the wicked problems of today both require and challenge interdisciplinarity. "The real-world research problems that scientists address rarely arise within orderly disciplinary categories, and

neither do their solutions" (Palmer 2001: vii). There is a need for unsimple truths (Mitchell 2009). But the conventional ideas and methods of interdisciplinary research fall short in the case of wicked problems. It is well-known that there are fundamental problems of communicating across disciplines and carrying out cross-disciplinary[1] research in practice (e.g., Miller et al. 2008; Bracken & Oughton 2006; Harrison, Massey & Richards 2008; Noe, Alrøe & Langvad 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.

« 5 » Interdisciplinary studies have generally been developed as complementary to the development of specialized disciplines, based on the need to understand complex issues, answer complex questions and solve complex problems (e.g., Klein 1996, 2004; Moran 2010; Repko 2012). But the epistemological aspects are rarely considered within the field where we might expect it, the philosophy of science, though philosophers of science have recently begun to focus more on the interaction of epistemic and social practices (Krishnan 2009: 19).

« 6 » We argue that the existing approaches to cross-disciplinary research are problematic because they remain first-order. This can be in the form of independent and uncoordinated research perspectives on a given problem, a patchwork of coordinated but still separate research perspectives, a synthesis through the lens of a hegemonic discipline (such as, often, economics), or a synthesis based on a new integrated discipline (such as first-order system theories). Accordingly, we work to overcome the challenge to interdisciplinary science and the conundrum of doing cross-disciplinary research by way of a thorough perspectivist understanding of science that operates with both first-order and second-order observation. Our aims in this paper are to present a second-order polyocular framework for doing interdisciplinary research on wicked problems, and to describe workable methods and research designs for this second-order science.

« 7 » The proposed methodologies are empirically grounded in our participation in a range of large interdisciplinary research projects. The paper is based on fifteen years of research and a number of earlier publications that propose perspectivist analyses and second-order research methodologies in the domain of agriculture, food and environment.

« 8 » In the following, we first present the perspectivist view of science and lay out the principles of polyocular research. Then we illustrate and discuss the implications of the polyocular framework for cross-disciplinary research, and for practice. Finally, we discuss future directions and sum up our conclusions.

The perspectivist view of science

« 9 » Perspectivism has had a long but marginal presence in philosophy, with roots in Kant and Nietzsche (e.g., Palmquist 1993; Anderson 1998; Hales & Welshon 2000). In a perspectivist view, science is observer-dependent to the core, and we see a growing recognition in science studies that all scientific knowledge is perspectival; i.e., that the context established by a scientific discipline is decisive for the kind of observations that can be made by that discipline. This development is connected to the development of radical constructivism, which suggests that we, including science, actively construct our world and that deeper insights in the knowledge constructions of science can be gained from cognitive sciences (Riegler 2001).

« 10 » The perspectivist view of science that we present here is a radicalization of the existing perspectivist, cognitive approach to science by way of a Luhmannian social systems approach to science as a communicative system (Alrøe 2000; Alrøe & Noe 2011).

« 11 » The cognitive understanding of science, where the focus is on scientific models and representation rather than theories and truth, has been growing and developing in philosophy of science over the last few decades (e.g., Giere 1988; Cartwright 1999; Fraassen 2008), and it has recently been developed into an explicitly perspectival philosophy of science, labelled "scientific perspectivism," by Ronald Giere (2006a). This implies that all scientific knowledge is perspectival, given that scientific knowledge is created in scientific perspectives, and that scientific representations and measurement outcomes are perspectival (Fraassen 2008: 8, 183). With regard to interdisciplinary science, the cognitive perspectivist approach has led to a pluralist view of science, a "perspectival pluralism" (Giere 2006b), where different perspectives highlight different aspects while ignoring others (Giere 1999: 28), and maintaining a plurality of perspectives promotes scientific progress (Longino 2006):

> "A thorough-going disciplinary pluralism […] suggests that sometimes the perspectives don't fit nicely together on the same plane: they overlap or conflict or cannot both be held at the same time, and yet you need both of them." (Kellert 2006: 225)

The perspectivist view of science implies that there are many scientific truths about any complex problem, and the question is not how to select the correct one, but how to appreciate and use the "nonunifiable plurality of partial knowledges" (Longino 2006: 127). But no real perspectivist methodology has so far been developed to handle the challenge of interdisciplinary science in this line of work.

« 12 » In the social systems approach to science, the specialization of disciplines is studied on the basis of an evolutionary understanding of science as a communicative social system that undergoes specialization through functional differentiation (Luhmann 1990; Stichweh 1992). "The sciences are diverging and there is no reason to think that any kind of convergence will ever occur" (Suppes 1978: 6). In this scenario there is no hope of Habermasian consensus communication and integration between the disciplines; specialized communication is basically incommensurable (whereas communication between different disciplines using our general, daily language is always possible, though fallible), and strong interdisciplinary communica-

1| We use "cross-disciplinary" as a generic term to encompass the various forms of multi-, inter- and transdisciplinary cooperation between scientific disciplines on a common issue. Often "interdisciplinary" is used as the general term, but this can be confusing since interdisciplinary is also one of the different forms of interdisciplinarity (see Klein 2010 for a taxonomy of interdisciplinarity).

tion is only possible by co-creating a new, shared genre of discourse (Holbrook 2013). From this evolutionary, communicative view of science, *the paradox of scientific expertise* becomes evident: that the growth of scientific knowledge leads to a fragmentation of scientific knowledge (Alrøe & Noe 2011). The differentiation and specialization of science and expertise results in what we call perspectival knowledge asymmetries: different scientific perspectives see complex matters differently, and these differences cannot, and should not, be merged.

« 13 » The perspectivist view of science that we advocate sees different research approaches (including disciplines, sub-disciplines, and more specific research approaches, as well as "schools of thought," Kuhnian paradigms[2], and Lakatosian research programs[3]) as perspectives for observing the world (Giere 2006a; Alrøe & Noe 2011). Different scientific perspectives are characterized by different methods, instruments of observation and entire experimental arrangements, different concepts, categories, and theories, and different concerns and questions, as well as implicit values and tacit embodied knowledge and practices (cf. Collins 2010). All of this determines what a specific scientific perspective can observe and what it cannot observe.

« 14 » Thomas Kuhn's paradigms are examples of scientific perspectives in our understanding, according to his "Postscript 1969" to the highly influential "The Structure of Scientific Revolutions," where he suggests the term "disciplinary matrix" as a more precise term for "paradigm" (Kuhn 1996). But where Kuhn and the Kuhnian tradition generally have a historical, diachronic focus on how paradigms may shift within a single scientific field (scientific revolutions), we focus on the synchronic differences across disciplines and perspectives in line with Magoroh Maruyama (1974).

« 15 » The concept of perspective, as we use it, originates from investigations of science as an observing system that is directed at learning (Alrøe 2000; Alrøe & Kristensen 2002; Alrøe & Noe 2012). It draws on the one hand on an analogy with organisms, focusing on the characteristics of the sensory or observational apparatus, and the interactive aspect of observation, such as experiments. In this, we build on the autopoiesis of living systems (Maturana & Varela 1980), the field of embodied cognition (e.g., Varela, Thompson & Rosch 1991), and especially on Jakob von Uexküll (1982), who investigated the different phenomenal worlds (Umwelten) that animals have due to their different sensory and cognitive apparatuses, and the later development of biosemiotics, of which he is now considered the founding father (Sebeok 2001). The connection to biosemiotics suggests a theoretical grounding of the perspectivist understanding of science in Peircean semiotics, which we will unfold in the next section.

« 16 » On the other hand, our conception of perspective draws on an analogy with autopoietic social systems, such as organizations and firms (Luhmann 1995, Andersen 2003), who observe their environment and themselves, based on operational closure and blind spots. "The blind spot of observation exists because of the fact that observation cannot see that it cannot see that which it cannot see" (Andersen 2003: 65). Niklas Luhmann very clearly operates with a perspectivist approach (though he does not call it that),[4] laying out the premises of observation of observation of social communicative systems, following Heinz von Foerster's (1981, 2003) second-order cybernetics.

« 17 » In short, *a perspective is that which determines what an observer can observe and what it cannot observe*. The perspectives that we are mainly concerned with in this article are scientific perspectives, and the observers we look at are social systems, the observing systems of science. Observation is of course a key notion,[5] and it is treated in more detail in the next section (see Figure 1). The term "polyocular" has been constructed in analogy with binocular and monocular (Maruyama 1974), and here "ocular" is used in nearly the same sense as perspective, but with a built-in social systems theoretical meaning in the form of the "blind spot" of an eye (Latin: *oculus*).

« 18 » A *scientific perspective* is thus an autopoietic system that is reproduced and refined through internal processes (Alrøe 2000), and which produces its own methods, theories and instruments for observation, and thereby also its own inputs (data).

« 19 » On the basis of this perspectivist understanding of science, we describe a second-order, polyocular framework for interdisciplinary research. The key point is that interdisciplinary cooperation must be based on an awareness and recognition of the interacting disciplines first and foremost as perspectives – not as social groups, not as discourses, not as "sciences working on different domains."

Five principles for polyocular research

« 20 » The second-order, polyocular framework for interdisciplinary research can be characterized by five interrelated but separate principles.

Principle 1 – Observing observations

« 21 » The first principle is grounded in the perspectivist view of science, which sees different research approaches as perspectives for observing the world (Giere 2006a; Alrøe & Noe 2011).

« 22 » Science has no access to the world or "that which is observed," except through observations (including interactions), as we shall explore in Principle 2.[6] All scientific observations belong to a scientific perspective, and the observations of a perspective include that perspective. The perspective is part of what an "observation" is. In his philosophy of quantum physics, Niels Bohr advocated that the very word *phenomenon* be applied exclusively to refer to the observations obtained under specific circumstances, including an account of the whole experimental arrangement (Bohr 1985: 27).

2| See "Postscript 1969" in Kuhn (1996).

3| See Lakatos (1978: 47ff).

4| Doubts have even been raised about whether Luhmann's standpoint was properly constructivist (Riegler & Scholl 2012), but his critical arguments are also considered a help in clarifying radical constructivist epistemology (Scholl 2012).

5| Alrøe & Noe (2012) investigate different constructivist conceptions of "observation" and the corresponding notion of "environment" or "world."

6| A more thorough analysis of constructivist approaches to the relation between world/environment and observation can be found in Alrøe & Noe (2012).

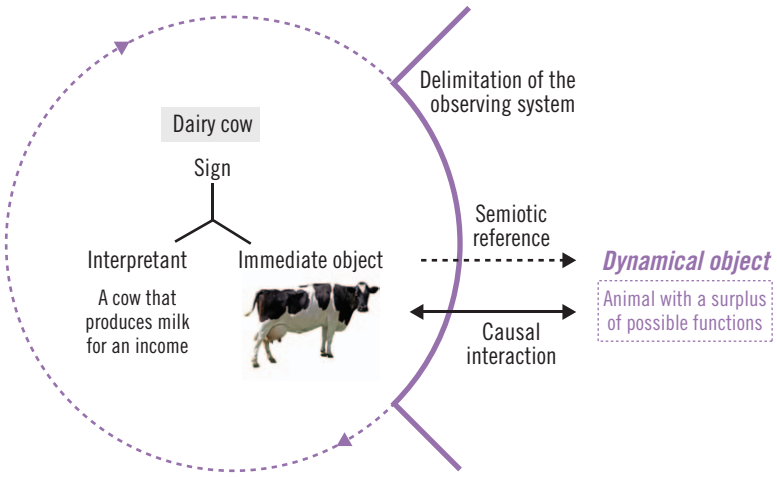

Figure 1 • The semiotic model of a scientific perspective, with three key conditions for observation (Alrøe & Noe 2011: 157). The dotted circle with arrows symbolizes that the perspective is an autopoietic social system, and the eye symbol indicates that it is also an observing system.

We advocate taking this as a general principle, based on the perspectivist view of science, and taking *complex phenomenon* to mean a phenomenon where multiple perspectives are needed to give an unambiguous description (*sensu* Bohr, see Favrholdt 1999: xlix; Alrøe & Kristensen 2002) of the phenomenon, and where the degree of complexity depends on the number and variety of perspectives needed. (This definition of complexity is very different from e.g., ideas about complexity building on statistical complexity, such as Ladyman, Lambert & Wiesner 2013).

« 23 » The only access for interdisciplinary science to studying a complex problem or complex phenomenon is through the (first-order) scientific perspectives that enter into the study. Or in other words, there is no all-encompassing scientific perspective. Aspirations in science to develop a deeper understanding of a complex problem can only be realized through specialization, which often involves a differentiation into separate specialized scientific perspectives, with their own semantics and means of observation. This differentiation of science has happened throughout the history of science (Stichweh 1992; Weingart 2010). Any attempt to reunite the fragmented sciences into a unitary science, such as the various systems sciences, either loses the powers of the specialized sciences or forms a new specialized perspective, or both.[7] As autopoietic systems, scientific perspectives are closed to each other, they are each other's environment. Second-order perspectives can only access the findings of first-order perspectives by observing them.

« 24 » It follows that the second-order science of interdisciplinary research must observe the *observations* of first-order perspectives; not the social systems as in a sociology of science study, and not the "results" as they are often presented in a de-contextualized form, but the results in a form where it is clear how they are constructed from observations through the cognitive and analytical tools of the scientific perspective.

7| This is not to say that integrating theories cannot be helpful and attractive, nor that integration in science is not a continuous aim (e.g., in the "unity of science" movement), and a sometimes very successful strategy (e.g., in molecular biology and nanoscience). But a recombination of relatively proximate fields will itself develop into another specialized field, such as molecular biology, and does not as such contradict the general process of differentiation in science; and the combinations of disciplines into applied research centers, such as nanoscience centers, with corresponding journals and funding programs, are compatible with, and depend on, the continuous independent development of disciplines (Riegler 2005; Weingart 2010).

Perspectival knowledge must always be of the form "seen from this or that perspective, such and such is the case." Only in this rich form can the observations enter into a polyocular communication.

« 25 » In headline form, the first principle is: Second-order science of interdisciplinary research must draw on the observations of first-order perspectives, because:

- all observations include the observer,[8] and only perspectives can offer observations;
- research approaches should be understood as perspectives, and scientific knowledge depends on the observing perspective;
- there is no holistic scientific perspective;
- first-order perspectives are the only access to observing complex problems.

Principle 2 – A shared dynamical object

« 26 » What observers see depends on how they see it, and "the same thing" may therefore be seen in different ways. But how, then, can observers determine whether they are looking at the same thing? This seemingly simple question is in fact a deep philosophical question that requires a comprehensive semiotic understanding that is able to address how observations relate to that which is observed.

« 27 » Interdisciplinary research requires a shared research object; this is part of the very definition of what interdisciplinary research is. But different scientific perspectives have different names and specialized concepts for the objects they observe; this is part of what makes them a specialized perspective. This means that we cannot be sure that we look at the same thing, even though we think we do. A farm from an economic perspective (a "farm enterprise") is a quite different entity from a farm from a sociological or an environmental perspective. A cow from an accounting perspective is quite different from a cow from a veterinary or a landscape conservation perspective. In a perspectivist, semiotic understanding, we can analyze this in the form of signs (Figure 1).

8| By "all observations include the observer" we mean that every observation is made from somewhere, from a certain perspective (Alrøe & Kristensen 2002).

According to Peirce a sign, or representamen, is something that stands to somebody for something in some respect or capacity.

> "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)

« 28 » Peirce's distinction between the dynamical and the immediate object to some degree corresponds to Kant's distinction between phenomena, things-for-us, and noumena – things-in-themselves (Alrøe & Noe 2011, 2012). Some say they differ in that the Kantian Ding an Sich is unknowable as it is in itself, whereas the Peircean thing in itself, the dynamical object, is essentially representable and knowable as a limiting case,[9] as truth is a limiting case for Peirce. But in order to approach the dynamical object, we have to acquire what Peirce calls collateral experience of the supposed same dynamical object (Hardwick & Cook 1977: 83).

« 29 » There is no position from where we can observe the dynamical object as it is in itself. (This is of course very different from a traditional realist conception, which takes the thing in itself as the immediately present object.)[10] Every perspective adds to the number of immediate objects that refer to, point at, or hint at the dynamical object. The immediate objects all refer to a dynamical object, but none of them are the same as the dynamical object in itself. What rescues the prospects for interdisciplinary research is that dynamical objects "strike back" in our interaction with them, and that this causal interaction is part of what makes up the observations of scientific perspectives (Figure 1). This relational nature of observation is also what enables scientific perspectives to make changes in the world that correspond to their specialized observations. However, the existence of a shared dynamical object can never be presumed, but must be established and synchronized in each case.

« 30 » For cross-disciplinary research efforts, the questions of a shared dynamical research object and collateral experience are particularly difficult because they concern complex phenomena; that is, phenomena that can only be established by the collaborative effort of multiple specialized perspectives, and which refer to complex dynamical objects.

« 31 » In headline form, the second principle is: Second-order science of interdisciplinary research must address a shared dynamical object (sensu Peirce), because:

- interdisciplinary research requires a shared research object;
- there is no position from where we can observe the "thing-in-itself";
- each perspective has its own immediate object.

Principle 3 – A shared problem

« 32 » The second principle focused on the cognitive problem for interdisciplinary research to ensure that the involved perspectives observe the same thing. But why bother? Generally, scientific efforts are driven by either internal or external questions, or some combination thereof. Internal questions rarely motivate interdisciplinary cooperation; interdisciplinary research is mostly motivated by external questions, often formulated as "problems" for society or certain groups in society. Therefore it is a separate requirement for interdisciplinary research to establish a shared problem. Whereas having a shared dynamical object is the enabling factor for interdisciplinary research, having a shared problem is the motivating factor that calls for cooperative work (see also the section "Phases of polyocular research").

« 33 » An important societal problem is an irritation, like an itch, a pain, or a general discomfort is an irritation for a person; this societal irritation we call a dynamical problem in analogy to the dynamical object and dynamical interpretant of Peirce. The problem is felt in different ways by different stakeholders, who occupy different perspectives, and is not necessarily perceived as one and the same problem. Science is needed to establish these perceived problems as a shared problem. On the other hand, shared problems need to be formulated in a shared language, which is connected to our daily relations with the world, in line with Bohr's view that there is no alternative to ordinary language for unambiguous description (Favrholdt 1999: xxxvii). The use of ordinary language is necessary for scientific communication to couple with the experiences, feelings, and motivations of stakeholders in relation to wicked problems.

« 34 » The perspectival nature of scientific disciplines leads to the problem of problem making. Different disciplines necessarily see different types of immediate problems due to their different methods and instruments of observation, different concepts, categories and theories, and different concerns, questions and values. Each research perspective forms its own version of what the problem is, and this is part of what makes the problem "wicked." The paradox that has to be resolved in the face of wicked problems is thus that it takes a concerted effort to establish a shared problem, and it takes a shared problem to establish a concerted effort.

« 35 » Part of why having a shared problem is an essential motivation for interdisciplinary research is that faced with a shared problem there is a need for a shared solution. (This is science taken as the key to societal learning, complex problem solving, and creative transformation.) But as we said, different scientific perspectives see different immediate problems, and therefore they provide different solutions that often contradict each other.

« 36 » The shared problem of interdisciplinary research is therefore only really possible in a second-order framework. Wicked problems, such as the current sustainability crises, can only be adequately addressed in a second-order problem solving process, where the shared problem can be formulated in a polyocular way that is sufficiently flexible to incorporate the different versions of the problem that scientific perspectives offer, and that is thereby able to offer a common or coordinated solution.

« 37 » In headline form, the third principle is: *Second-order science of interdisciplinary research must establish a shared problem*, because:

9| See Joseph Ransdell's "On the use and abuse of the immediate/dynamical object distinction." Retrieved from http://www.cspeirce.com/menu/library/aboutcsp/ransdell/useabuse.htm on 5 May 2014.

10| See also Winfried Nöth (2011) on the relation between the Peircean semiotic idea that representation is always incomplete and radical constructivism.

- the shared problem is the driving force for doing interdisciplinary research;
- each research perspective forms its own version of what the problem is (and this is part of what makes the problem "wicked");
- having a shared problem is a precondition for being able to offer a common or coordinated solution.

Principle 4 – Perspectives must see themselves as perspectives

« 38 » One of the typical problems of interdisciplinary research is a lack of respect for other disciplines. The reason can be a hegemonic feeling of being the better science; that other disciplines are generally less scientific and their results therefore less dependable; or that other disciplines are generally too restricted by their theoretical framework and their results therefore less useful. Or the reason can be a more specific assessment that since the other disciplines come up with other explanations and other solutions in this case where we really know what we are doing, they must be wrong.

« 39 » The perspectivist view of science recognizes that (1) there are many different scientific perspectives on any complex issue, (2) these different perspectives can all contribute valuable observations, and (3) no single scientific discipline can provide adequate solutions to complex problems, and therefore it is a strong tool for founding mutual respect between even very different scientific perspectives.

« 40 » In fact, the second-order science of interdisciplinary research is *dependent* on the ability of the scientific disciplines involved to see themselves as perspectives, through self-observation, and acknowledge that they are one among many different perspectives. First, the very process of second-order observation requires that first-order observations are made available for observation. The second-order science we describe is not just a science of sciences, such as sociology of science, but a polyocular framework based on scientific observations of scientific observations. And scientific observations cannot be observed without the willing and skillful cooperation of the scientific perspective making those observations.

« 41 » Second, establishing a shared dynamical object, which is required for interdisciplinary research to qualify as interdisciplinary research at all, depends on the involved first-order scientific perspectives being able to distinguish between their immediate objects and the dynamical objects that they refer to. There is no way in which an individual perspective can gain access to observe directly the difference between the immediate and the dynamical object. This distinction is only accessible as a theoretical construct that can be actualized in relation to other perspectives, through polyocular communication.

« 42 » Third, to help resolve a wicked problem in a constructive way, first-order perspectives must participate in the polyocular communication about how their different immediate problems can contribute to the determination of a shared, polyocular problem. To do that, each scientific perspective needs to recognize itself as a perspective on the world among other valid and valuable perspectives. This can be difficult because researchers are usually not trained to think of their approaches as perspectives. And the first-order perspectives need to enter into a form of partnership where they promise not certain observations, but certain promises of observations by way of their perspective (cf. Andersen 2008: 4).

« 43 » In headline form, the fourth principle is: *Second-order science of interdisciplinary research must rely on first-order perspectives to see themselves as perspectives*, because:

- this is necessary to make first-order perspectives volunteer their observations as objects for second-order observation;
- this is necessary to determine the dynamical object that is referred to by the immediate objects of the first-order perspectives;
- in order to observe wicked problems, the first-order perspectives must participate in the polyocular communication about the shared problem.

Principle 5 – Different rules for second-order science

« 44 » Polyocular cognition is the form of cognition needed to observe and understand complex phenomena. There is no holistic first-order perspective; no all-encompassing perspective that can observe the whole of a complex phenomenon as a replacement for the many specialized perspectives, and there is no complete cognition except as an ideal limiting case (*sensu* Peirce).

« 45 » Polyocular cognition is based on observations of first-order observations, but it is not itself merely another first-order perspective. This does not mean that the polyocular second-order perspective is a privileged perspective; it is not a new gods-eye perspective. Perspectivism must also be applied to itself. The second-order scientific perspective is itself an autopoietic social system, it forms its own organization, and there can be different second-order perspectives on a complex phenomenon with different ideas about what the relevant first-order perspectives are and how the phenomenon is to be delimited.

« 46 » Polyocular cognition relies on collaboration with first-order perspectives, who must volunteer their observations for observation, as Principle 4 states, and offer self-descriptions. The first-order perspectives can only make their observations available for (second-order) observation in form of communication, and polyocular cognition is therefore also dependent on polyocular communication. The polyocular communication must be able to handle first-order observations in the context of their perspectives (as observer-dependent knowledge).

« 47 » Monocular perspectives operate with simple truth claims and work to sharpen their observational abilities, whereas polyocular perspectives operate with conditional truths, truths that only hold in the context of their perspective. From a radical constructivist view, there is no justification for an exclusive claim of objectivity (Riegler 2001). The criterion of scientific excellence for polyocular research is not objectivity as the ideal of context-free knowledge, but reflexive objectivity, which implies that the cognitive context must be observed and included in the scientific communication (Alrøe & Kristensen 2002; Alrøe & Noe 2008). And this requires that the scientific perspective is self-reflexive, that it becomes aware of its own state and role as a perspective by way of self-observation or other second-order observation. Whereas disciplinary communication is about providing consistent, efficient and precise knowledge in the context of a sharply delimited research world, poly-

ocular communication is about extending a multidimensional space of understanding of the dynamical object under study.

« 48 » The polyocular framework can reveal new observational dimensions that cannot be observed from any first-order perspective, like binocular vision can reveal depth or distance. Gregory Bateson (1979: Chapter 3) described the elaborate anatomical structures behind binocular vision, and how the difference between the information from the two eyes creates an extra dimension to seeing: information about depth, which is of a different logical type. Maruyama posed the more radical idea of polyocular vision, across cultures, professions, or disciplines, where the different views are seen as complementary in a polyocular logics and "the differentials between the different views enable us to add new dimensions to our perception" (Maruyama 1974: 187). He criticized previous interdisciplinary waves and suggested immersion in other disciplines as a way to enable polyocular vision and avoid "subunderstanding" due to the dimension reduction and blind spots of a single discipline (Maruyama 2004).

« 49 » Polyocular vision is therefore not merely a question of gathering collateral experience. It is a way of approaching an in-depth multidimensional understanding of complex phenomena and wicked problems that requires synchronization and spatial coordination (in the timeframes and spaces employed) of the involved perspectives (this is developed more in the section "Phases of polyocular research").

« 50 » In headline form, the fifth principle is: *Second-order science of interdisciplinary research must be based on other rules than first-order research*, because:

- polyocular cognition is based on observations of first-order observations, it is not merely another first-order perspective;
- perspectives can only make their observations available for (second-order) observation in form of communication;
- polyocular communication must be able to handle first-order observations in the context of their perspectives (as observer-dependent knowledge);
- while disciplinary communication is about providing consistent, efficient, and precise knowledge in the context of a sharply delimited research world, polyocular communication is about extending a multidimensional space of understanding that has its own requirements for synchronization and spatial coordination.

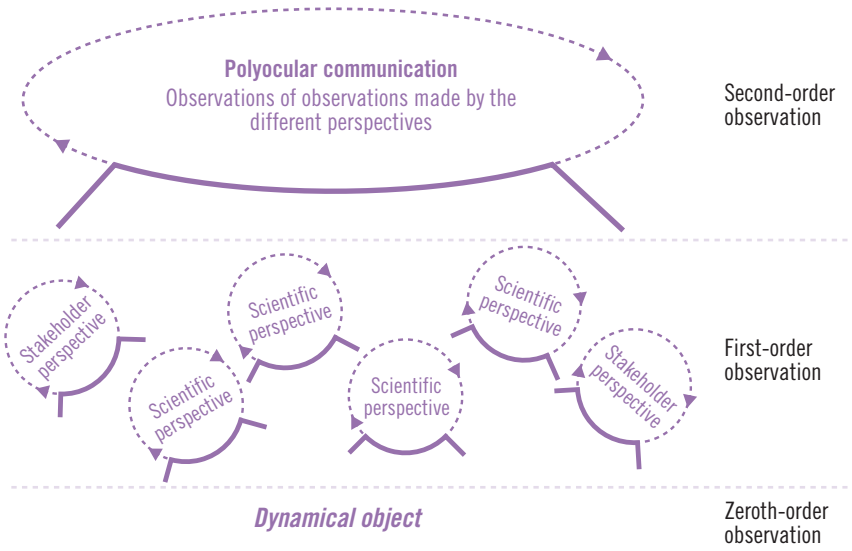

Figure 2 • The polyocular framework for cross-disciplinary research, indicating three levels of observation (modified from Alrøe & Noe 2008 and Noe, Alrøe & Langvad 2008). Scientific perspectives are typically disciplines or subdisciplines; stakeholder perspectives can be key stakeholder associations, industries, governmental institutions, or NGOs. As in Figure 1, the dotted circles with arrows represent autopoietic social systems, and the eye symbol indicates that they are observing systems.

Implications for research

« 51 » In this section we describe the implications of the polyocular framework for organizing and executing cross-disciplinary research. We present research methods and designs for doing second-order science in interdisciplinary research on the basis of the above principles as well as our experiences and experiments within a range of interdisciplinary agroecological research projects. As a simple example, we have employed workshop setups where discussions have been carried out first in uniperspectival groups (participants having the same perspective) and then in multiperspectival groups where participant with different perspectives are mixed.

« 52 » In a full-blown polyocular research project, there are three levels of observation and three pivotal phases of carrying out research (Figure 2 and Table 1). The middle level of observation is the familiar first-order observation in research execution. The top level is second-order observation; this is the observation of observations made from different scientific perspectives, including the self-observations of first-order perspectives (Luhmann 2000: 62f). First-order observation is necessarily unobservable to itself, and only becomes observable in second-order observation, which can place first-order observations in the context of the perspective that has determined the observations. On the bottom level we have the dynamical objects that are presumed and hinted at in scientific observation, but which cannot directly enter into scientific communication. We characterize this as zeroth-order observation because, whereas second-order observation is the level of observation necessary for an observation to be seen as an observation, zeroth-order observation is the level of observation necessary for an observation to be considered

an observation, though it cannot be seen. If there is no reference, however feeble, to "the dynamical object, or really efficient but not immediately present object," as Peirce puts it, there is no observation.

« 53 » We have previously suggested second-order polyocular understandings of multifunctional farming (Noe, Alrøe & Langvad 2008), organic agriculture (Alrøe & Noe 2008), sustainability (Noe & Alrøe 2014a) and regulation (Noe & Alrøe 2014b). The research project MultiTrust[11] was organized as a multi-perspectival approach that worked explicitly with the different aspects of multicriteria assessment of food system sustainability exposed by the involved scientific perspectives in order to facilitate interdisciplinary research and enable the participation of a diverse range of organic actors and stakeholders in the project. At the onset of the project, all the involved partners produced self-descriptions of their own perspective on the problem of making, communicating, and implementing sustainability assessments. An example of polyocular work in this project is a study on motivation in sustainability assessment based on three research perspectives – an economic, a psychosocial, and a semiotically-based relational perspective – resulting in a multiperspectival research article (Læssøe et al. 2014). The polyocular work was difficult and unfamiliar for the researchers involved, but the experiment showed that such work can bring out a new level of understanding that could not be obtained otherwise. An added benefit was that this polyocular work encouraged mutual respect and insight between the research groups. Another example from this project on polyocular understanding is a scientific paper that investigates the role of values in different scientific perspectives on sustainability assessments, without presuming a unitary conclusion is possible (Thorsøe, Alrøe & Noe 2014).

« 54 » The current EU project HealthyGrowth[12] is from start to finish organized around a polyocular framework: in-depth case studies of mid-scale organic values-based food chains are carried out in nine participating countries, followed by six comparative analyses based on different research perspectives and a multi-perspectival (polyocular) meta-analysis. This is done to obtain a nuanced and coherent understanding of the underlying mechanisms and principles for a healthy growth of organic value chains. The project is still ongoing, but the preliminary experiences with polyocular research processes are similar to that in MultiTrust.

« 55 » Experiences from these research projects show that the main challenge in implementing the polyocular framework is that it involves a paradigmatic shift compared to conventional thinking about multi-, inter-, and transdisciplinary research. Multidisciplinary research, which involves coordinated but independent research perspectives on a given problem, does not ensure a shared dynamical object and therefore often fails to provide a shared solution. Interdisciplinary research, which involves a patchwork of cooperating but still separate research perspectives, is often synthesized through the lens of a dominating or hegemonic discipline (e.g., Noe, Alrøe & Langvad 2008, Riegler 2005), and thus lacks the means to make fair use of the variety of first-order perspectives. Transdisciplinary research generally provides a synthesis based on the transformation of the involved disciplines into a new theoretically integrated discipline or the formation of such a discipline in between the existing disciplines; this results in a new first-order perspective, which can be fine, but it is neither possible nor desirable as a general approach to cross-disciplinary research on wicked problems, which involves disciplines from across the human, social, and natural sciences.

« 56 » The polyocular framework involves a paradigmatic shift because all the conventional approaches to cross-disciplinary research remain first-order, whereas the perspectivist understanding of science leads to a second-order science of interdisciplinary research that is qualitatively different. This is a shift to what may be labelled as "post-disciplinary research" in the sense of Karl Müller (2014): research that operates on two different levels – a normal science level and a meta-level – and which thereby transcends the conventional disciplinary framework of science.

« 57 » Figure 2 includes scientific perspectives, with their special powers of observation, as well as other stakeholder perspectives. Including stakeholder perspectives corresponds to moving from interdisciplinary research to transdisciplinary research[13], where stakeholder participation is considered a vital part of research. Stakeholders, or actors, can have their own perspectives on a complex problem, which are important to include in cross-disciplinary research. Stakeholder perspectives may be as manifest as scientific perspectives, if they reside in an organizational structure where their perspective on the world is produced and reproduced as an important part of the autopoiesis of the organization (in accordance with social systems theory, see Luhmann 1995, Andersen 2003), such as, e.g., many NGOs. They may be closely connected to particular scientific perspectives or be very different and based on specific forms of practices. In any case, they differ from scientific perspectives in not necessarily being guided by the norms of scientific inquiry in their observations. But they may provide interactions through actor practices, which are very difficult to achieve in scientific observation. And they may suggest perspectives that are not currently found in science.

Three phases of polyocular research

« 58 » Based on our experiences and experiments with polyocular research methods, Table 1 sums up three pivotal phases of polyocular research. They are modelled on the familiar pragmatic problem-solving model of science, but incorporate the five principles of second-order science of interdisciplinary research. In actual research there may well be iterations across these phases, such as going back to reassess the shared problem after some amount of re-

11| "Multicriteria assessment and communication of effects of organic food systems," 2011–2014, funded by the Danish Ministry of Food, see http://www.multitrust.org

12| "Healthy growth: From niche to volume with integrity and trust," 2013–2016, funded by the European Commission's 7th Framework Programme, see http://www.healthygrowth.eu

13| Transdisciplinary research in a different sense than the integrative sense above, namely interdisciplinary research that incorporates stakeholders in the research process (e.g., Klein 2010).

search studies, making a first attempt at a multidimensional understanding to help synchronize the different specialized research efforts, or instigating changes and going back for a new round of observations to check the results. But this does not change the essential character of these three phases. In Table 1, the three phases are boldly named "shared problem," "shared research" and "shared solution," but, as the observant reader will suspect, these titles must be taken with a grain of salt; taken literally they suggest a naïve idea of the options for doing common research across different disciplines, which we have argued against above.

Phases	1 – Shared problem	2 – Shared research	3 – Shared solution
2nd order	Polyocular problem making (addressing the wicked problem)	Polyocular synchronization (addressing the mosaic of phenomena)	Polyocular understanding (addressing the plethora of solutions)
1st order	Perspectival descriptions (self-descriptions, immediate problems)	Perspectival observations (immediate objects)	Perspectival implications (immediate solutions)
0th order	Determining a shared dynamical research object	Unfolding dynamical objects	Instigating dynamical change and transition

Table 1 • The three pivotal phases of a polyocular research project, indicating the research elements involved at each of the three levels of observation.

Phase 1 – Establishing a shared problem

« 59 » The first phase of polyocular research addresses the problem of problem-making (e.g., when faced with a "wicked problem"). As a preparatory step for this and for the whole research endeavor, each perspective involved must make a self-description. The description should include the key interests (concerns, problems, questions, goals, values) in relation to the suggested cross-disciplinary research effort and the main ways of observing and tackling the suggested problem (practices, examples, and classifications, concepts and logic, theories and models, methods, and instruments). Obviously, this phase runs into the paradox that it takes a concerted effort to establish a shared problem, and it takes a shared problem to establish a concerted effort (see "Principle 3 – A shared problem"). There is probably a need for an iterative process of making perspectival descriptions of immediate problems to resolve this paradox and create a shared polyocular problem. An important aim of this first phase of polyocular research is to move towards determining a shared dynamical object – a shared research object that can establish the collaborative research effort as interdisciplinary research proper.

Phase 2 – Ensuring shared research

« 60 » The second phase of polyocular research addresses the mosaic of phenomena offered by the involved perspectives as they carry out their research observations, which unfold dynamic objects by constructing and refining immediate objects (see Principle 2). Eventually, the studies are to contribute to a polyocular understanding of the shared research object. The challenges and problems of cross-disciplinary research are deeply rooted in the differentiation of disciplines that operate in different codes, delimitations, timescales, and spatial scales (Noe, Alrøe & Langvad 2008). Therefore there is a need to synchronize the research efforts of the perspectives involved, using, among other things, the perspectival self-descriptions from Phase 1, so that the findings can enter into a multidimensional polyocular understanding in an unambiguous way. But how to do this?

« 61 » The problem of communicating across disciplinary boundaries is recognized as a key problem in interdisciplinary research (Bracken & Oughton 2006; Harrison, Massey & Richards 2008; Riegler 2005), and the languages of science are continuously diverging into new specialized languages (Suppes 1978). No doubt "interactional expertise" in the sense of Harry Collins (2004), as the ability to communicate in the language of another perspective, plays some practical role in most interdisciplinary collaboration. And the amount of interactional expertise is probably decisive for the degree of interdisciplinary integration possible. But the notion of polyocular communication differs from ideas about interdisciplinary communication such as interactional expertise and "trading zones" (Collins, Evans & Gorman 2007; Galison 1997: 803 ff). These focus exclusively on the possibility of communication between first-order perspectives, whereas the polyocular approach acknowledges that first-order communication is not adequate as a general methodological approach to interdisciplinary communication (Alrøe & Noe 2011).

« 62 » There is no common, first-order language that can be used in interdisciplinary research. Using the semantics of e.g., economics or general systems theory as a common language leads to hegemony, and blinds the communication to the insights of other perspectives. The "shared research" can only be shared and synchronized in a very specific, but crucial sense: that of second-order polyocular communication, which is the only generally applicable form of common communication in interdisciplinary research. Polyocular communication builds on self-observation, perspectival knowledges and grounding in a concrete wicked problem.

« 63 » First of all, the findings need to be communicated in a form that incorporates a description of the observational conditions that enabled the findings, in line with Bohr's definition of phenomena. As noted in Principle 5, the scientific hallmark for polyocular research is the inclusion of the cognitive context in scientific communication. This perspectival communication is necessary for polyocular communication to avoid blind disagreement and miscommunication and enable coherence where there seems to be insurmountable contradiction between complementary perspectives (Alrøe & Noe 2011).

« 64 » The task of producing perspectival knowledge relies on self-observation and the second-order observation of other perspectives to see how the perspectival context determines what the perspective is

able to observe and not able to observe. By contextualizing observations, specialized communication can enter into (second-order) cross-disciplinary communication without becoming ambiguous due to shifting contexts – it is transformed into generally understandable, and commensurable, communication.

« 65 » Finally, polyocular communication always takes place in relation to something concrete, here the specific wicked problem. The reference to the shared problem and a shared dynamical research object, which is made possible by contextualizing observations, enables the different scientific perspectives to synchronize their research efforts and communications.

Phase 3 – Enabling a shared solution

« 66 » The third phase of polyocular research addresses the plethora of solutions offered by the perspectives involved. Polyocular understanding – the multidimensional space of understanding that can be established through polyocular observation and communication of the perspectival observations in Phase 2 – forms the basis for a shared or coordinated effort to instigating change and transformation. An important precondition is that, just as any observation that is part of inquiry must be made through an established perspective, any deliberate approach to instigate change and transformation must take place through an established perspective. Such perspectives can be very different, from practice-based stakeholder perspectives to high-tech scientific perspectives, but there is no way around perspectives to attempt changing dynamical objects intelligently.

« 67 » There are particular requirements for polyocular research projects to gain support in competition with conventional disciplinary or multidisciplinary research. Firstly, the second-order science framework needs to be recognized as scientifically valid and valuable. Secondly, the procedures for project application and evaluation need to take into account the special features of second-order science, for instance that problem-making and synchronization of the scientific perspectives are part of the research project and not something that can be done in advance.

Stakeholder participation

« 68 » As noted earlier, the paradoxical challenge of solving (or alleviating) wicked problems is that they can only be observed and addressed through particular specialized perspectives, but a common solution is needed. Polyocular research and polyocular understanding is a way to resolve this paradox, but polyocular research also poses distinct challenges with regard to stakeholder participation.

« 69 » When dealing with wicked problems, participation of stakeholders is needed from Phase 1, since the establishment of a shared problem must also be based on how the problem is experienced outside of science. And stakeholder participation is equally needed in Phase 3, since a shared solution cannot be found and instigated based on scientific perspectives alone, but needs to involve the relevant practices in society. In general, stakeholder involvement in cross-disciplinary research is faced with the two-fold challenge of how the varied and fragmented knowledge of science is made accessible for stakeholders and how the many different interests and perspectives of stakeholders are made accessible for the scientific endeavors. The polyocular framework outlined in Figure 2 treats scientific and stakeholder perspectives in parallel, allowing polyocular observation of all the perspectives. By being based on ordinary language and by contextualizing specialized observations, polyocular communication can become accessible for stakeholders, political decision makers and scientific experts alike.

Implications for practice

« 70 » In the previous sections we have sketched the implications of the perspectivist view for research, but what are the implications for practice? On the one hand the second-order science framework for interdisciplinary research is a way forward to address the wicked problems of society, remedying the shortcomings of the existing scientific approaches. On the other hand, polyocular answers may be seen as a new challenge for making decisions based on science. There is strong competition with monocular answers, which offer an extensive reduction of complexity and simple truths. But of course this reduction comes at the expense of the big picture. However, the competition between basing decisions on few or many perspectives is nothing new; the news is that the polyocular framework provides a coordinated and intelligible perspectival understanding based on multiple perspectives.

« 71 » Apart from the direct implications for cross-disciplinary research proper, the perspectivist view of science also has implications for the use of science in societal decisions on complex problems, such as reviews (assessment and synthesis) of disciplinary knowledges from a problem-oriented perspective in policy or practice, or the direct use of a range of specialized knowledges from across the sciences in such decision processes. Space does not allow us to develop these implications here, but we think the polyocular framework can in many ways be adopted to this broader use of science.

« 72 » More generally, the perspectivist view of science has implications for how scientific expertise is dealt with in democratic processes. There is a peculiarly strong idea that "economics," or "science" in a narrow sense, has the right and the only answer to the complex problems of society. Selected scientific experts, or monocular expert commissions (often consisting of neoclassical economists), are commonly used to underpin certain political decisions. The uniperspectival basis enables the argument that the decision is "necessary" by eschewing the broader range of perspectives that might suggest other possible decisions. And with a careful selection of scientific experts, most political positions can claim to be based on a firm scientific grounding. Even though it is evident that different scientific experts give different advice, the scientification of politics is still a strong trend. If the construction occasionally breaks down, the blame is usually placed on the experts being political and in essence unscientific. That may of course be the case, but in general scientific experts can be expected to give different advice, based on a perspectivist view of science, and we have to let go of the idea of that there is one common rationality. The idea of polyocular understanding would

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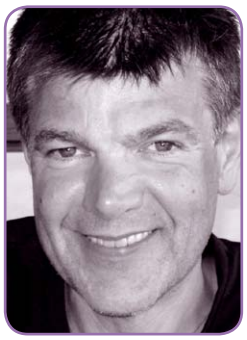

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provide a very different scientific input to democratic debate and political decision making, and polyocular inquiry and learning could help us resolve the paradox of scientific expertise by enabling us to better handle perspectival knowledge differences.

Future directions

« 73 » In the present paper we have described the polyocular methodological framework and introduced the theoretical background necessary to substantiate this approach. But the perspectivist approach to interdisciplinary science raises a range of other fundamental issues that would be interesting to pursue in the future. Here we will sketch three such issues: ontology, incommensurability, and complementarity.

« 74 » The perspectivist approach to science has decisive implications for the discussions on realism, constructivism, and relativism (Giere 2006a: 4–20; Alrøe & Noe 2012), and Ronald Giere has given substantial arguments to show that "perspectival realism is as much realism as science can provide" (Giere 2006a: 20). In connection with this general discussion, there are also distinct implications for the concept of ontology. The perspectivist approach starts with observation, and thereby primarily with an epistemological and constructivist understanding. This does not mean that there is no need for an ontological foundation. But this foundation must be in the form of a "working ontology," in accordance with the fallibilist nature of science (Müller 2007; Noe & Alrøe 2003). The foundational working ontologies of scientific perspectives are indispensable and must be discussed as intensely as realists discuss "reality." But it remains to be investigated how the working ontologies of different scientific perspectives in interdisciplinary research can be processed in the framework of second-order science to form a multidimensional working ontology as the basis for polyocular understanding.

« 75 » Kuhn's views on the incommensurability between consecutive paradigms correspond to problems in integrating and communicating across perspectives in cross-disciplinary work (Alrøe & Noe 2011). But where Kuhn's approach was linguistic, talking of the untranslatability between different paradigms (Kuhn 2000, Chen 1997), the perspectivist approach points out that the reason why it is 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. The perspectival understanding of incommensurability 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 diachronic and historical approach, and this can provide a new angle on the contested issue of incommensurability. The barriers of communication between scientific perspectives are not lifted, but transcended through a separate process of polyocular communication that includes observations on what the different perspectives can and cannot observe.

« 76 » As we have argued, polyocular communication can only happen with reference to a shared dynamic object that is observed through different scientific perspectives. We must expect this sometimes to bring forth mutually excluding representations of the research object, that is, complementary phenomena in Niels Bohr's sense.

Bohr and others have pointed out that there are complementary phenomena in a range of other areas of science beyond quantum physics (e.g., Favrholdt 1999; Folse 1985), but very little has been done to investigate what complementarity means for cross-disciplinary research (Alrøe & Noe 2011). Some of the tasks for such an investigation are to develop a typology of forms of complementary phenomena, and use this typology to identify forms of complementarity between scientific perspectives and their relation to the general conditions for observation. Based on this, an analysis can be made of what role complementarity plays in cross-disciplinary research, how scientific disagreements may be connected to the complementarity of scientific perspectives, and what this means for the options to produce unambiguous descriptions of complex phenomena through second-order science.

Conclusion

« 77 » The paradoxical challenge of solving (or alleviating) wicked problems is that they can only be observed and addressed through particular perspectives, but a common solution is needed. Polyocular research is a way to transgress this paradox, and in this paper we have outlined a polyocular framework for wicked problems that forms a new basis for planning and performing interdisciplinary research. We have identified five principles for second-order science of interdisciplinary research. It must:

1 | draw on the observations of first-order perspectives,
2 | address a shared dynamical object,
3 | establish a shared problem,
4 | rely on first-order perspectives to see themselves as perspectives, and
5 | be based on other rules than first-order research.

« 78 » The polyocular framework can be characterized in a three by three matrix of observational levels and research phases. The observational levels are the level of familiar research work (first-order observation), the level of dynamical objects that are hinted at in scientific observation, but which cannot directly enter into scientific communication (zeroth-order observation), and the level of polyocular communication based on observations of observations made by different scientific perspectives (second-order observation). The three research phases follow the conventional problem-solving approach, and at the level of second-order observation, the three phases are polyocular problem making, polyocular synchronization, and polyocular understanding. Polyocular vision can reveal new observational dimensions that cannot be observed from any first-order perspective, like binocular vision can reveal depth or distance. Solving (or alleviating) complex problems requires the participation of stakeholders. In Phase one they are needed to establish a shared problem, and in Phase three they are equally needed to find and instigate a shared solution. The twofold challenge of making the fragmented knowledge of science accessible to stakeholders and making the diverse interests and perspectives of stakeholders accessible to science can only be overcome by making both scientific and stakeholder perspectives explicit, and by grounding the polyocular communication on ordinary language that is accessible to the diversity of stakeholders and scientific experts. The idea of polyocular understanding can also provide a very different input from science to democratic debate and political decision-making: a coordinated and intelligible perspectival understanding based on multiple perspectives. There is strong competition with monocular answers that offer a more extensive reduction of complexity and simple truths, but polyocular inquiry and learning could help us resolve the paradox of scientific expertise by enabling us to better handle perspectival knowledge differences.

« 79 » The main challenge for implementing the polyocular framework is that this is a paradigmatic shift compared to traditional thinking about multi-, inter-, and trans-disciplinary research; a shift to what may be labelled as "post-disciplinary research" (*sensu* Müller), which retains the strengths of first-order science but adds the strengths of second-order science. This challenge is accentuated because the new framework for interdisciplinary research is decisively constructivist and perspectivist, whereas some of the first-order scientific perspectives that are required to take an active part in the framework may have a more realist view of science. In other words, the successful implementation of this new framework demands that those involved in the interdisciplinary research, at least to some degree, subscribe to the perspectivist view.

« 80 » With regard to the special issue on second-order science, of which the present paper is part, these findings show that the (constructivist, observer-inclusive) perspectivist approach offers workable methods and research designs for doing second-order science. Ideally, the second-order polyocular framework can produce perspectival knowledge and a multidimensional understanding that cannot be assembled from any number of first-order perspectives. The outcome is not a new global integration of knowledge, but a specific polyocular understanding of the concrete wicked problem based on a realization of the scope and limits of the different perspectives involved. The second-order approach to interdisciplinary science offers a harsh critique of most cross-disciplinary research efforts on wicked problems, which are less than successful because they remain first-order. But it also offers a view of different (first-order) scientific perspectives as valid and valuable in their own right and the only access to observing wicked problems, which might encourage more mutual respect between different disciplines and sciences than is common today. The perspectivist understanding of science that we have presented here, shows that ideas and theoretical grounding for second-order science can be found in Peircean semiotics, though this is not commonly seen as a constructivist approach. Luhmannian social systems theory is also brought to the fore here, and Luhmann calls for second-order cybernetics because any first-order observation of the environment is not in a position to grasp the wicked problem of environmental sustainability:

> "We have to choose a second-order cybernetics as the point of departure. We have to see that what cannot be seen cannot be seen. Only then can we discover why it is so difficult for our society to react to the exposure to ecological dangers despite, and even because of, its numerous function systems." (Luhmann 1989: 26)

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Open Peer Commentaries

on Hugo F. Alrøe & Egon Noe's "Second-Order Science of Interdisciplinary Research"

Seeking Common Ground on the Nature of Interdisciplinarity

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> Upshot • I draw connections between the target article and the broader literature on interdisciplinarity, highlighting areas of both agreement and disagreement. Suggestions are made regarding how interdisciplinary research should proceed.

« 1 » The literature on interdisciplinarity is widely dispersed. Yet there is, I think, increasing consensus among those who study interdisciplinarity around the nature of both interdisciplinarity itself and sound interdisciplinary research practices. I very much liked Hugo Alrøe and Egon Noe's target article, in part because it reinforces much of what I and other scholars associated with the Association for Interdisciplinary Studies (AIS) have been saying for some time. Yet the authors examine these issues from a different perspective than my own. As we both agree, it is by looking at issues from multiple perspectives that we gain our best understanding. I will in this commentary outline areas of both agreement and disagreement.

« 2 » The idea of "disciplinary perspective" has been central to the discourse in AIS for decades, though it is only in recent years that the components of disciplinary perspective have received much attention. The key elements of this are now clear to both of us: theories, methods, concepts, questions (§13). We would add "epistemological outlook" and stress that these various elements are mutually reinforcing: methods are chosen that are good at investigating favored theories, and variables are investigated that are implicated by theory and amenable to methods. We would also stress that perspective is largely subconscious, and that it is strongly reinforced by Ph.D committees, journal editors, hiring committees, and tenure and promotion committees. But we agree with these authors on the central point: that disciplinary perspective shapes the way that disciplinary scholars approach their research. And one of the key barriers to interdisciplinarity is indeed that each discipline regards its approach as superior (§38): note that scholars in one discipline are likely to doubt results obtained in other disciplines because these not only use the "wrong" theory and method but investigate the "wrong" variables. Scholars in one discipline will be very familiar with the standards employed to evaluate research in their own discipline but are often doubtful that such standards exist elsewhere.

« 3 » "Interdisciplinarity" is, the target authors and I both appreciate, a contested term. As university presidents and granting agencies sing its praises, it is hardly surprising that many scholars have declared themselves interdisciplinary without reflecting on what this means. The mission that Alrøe and Noe and I share, of defining interdisciplinarity and suggesting how this is best pursued, is thus a vital one. Superficial analysis passing itself off as interdisciplinary threatens the entire interdisciplinary project. It is not enough to do a little reading in another discipline or have coffee with someone from another department – valuable though such practices are – in order to be truly interdisciplinary. It is thus unfortunate that these authors themselves equate "interdisciplinarity" as practiced at present with disciplinary imperialism (§55).

« 4 » Good interdisciplinary research, we both agree, requires that we self-consciously look at issues from multiple perspectives. Scholars associated with AIS have delineated what this might look like: we suggest a focus on the "insights" (conclusions) reached within each perspective, we stress the importance of an unbiased research question (object), we urge evaluating insights within the context of the perspective in which they were generated, and we have identified a handful of strategies for integrating insights into a more holistic understanding.[1]

« 5 » The authors say relatively little about how we might evaluate the insights generated within different perspectives. One useful approach here is to appreciate the key strengths and weaknesses of different methods and types of theory. Even specialist scholars will generally appreciate that their favored theory and method are imperfect, though they are likely to judge all alternatives as far worse. The interdisciplinary message is that different theories and methods often have compensating strengths and weaknesses. One method may be good at examining numerous data points simultaneously, while another is good at providing detailed analysis of one event or process. One theory may stress an agent's rational impulses, while another theory emphasizes the agent's non-rational impulses: both impulses may be at play.

« 6 » It is also useful to ask if the theory of one discipline excludes variables that other disciplines suggest might be impor-

1| The book by Allen Repko (2012), which the authors cite, is a good resource here, as is the "About Interdisciplinarity" section of the AIS website at http://www.units.muohio.edu/aisorg/

http://www.univie.ac.at/constructivism/journal/10/1/065.alroe

tant. To avoid the risk that all disciplines are missing something in addressing a particular problem, recourse can be had to a classification of all of the things investigated by scientists – this hopefully approximates the set of things that people care about. It can then be asked if a particular theory can be expanded to embrace other variables.

« 7 » The value of this paper is that Alrøe and Noe reach important conclusions regarding the nature of interdisciplinarity from a "perspectival" perspective. Much of the literature on interdisciplinarity has emerged from the practice of interdisciplinary teaching and research. It is also very important to ground interdisciplinary practice in philosophical reflection. The authors start from the recognition that observers shape what is observed. They note that philosophers of science have devoted far too little time to grappling with the challenges of interdisciplinarity. They hope that their paper will provide a philosophical justification for and understanding of interdisciplinarity. This is a laudable goal.

« 8 » I myself have urged a "Golden Mean" approach to a variety of epistemological questions (Szostak 2007). We need to critique the (often "positivist") assumptions on which disciplinary hegemony rests. Yet we must do so without abandoning hope of scientific progress, for there is no value in interdisciplinarity unless it allows understandings that are in some way superior. These authors clearly embrace the idea of scientific progress (§11). However, they could have been clearer with respect to other epistemological issues. Though thoroughly "perspectival," they argue that we can gain an "unambiguous" description of a "complex phenomenon" by looking at this from multiple perspectives (§22). Is there perhaps an objective external reality that we are limited in our ability to perceive but gain a better appreciation of by examining from different angles? It would seem that Alrøe and Noe must embrace dualism here but do not say so. They seem to speak favorably of the idea of incommensurability early on (§12), but admit later that some significant degree of cross-disciplinary understanding is possible (§75). I think we cannot speak of scientific progress unless we can understand each other well enough to recognize progress collectively.

« 9 » The authors at times exaggerate the novelty of their approach. This is understandable given the vast and diverse literature on interdisciplinarity. They argue that interdisciplinary scholars have stressed the language barriers to cross-disciplinary communication but not the perspectival barriers (§61). I would point them to O'Rourke et al. (2014), which addresses both challenges. The book grew out of the Toolbox project at the University of Idaho: members of (dozens of) interdisciplinary research teams were given an epistemological questionnaire, the different answers were then discussed by the research group, and the questionnaire re-applied. The range of answers generally narrowed, and team members reported that it was useful to appreciate the different perspectives of team members.

« 10 » Alrøe and Noe's proposals clearly overlap a great deal with those in Repko (2012): clarifying terminology, analyzing each insight within its perspective, mapping the connections among phenomena. Yet there seems very little about what I would see as the critical step of integration. There is a remark, "any deliberate approach to instigate change and transformation must take place through an established perspective" (§66) that I find rather cryptic. Repko (2012) instead stresses the value of finding some common ground: a concept or conceptual map or even a theory that all might potentially accept. This seems to be an important distinction. I do not see how the value of examining issues from multiple perspectives can be achieved unless we are able in the end to achieve some superior cross-disciplinary understanding.

« 11 » Careful definition of key concepts is one strategy for achieving common ground. Scholars sometimes appear to disagree because they define key terminology in different ways. Mapping the key causal relations involved in a complex problem is another: specialized scholars may disagree about the relative importance of different relationships but can potentially appreciate the overall set of relationships. Sometimes it is possible to expand a theory to embrace the variables emphasized by each perspective. When disciplines seem to disagree directly, it is often useful to transform dichotomies into continua: the economist's emphasis on rationality and the sociologist's emphasis on non-rationality can be combined if we appreciate that humans are neither completely rational nor non-rational. Strategies such as these respect the importance of disciplinary perspective while allowing us to achieve cross-disciplinary understanding.

« 12 » The authors do not quite say it, but the implication of their paper is that the academy needs a body of scholars who are self-consciously interdisciplinary, and take as their task the examination of complex problems from multiple perspectives. Such scholars cannot replace disciplinary specialists but rather work symbiotically with these: drawing on specialized perspectival understandings and feeding back information regarding what might be learned from other perspectives. Happily, this sort of interdisciplinarity is entirely feasible: one need not master multiple disciplines but rather evaluate their insights into a particular problem in the context of disciplinary perspective. Strategies have been identified for each step in the interdisciplinary research process. Both individually and in teams, interdisciplinary scholars can usefully integrate diverse insights from diverse disciplines. The skills and attitudes of such interdisciplinary scholars may be quite different from those of disciplinary specialists, but the academy needs them both.

« 13 » In sum, I applaud Alrøe and Noe for providing a philosophical analysis of interdisciplinarity, for advocating a philosophically sound and feasible type of interdisciplinarity that will encourage scientific progress, and for suggesting what this approach might look like in practice. I join them in urging a specific understanding of "interdisciplinarity" centered on an appreciation of the importance of disciplinary perspective. We need to ensure that when granting agencies, university administrators, and journal editors seek to encourage interdisciplinarity, they have a strong sense of what good interdisciplinary practice involves.

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Beyond a "Levels View" of Science

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> Upshot • I critically assess Alrøe and Noe's plea for a "second-order science of interdisciplinary research" from the perspective of a consistently naturalized philosophy of science, arguing that the latter precludes the "levels view" of science implied by the former. I also suggest we avoid the term "polyocularity" as it perpetuates the persistent bias toward vision in our scientific and philosophical understanding of human perception.

« 1 » Having recommended scientific perspectivism myself as the best remedy at hand to counter the dominant "flat earth perspective" (Mesarovic & Sreenath 2006) in systems biology, and the "gene's eye view" and related temptations in big data science more generally (Callebaut 2012), I applaud the spirit of Hugo Alrøe and Egon Noe's perspectivist manifesto (for that is what it is: a promissory framework that invites further implementation.) But I disagree on several of their specifics. The critical remarks that follow mostly aim at *generalizing* the authors' proposal, and should be read in the spirit of sympathetic approbation.

« 2 » Referring to Julie Klein, the authors state, without offering much of an argument, that "the problems most in need of interdisciplinary cooperation" – and hence most prone to benefit from their second-order, polyocular framework – "are 'wicked problems' such as food crises, climate change mitigation, and other resilience and sustainability problems" (§2; see also §55). The notion of "wicked problems" as presented here, which the authors associate with "post-disciplinary research," remains somewhat woolly for my taste. But I propose it could be made more precise in terms of Silvio Funtowicz and Jerome Ravetz's articulation of a framework for *post-normal science* (inspired by Thomas Kuhn's "normal science"). Post-normal science is the outer layer of their cake diagram, which has applied science at the core and professional consultancy in the middle; it is characterized as combining the highest decision stakes (for instance, life or death issues) with the greatest systems uncertainties (Funtowicz & Ravetz 1990).

« 3 » A perspectivist reflection on the inclusion of "extra-scientific" stakeholders among the actors in post-disciplinary research, I would think, could also benefit from a confrontation with the literature instigated by Esben Andersen's (1991) work on "techno-economic paradigms." In addition to enabling coordination of the production of knowledge, techno-economic paradigms are also a means of *coordination between groups of producers and users* of specific types of artefacts, etc. (the idea can be readily generalized) as shared specifications of typical interfaces between the two parties. In particular, this literature can offer perspectivists useful clues as to the necessary tradeoff between, on the one hand, the requirement of simplicity and standardization of such interfaces, imposed by human bounded rationality (Callebaut 2007), and, on the other, the requirement of information-rich interactions and non-standardized interfaces necessary for successful product innovation, etc.

« 4 » Contrary to what the authors suggest (§§6, 56, 79), I see no good reasons to restrict "polyocular" problem solving to the sole realm of "post-disciplinary research." Perspectivism seems to me to be the way to go in the domains of professional consultancy and applied science as well, and, indeed, in science generally, as Ronald Giere and Bas van Fraassen, among others, have suggested. The history of science abounds with episodes where problems that are deemed worth solving in a field (including Kuhnian "anomalies") can only be tackled fruitfully by appealing to the resources (methods, techniques, concepts, theories, etc.) of another field (see, e.g., Darden & Maull 1977; Callebaut 2010 applies their account of "interfield theories" to the history and aftermath of the Modern Synthesis in biology). Alrøe and Noe (§6 and §62) rightly point to the problem of hegemonic claims by one field over the other(s) that often arise in such situations of knowledge transfer. But these situations seem to me to be almost the rule – by no means are they restricted to "wicked problem" solving. *Perspectivism*, I suggest, *is needed everywhere* (and, actually, not just within science and its philosophy)!

« 5 » Perspectivism has an impressive philosophical pedigree; Alrøe and Noe mention only Immanuel Kant, Friedrich Nietzsche, and José Ortega y Gasset, but one could add Gottfried Leibniz, John Dewey, Ludwig Wittgenstein, Ludwig von Bertalanffy, Paul Feyerabend, and several others with equal right. However, *scientific* perspectivism has come to the fore only quite recently (Giere and van Fraassen, as mentioned by the authors, but prominently also Griesemer 2002, and Wimsatt 2007). It is not, as of now, a unitary stance, and has barely begun (with the exception of van Fraassen) to tap the many rich resources the older perspectivisms have to offer. As far as I am concerned, the first priority on the scientific-perspectivist agenda should be *the elaboration of a grammar of perspectives* (Callebaut 2012: 79), to which Alrøe and Noe, I am afraid, have not begun to contribute.

« 6 » For fairness' sake, it should be stressed that with the sole exception of van Fraassen (who now prefers to label his own constructive-empiricist position as "empiricist structuralism"), the scientific perspectivists I am aware of (and this includes myself) aim to be as "realistic," epistemologically speaking, as is reasonably possible. The intimate connection between "polyocular perspectivism" and "constructivism" that Alrøe and Noe take for granted – without much clarification of what they mean exactly by "constructivism" – seems to me optional to at least some extent. Please read this as a comment about constructivists *and* realists! Here I fully endorse van Fraassen's call, in his *Scientific Representation*, for cooperation across the empiricism/realism divide:

> "While this will undoubtedly shape my discussion, I have tried to write as much as possible of this book in a way that does not trade on the differences between this view of science ('constructive empiricism') and its contraries ('scientific realisms'). What scientific representation is and how it works is everyone's concern, and there we may find a large area where more general philosophical differences need make no difference." (Van Fraassen 2008: 3)

http://www.univie.ac.at/constructivism/journal/10/1/065.alroe

« 7 » Social constructivism at large has benefited our global understanding of science in counter-balancing the rationalist excesses of the pre-Kuhnian philosophies of science in the analytic tradition. But for a long time it has also been largely counterproductive by delighting in "silly" (dixit Giere) epistemological relativisms (mostly to provoke philosophers) instead of doing proper – sociological – work (see, e.g., Kitcher 1998; Hull 2000). I urge "polyocular" researchers to try to avoid making similar mistakes – roughly, having order two "control" order one. Although the authors seem to be aware of this danger, I still want to ventilate my worry that a too strict separation, in both conceptual and sociological terms, between their first and second orders could lead to new alienations. In Henri Atlan's (1986: 336) words: let us avoid the pitfalls of "a sociology that unveils the truth about the sciences." Alrøe and Noe remain silent on who are to be the polyocular problem solvers. I would suggest that, rather than a separate caste of holders of a "new paradigm" (§55 and §79), these should first and foremost be the scientists themselves (and of course, in the cases envisaged by the authors, other direct stakeholders as well). Occasionally (most notably in §74), Alrøe and Noe's proposal still smacks of what Donald Campbell used to call "foundationalist longings," whereas the apter metaphor to go with perspectivism is *scaffolding* (Caporael, Griesemer & Wimsatt 2013).

« 8 » This brings me to my main objection: *a consistently naturalized philosophy of science precludes a "levels view" of science*. Naturalistic philosophy of science is the position toward which post-relativistic (including post-Kuhnian) philosophies of science have been converging in recent decades (Callebaut 2003). The point of departure of philosophical naturalism is not the epistemic subject's phenomenal world but the physical world at large, which it regards as a natural unity that includes human beings. Naturalistic epistemology and ontology are neither intuited nor the result of some transcendental reduction, but derived from our current understanding of inorganic, organic, and cognitive evolution. Naturalistic understanding is also based on a peculiar but plausible interpretation of the historical relation between science and its philosophy. On this view, *science is a self-corrective activity*, and the theory of science may be viewed as a sort of "meta-learning module" that allows science to "learn how to learn" (Shapere 1984). This research strategy, which regards all ontology as theory-dependent, is in line with Quine's "ontological relativity," and more generally with the naturalist's rejection of any first philosophy whatsoever.

« 9 » However, "meta-learning" should not invite us to think that naturalistic theories of science require a "levels view" of science – one that dismisses, say, cognitive evolution at the "methodological" level, as was the case in the logical empiricists' and Popper's analytic a priori philosophies of science. As a matter of principle, any naturalistic/scientific account of science must be *reflexive*, for otherwise one would "get out of the system." Atlan's (1986) "acrobatic reason" is an apt description of what is at stake here: a reason without safety net (*filet*) that can no longer take advantage of a meta-discourse, of a meta-theory (meta-physical, meta-biological, meta-psychological, or other).

« 10 » Irrespective of the accomplishments of second-order cybernetics (which I am not in a position to comment on competently), I want to drive home the point that scientific perspectivism, which is largely a particular elaboration of the naturalistic account of science, is better not phrased in terms of first- and second-order science, or "levels." Interestingly, the same point has been made by Niklas Luhmann, an author whom Alrøe and Noe cherish:

> "Irrespective of specific theory assumptions (concerning consciousness, reason, subjectivity), one can characterize a theory [of knowledge] as transcendental if it does not allow the conditions of knowledge to be questioned by the results of knowledge. Transcendental theories disallow self-referential conclusions. In contrast, theories can be considered as empirical or naturalistic if they do not exempt themselves from the domain of objects worth knowing, but concern themselves with empirical research, and allow a restriction of the range of knowable options." (Luhmann 1990: 15f; my translation)

This is not a mere quibble over words.

« 11 » To round off, I would like to suggest sticking to "perspectivism" (or, if one prefers, "multi-perspectivism") to denote the enterprise we are jointly advocating, and refrain from using the term "polyocularity," for the very simple reason that the latter perpetuates the persistent bias toward vision in our scientific and philosophical understanding of human perception to the detriment of audition, olfaction, and other human senses (Barwich 2014). If, for instance, with the authors we are interested in *food*, we will want to know, among other things, how it tastes. Here mere polyocularity will not do; it will have to be supplemented by other perceptual investigations, including qualitative ones (see, e.g., Levinson & Majid 2014). Science does extend beyond the realm of the quantitative (Rudolph 2013)!

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Editors' note: In the course of preparing this commentary Werner Callebaut unexpectedly passed away before he could attend to the final proofs. We very much regret this loss for the scientific community.

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Ascending to the Second-Order: An Alternative Systems Take on Wicked Problems

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> Upshot • Contrary to Alrøe and Noe, problems are wicked not because they escape the technical expertise of the special sciences but because they reawaken the sciences' totalizing impulse, which then leads to conflicting cross-disciplinary claims, on the basis of which the state must intervene. This situation is understandable against the backdrop of an "open systems" perspective, in which the sort of second-order perspective presupposed by wicked problems is spontaneously generated.

« 1 » Perhaps the most curious feature of Hugo Alrøe and Egon Noe's target article is its failure to define conditions that within a systems-theoretic perspective permit the organization of different disciplinary perspectives into a second-order, "polyocular" vision capable of addressing "wicked problems." These problems can be defined as ones of great societal import but that, due their complexity, lack a natural disciplinary home. Instead, despite the article's systems-theoretic talk, polyocular vision is presented as an ad hoc construction, which takes for granted the existence of well-bounded disciplines, an amorphous problem space and some undisclosed agency with the power to bring these disciplines to bear on the problem space, resulting in the vaunted "polyocular vision." Most of the paper is spent describing polyocular vision as an outgrowth of certain "perspectivalist" tendencies in recent analytic philosophy of science against the backdrop of a broadly Kuhnian account of disciplines as paradigms. As a result, the exact sense of key terms such as "system" and "problem" remain unclear. In what follows, I elaborate these concerns by offering an alternative account of the issue that the authors claim to be addressing.

« 2 » To their credit, Alrøe and Noe admit that the phrase "wicked problems" is a misnomer because they are not really "problems" in the strict sense. A problem presupposes recognized constraints on permissible solutions. The pragmatists, notably John Dewey, were clear that the relevant constraints are provided by life processes, whose problematic character we discover as the resistance we (individually or collectively) face in the course of trying to achieve some goal. In this respect, there is no single solution to "the problem of justice" in the philosophical sense, because each society brings a different set of resources and constraints ("affordances and resistances") into the situation. But this does not necessarily render the problem of justice "makeshift" (i.e., each society arrives at its own solution, reflecting its unique circumstances). It does, however, raise interesting questions about what might constitute an "optimal solution" with any degree of generality, since the amount and nature of constraints and resources available in specific cases influence how possible solutions are judged. Algebra comes in handy for stuff like this – namely, the representation of functional relations in conditions of great variability. Here one might have recourse to what economists call "theories of the second best," which particular cases force a re-ordering of priorities (or re-weighting of values) because of radically changed circumstances (Lipsey & Lancester 1956). A simple example is that in times of war, minimizing harm may be lowered as a policy priority vis-à-vis the maintenance of social order due to the external threat, thereby influencing judgements about what to count as a "just policy."

« 3 » In this respect, the identification and solution of problems constitute the epistemological trace of ordinary biological survival. They mark the moments when the organism distinguishes itself from its environment. Herbert Simon (1977) famously spoke of "satisficing" as the second-order goal of all problem solving, i.e., an organism's self-understanding grows as it adopts solutions that allow it to solve more problems in the future. However, "problems" in this sense are not "wicked," because they actually help to craft the organism's identity. In contrast, at least according to Alrøe and Noe, a "wicked problem" escapes the established self-understandings of several (disciplinary) organisms. Such a problem would seem to enjoy an autonomous existence, one independent of any particular framing. Thus, "global warming" is presumed to be problematic even if it does not pose a palpable threat to anyone's life or, for that matter, does not register as a technical puzzle in some related scientific discipline. Yet, for the classical tradition in the philosophy of science that extends from the logical positivists to Karl Popper, Thomas Kuhn and their followers, the recognition of problems is constrained by a theoretical and methodological framework explicitly imposed on the world.

« 4 » To be sure, these philosophers specified the relevant constraints differently, not least whether they are borne by an individual or a collective – all of which are put to one side for purposes of this discussion. Nevertheless, they concurred that "science" in the proper sense requires sufficient control over the operable environment to enable agreement on whether, say, a particular experiment did or did not vindicate a particular hypothesis. (Of course, diagnoses and follow up actions may then vary.) It is from this general standpoint that Alrøe and Noe's conception of "wicked problems" begins to make sense, namely, as belonging to aspects of experiential reality that remain unconceptualized – and in that sense, "unproblematized" – by the current scientific paradigms. Moreover, there is precedent for dealing with "wicked problems" in this sense, most notably the German "finalization" movement, which called for state science policy agencies to divert the energies of "mature sciences" from solving technical puzzles in their own fields to jointly tackling complex societal problems, broadly covering the biomedical and environmental fields (Schaeffer 1984). The historical specificity of this development is worth recalling. When Patrick Suppes (1978) complained at the height of the Cold War that Kuhn was all too correct – namely, that increasingly divergent disciplinary trajectories were turning any hope of scientific unification into a lost cause – the state was by far the main funder of scientific research, and hence arguably enjoyed a prerogative to steer the science that it funded in more socially beneficial directions, *à la* finalization. The last great effort in this vein may be the "converging technologies" agenda launched by the US National Science Foundation in 2002, soon followed by a similar European Union initiative, which proposes to harness nano-, bio-, cogno-, info- (and now neuro-)

http://www.univie.ac.at/constructivism/journal/10/1/065.alroe

sciences and technologies to "enhance human performance" (Fuller 2011: chap. 3).

« 5 » The main objection to finalization, both in its own day and today, is its apparent willingness to compromise the integrity of free inquiry in the name of some politically defined ends. However, there is a deeper objection. This general way of understanding the history of science, especially the expectation that some external agency – the state, in this case – will force otherwise wayward disciplines to work together to address free-standing social problems. It is an artefact of a certain vision of the history, namely, one of gradual specialisation from an initially undifferentiated spirit of inquiry, which is typically associated with philosophy. However, another way to read the same history, which was more prominent in the 19th century, when disciplinary specialisation began to be institutionalised in university departments, is that what we now call "disciplines" started life as totalising world views ("mechanism," "vitalism," etc.). These world views, through various confrontations with each other and the larger non-academic world, retreated to their current disciplinary boundaries – in different configurations, in different universities. From this standpoint, "wicked problems" reawaken this totalitarian spirit, as each discipline then tries to colonize a domain from its own perspective. Note that the role of philosophy is thus different in the two cases: instead of providing a primordial "confused" source of ideas that is then "clarified" by the special disciplines, this "deviant" reading of the history suggests that philosophy is better understood as common intellectual inheritance, subject to multiple investment strategies (aka the special sciences) that nevertheless remain in touch with the original philosophical drive toward universal knowledge (Fuller 2010).

« 6 » In terms of Alrøe and Noe's quest for a second-order systems-based perspective, this deviant reading of the history of science implies that disciplines spontaneously generate their own second-order visions when encountering domains of reality currently outside their remit. Science and technology studies provides one interesting way to understand this matter. If one takes seriously what I earlier called "the classical philosophy of science tradition," it is unclear how to establish the relevance of phenomena generated in the artificial setting of the laboratory to the world outside its walls. While psychologists had long made this matter central to research methodology under the rubric of "external validity," it was only in the late 1970s that sociologists of science such as Michael Mulkay, Karin Knorr-Cetina and especially Bruno Latour, charted how relatively rarefied lab moments could have enormous extramural consequences – to the point that they come to be recognized as having solved problems of interest not merely to scientists but to society at large (Fuller 1993). The general drift of this work is that science colonizes the public sphere through various forms of network-building, such that people come to identify with the scientific world-view. Thus, they presume that solutions to scientifically defined problems solve their personal problems as well. Latour (1988) held up Louis Pasteur as a spectacularly successful version of this strategy in the Third French Republic.

« 7 » To set the stage for what "wickedness" might mean in terms of this revised understanding, a couple of observations are in order, which are best made by focusing on Latour's account of Pasteur. To start, it is notably at odds with the influential US science policy account given by Donald Stokes (1997), for whom Pasteur exemplifies research based on industrial and health policy concerns (in this case, the deterioration of wine, beer and milk) that ended up having far reaching consequences for fundamental research (namely, the science of microbiology). However, Stokes's perspective fails to explain how Pasteur managed to persuade rather differently situated parties to adopt solutions that, notwithstanding their practical intent, had been crafted in specific laboratory settings. Here the appeal to "science," as the brand under which Pasteur's experiments travelled, served a persuasive function that might be otherwise matched only by political coercion. The difference between Stokes's and Latour's accounts is that Stokes takes for granted the basic-applied research distinction, whereas Latour does not – in fact, Pasteur's intervention turns out to be instrumental in constructing the distinction.

« 8 » At the same time, Latour's basic idea that Pasteur forged a *network* rather than a *system* challenges a signature innovation of systems theory, which originally attempted to provide a dynamic solution to the metaphysical problem of "mereology," that is, the whole-part relation. Based on his understanding of biology, Ludwig von Bertalanffy translated this problem into one of an organism including aspects of its environment into its own normal functions, thereby extending its "system boundary" (Strijbos 2010). In this respect, organizational complexity – evidenced by functional differentiation – may be seen as an internalized version of the variety of external challenges that an organism faces in realizing its objectives. Such latter-day ideas as the "extended phenotype" (Dawkins 1982) and "extended mind" (Clark 2008) are worthy descendants of this tradition, which treats the organism as an "open system." The sociological trace is provided by the history of the *universitas*, the Roman legal entity translated as "corporation," which includes all autonomous collectives from cities and firms to universities and churches that flourish by growing through "incorporation." But this venerable tradition of systems-thinking, with which I have been broadly sympathetic from the start of social epistemology (Fuller 1988), presupposes a sense of overriding purpose that continues to stabilize the (social) organism's identity as it engages in its various transactions with the environment.

« 9 » However, Latour's counter-image of the network is meant to be something quite different – namely, a redistribution of significance across the system parts (now called "network nodes") in the course of its growth, resulting in an entity whose orientation is fundamentally different from its previous incarnations. Put concretely: an unintended consequence of Pasteur's success in persuading people to adopt his science-based policies for extending the longevity of wine, beer and milk is that they became stakeholders in the "pasteurization" process, at which point the science was no longer exclusively – or perhaps even primarily – in the hands of the scientists. At that point, Pasteur's project was no longer about science colonizing a feature of public life; rather, it was about science's contribution to a rise in the default standard of society's collective intelligence. As a result, the role of scientific authorities would be invariably diminished, reduced to prominent nodes in an indefinite network – as opposed to nerve centres of a well-bounded system.

« 10 » The following summarizes the preceding line of reasoning as a series of propositions in support of an argument:

- *Contra* Alrøe and Noe, "wicked problems" are not artefacts of the narrowness of scientific paradigms vis-à-vis real world problems, which requires state intervention for the problems to be treated adequately.
- On the contrary, what makes such Alrøe and Noe's problems "wicked" is that they reawaken the sciences' totalizing impulse – a legacy of their philosophical origins – which then leads to conflicting cross-disciplinary claims, on the basis of which the state must intervene.
- The emergence of this state-of-affairs is understandable against the backdrop of a systems-theoretic conception of "open systems." It amounts to a spontaneous generation of second-order perspectives in the process of system boundary extension.
- Moreover, to simplify matters, the state's legitimacy is granted – perhaps grudgingly – as a fair arbiter of these contesting second-order perspectival claims.
- However, science and technology studies, especially Latour's work, offers an alternative take on what such a resolution might look like. Instead of one or more sciences colonizing a previously "undisciplined" domain, solutions to wicked problems may end up forcing the sciences to cede some of their epistemic authority in exchange for stabilizing their position in society at large.
- In light of this alternative resolution of wicked problems, the sciences are then forced to redefine themselves as either systems or networks. The more that science agrees to the network-based self-understanding, the greater science's struggle to define its own epistemic distinctiveness (aka system boundary) in society.

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What is "Science"? For What Do We Need a "Polyocular Framework"?

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> Upshot • Alrøe and Noe are right in addressing Rittel and Webber's notion of "wicked problems" as crucial for interdisciplinary research. However, I cannot see that they are providing a sufficiently clear understanding of "science" in their concept of a "second-order science of interdisciplinary research," nor that their "polyocular framework" can contribute anything useful to addressing the practical challenges posed by wicked problems.

« 1 » When Horst Rittel and Melvin Webber introduced the extraordinarily influential concept of "wicked problems" in 1973, they already indicated that one of the most important features of these problems is that they can be described from a multitude of different perspectives. The first of the ten defining characteristics of a wicked problem is, according to them: "There is no definitive formulation of a wicked problem" (Rittel & Webber 1973: 161). Instead, there is a multitude of possible ways to describe a wicked problem or to formulate what the problem is. The reason they provide for this feature of wicked problems is that "every specification of the problem is a specification of the direction in which a treatment is considered." They illustrate what they conceive as the identity of problem formulation and envisioning of a solution by referring to poverty as a wicked problem:

> "Does poverty mean low income? Yes, in part. But what are the determinants of low income? Is it deficiency of the national and regional economies, or is it deficiencies of cognitive and occupational skills within the labor force? If the latter, the problem statement and the problem 'solution' must encompass the educational processes. But, then, where within the educational system does the real problem lie? What then might it mean to 'improve the educational system'? Or does the poverty problem reside in deficient physical and mental health? If so, we must add those etiologies to our information package, and search inside the health services for a plausible cause. Does it include cultural deprivation? spatial dislocation? problems of ego identity? deficient political and social skills? – and so on. If we can formulate the problem by tracing it to some sorts of sources – such that we can say, 'Aha! That's the locus of the difficulty,' i.e., those are the root causes of the differences between the 'is' and the 'ought to be' conditions – then we have thereby also formulated a solution. To find the problem is thus the same thing as finding the solution; the problem can't be defined until the solution has been found." (Rittel & Webber 1973: 161)

« 2 » Since wicked problems allow a multitude of different approaches that might contribute to their solution, the identity of problem formulation and of conceiving a solution implies that there will be a multitude of possible problem formulations.

« 3 » Thus, it seems to be clear that Rittel and Webber already have in mind what Hugo Alrøe and Egon Noe call in the target article a "polyocular framework for wicked problems," even though they do not use the term (nor something more colloquial such as "multi-perspectival"). This becomes visible in the fact that Rittel and Webber wrote, in 1973, that wicked problems should be approached…

> "based on a model of planning as an argumentative process in the course of which an image of the problem and of the solution emerges gradually among the participants, as a product of incessant judgment, subjected to critical argument." (Rittel & Webber 1973: 162)

« 4 » Alrøe and Noe do an excellent job of connecting the idea of the insufficiency of particular perspectives with Ronald Giere's "scientific perspectivism" and related discussions in philosophy of science. However, their most original contribution to perspectivity in general and research on interdisciplinarity in particular seems to be their claim that we need what they call a "second-order science of interdisciplinary research." Now, even though I agree with much in the article, I see two major problems that deserve, I think, further consideration.

« 5 » First, I am struggling to get an appropriate understanding of what this

"second-order science of interdisciplinary research" exactly is. Why is this supposed to be a "science"? Is it a "science" in the sense of an institution, as indicated by describing the "second-order scientific perspective" as an "autopoietic social system" with "its own organization" (§45)? Should there be departments of "second-order science of interdisciplinary research," corresponding science organizations with journals, and so on? Or at least a clearly identifiable, interdisciplinary research community as we find, for example, in the newly developed "Science of Team Science" (Börner et al. 2010)? Or is an institutional approach to "science" misleading, and should it be replaced by an understanding of science as a corpus of knowledge? I would be perfectly happy with a second-order "approach" to the problem of perspectivity, but I do not know what it means to discuss this as a "science." An "approach" would shift the focus from institutions and bodies of knowledge to a specific method – a "way," as the Greek *met-hodos* indicates, to deal with the problem that no particular perspective is sufficient to deal adequately with wicked problems.

« 6 » Even though a second-order "approach" to interdisciplinarity would indicate that wicked problems require us somehow to overcome the limitations of first-order, disciplinary perspectives, it still does not tell us what that exactly means. It seems to be clear that an answer to this question requires the formulation of fulfillment conditions. We need to know what it takes to distinguish a second-order approach from any other approach that tries to overcome first-order limitations. For example, do we already have second-order science of interdisciplinarity when we – trained in a specific but limited discipline – try to learn the language of another discipline? Do we have second-order science of interdisciplinarity when we conceive the wicked problem as a "boundary object" in the sense of Star & Griesemer (1989) that we approach by the disciplinary means that are available to us, and that we then simply send over to the experts of another discipline, hoping that the overall process will make sense even if we are not able to see it? Or does the characterization of "second-order science" require some sort of integration of a multitude of different perspectives?

« 7 » This last question leads directly to my second, more important problem. What exactly can be achieved by the proposed "polyocular framework"? For what can it be used?

« 8 » Alrøe and Noe provide the following definition (§17):

> "The term 'polyocular' has been constructed in analogy with binocular and monocular (Maruyama 1974), and here 'ocular' is used in nearly the same sense as perspective, but with a built-in social systems theoretical meaning in the form of the 'blind spot' of an eye (Latin: *oculus*)."

Thus, given that the Greek *polus* means "many," "polyocular" seems to stand for "multiperspectival, but in a way that each particular perspective leaves a blind spot." I hope this is indeed the intended definition. But what can we do with such a "polyocular framework"? How can it help us to cope with wicked problems?

« 9 » Unfortunately, I cannot see that this concept contributes anything to the very concrete challenge that is posed by wicked problems. The reason for this frustration of my expectation is that Alrøe and Noe's "three pivotal phases of a polyocular research project" as they are outlined in Table 1 of the target article (§58) only lead – on the level of interdisciplinarity – to what they call "polyocular understanding," a term that is somewhat further illuminated by the phrase "addressing the plethora of solutions." What does it mean to "address" a plethora of solutions? The elaboration of this phrase in §66 does not contribute much to a better understanding:

> "The third phase of polyocular research addresses the plethora of solutions offered by the perspectives involved. Polyocular understanding – the multidimensional space of understanding that can be established through polyocular observation and communication of the perspectival observations in Phase 2 – forms the basis for a shared or coordinated effort to instigating change and transformation."

« 10 » Already Rittel and Webber made clear in their seminal paper that the many perspectives from which a wicked problem can be observed need to be addressed. But the crucial question is obviously not that many perspectives should be addressed, *but how a shared, coordinated, or integrated perspective can be achieved.* Rittel and Webber themselves suggested, as quoted above in §3, an "argumentative process" in which a solution might emerge "gradually." This is an approach to solving wicked problems by integrating a multitude of perspectives in practice, an approach that I developed further in my own work (Hoffmann & Borenstein 2014).

« 11 » There are some indications – even though, again, not clearly enough articulated – that Alrøe and Noe seem to assume that such a shared, coordinated, or integrated perspective is, first, not possible and should, second, not even be attempted. At one point (§12) they write – without saying explicitly whether this is their position or just the one that results from the position discussed in this context: "different scientific perspectives see complex matters differently, and these differences cannot, and should not, be merged." If this is indeed true, why should we engage in any polyocular research project? If first-order perspectives can never be merged, how should we ever be able to cope with wicked problems? We can talk forever about the multitude of perspectives that come into play when we want to build a highway – an example used by Rittel and Webber. But at the end of the day there needs to be a decision: should it be built or not? Wicked problems are not important because they can be addressed forever, but because they need a decision, and because any decision seems to be impossible to justify. All this makes me sceptical about how Alrøe and Noe's "polyocular framework" could help to make good decisions when facing wicked problems.

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What Kind of Autopoietic System, If Any, Can a Perspective Actually Be?

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> Upshot • The authors propose that a perspective is an autopoietic system. This commentary challenges the feasibility of this claim by pointing out the conceptual difficulties associated with such a proposal. But even granting that a perspective is, or can be, an autopoietic system, what sort of autopoietic system might best ground the authors' concept of perspective? This last question is also pursued here.

« 1 » Hugo Alrøe and Egon Noe's paper poses an intriguing philosophical claim: a perspective, scientific or – presumably – otherwise, is an autopoietic system. The authors claim:

> [a] *scientific perspective* is thus an autopoietic system that is reproduced and refined through internal processes […], and which produces its own methods, theories and instruments for observation, and thereby also its own inputs (data). (§18).

Yet one might have strong reservations against this view. To assign the properties of autopoietic systems to a (scientific) perspective would be to assign rather robust properties indeed to a perspective. Does the authors' definition of perspective stand up to the sort of robust demands that are put upon (the structural properties and dynamics of) autopoietic systems?

« 2 » Let us clarify the terms. The authors' definition of perspective is "that which determines what an observer can observe and what it cannot observe" (§17). But autopoietic systems contain more bells and whistles than this property that the authors attribute to perspective here; for instance, autopoietic systems have a complex structural dynamics. First, even granting that autopoietic systems play a strong role in determining what observers can and cannot observe, we must ask if the particular structural dynamics possessed by autopoietic systems provide a reasonable or satisfactory model for conceiving perspective, but also, more deeply and more broadly, we must ask if autopoietic systems provide a viable model for analyzing the determining dynamics of polyocular research (a combination vis-à-vis a non-unifiable plurality or asymmetrical synthesis of multiple perspectives), within which the concept of perspective is supposed to be cashed out by these authors. Complimentary questions then arise: *what* can polyocular research observe/not observe? (I think this first question is treated with some justice by the authors); and *how* can polyocular research observe/not observe? Here, I think the authors might do well to address this question in more depth. Further, do non-autopoietic elements not themselves play a non-negligible or even strong determining role in producing what a (partially blind) perspective can and cannot observe? If so, what might these non-autopoietic elements be?

« 3 » These last questions are of tremendous importance. They imply a whole host of theoretical commitments and presuppositions. This is complicated further by the fact that there is a surprisingly wide breadth of autopoietic theories (including social autopoietic theories). What concept of autopoietic system is the key reference for these authors? This is not stated outright; instead a range of influences are listed – but differences matter. More significantly, a formal or consistent definition of autopoietic system is not offered by the authors. The conceptual differences in the variety of autopoietic systems theories are sometimes intractable. They certainly were for Niklas Luhmann, Humberto Maturana and Francisco Varela, which references we, for the space of this commentary, focus on to the exclusion of the authors' other references. Such a reduction is not too drastic since Luhmann is one of the authors' key references and since Luhmann (1992: 70) explicitly borrows his theory of autopoiesis from Maturana and Varela, combining it uniquely with George Spencer Brown's laws of form, but maintaining Maturana and Varela's core concepts (operational closure, boundary, system/environment) while adapting these concepts to his own research program.

« 4 » While Maturana and Varela's canonical formulations concerning autopoietic systems make it clear that the dynamics of autopoietic systems play a role in determining what an observer can and cannot see, this fact is not enough to make the stronger claim that autopoietic systems offer a good ontological or epistemological basis for Alrøe and Noe's definition of perspective, which seems a bit too limited in scope and generic in nature. Yet these authors claim to wish only to illuminate perspective by drawing on analogy with autopoietic systems. But how far should one take this analogy? Again, should we assume that perspective, like an autopoietic system, is also endowed with the property of operational closure? Moreover, for Maturana and Varela, autopoietic systems do not strictly *determine* perspectives, even if they can be said to *ground* them; they merely reproduce themselves by reproducing their own parts in operationally closed networks of system dynamics according to that system's structure (at any time under analysis of the operations in question) (Maturana & Varela 1980: 78). Do perspectives possess the same sort of structure-determined dynamics, or is this just an analogy? If the latter, where to draw the line between the relative likeness and unlikeness of autopoietic systems and perspectives, viz., the structural dynamics at play in the work performed by a perspective (the work, namely, of generating through some combination or asymmetrical synthesis the polyocularity the authors prize)? As John Mingers puts the problem,

> [i]f the idea of autopoiesis is just used metaphorically […] then the only question is its fruitfulness, but if it is claimed that a society or organization *is* autopoietic then significant ontological problems are raised. (Mingers 2004: 405f)

Luhmann, for example, borrows the basic definition of autopoiesis from Maturana and Varela, but will generalize the results of this research in an application to social systems, which move has been highly scrutinized. This high level of scrutiny is owed to the fact that it is difficult to tell what the elements of a social system actually are, and it is difficult to tell whether social systems maintain the sorts of boundary conditions that autopoietic systems do. But the authors do

http://www.univie.ac.at/constructivism/journal/10/1/065.alroe

not include a discussion of the differences between these two conceptions or remark at due length upon the epistemological problems associated with Luhmann's generalization. They might have spent greater effort on this endeavor.

« 5 » So to recast a criticism: what autopoietic system conception do the authors have in mind when defining perspective or when claiming that social systems are autopoietic? And more importantly, which suite of autopoietic properties do they wish to attribute to perspective, observer, observation and polyocularity more generally? There may be a fair amount of undue equivocation in the authors' summary detailing of conceptual resources concerning these terms (autopoietic system, perspective, etc.).

« 6 » We might ask the authors if perspectives reproduce themselves by reproducing *their own* parts in virtue of their operational closure, following Maturana and Varela, as well as Luhmann. Yet we have a tough time imagining the authors answering in the affirmative because this seems a tricky claim to wish to endorse. For one, it leaves one wondering what serves the role of generating second-order observation. Taking the authors at their word, perspective seems to play a foundational role for first-order observation (though the observation one attains via perspective varies by social system). Perspective presupposes, rightly in the constructivist and radical constructivist traditions, a blind-spot ontology, but the authors leave open the question of *what* it is that synthesizes first-order observations into something adequately polyocular. Is it the autopoietic system, defined in Maturana's terms? Is it the social system (of science), defined in Luhmannian terms? Not knowing what type of autopoietic system performs this work leaves some thorny philosophical problems to address. Might it even be the case that a non-autopoietic, i.e., human synthetic, agent observes the observations? Well, the problem with this common-sense solution to the problem is that answering in the affirmative deprives readers of determining just what it is that *is* autopoietic about polyocular research. After all, for Maturana, it is unclear that human beings are autopoietic, while human social systems are not; and humans, in social systems, are also not autopoietic for Maturana (Koskinen 2013: 46). If anything, humans merely realize their (molecular or biological) autopoiesis through languaging in the social medium (ibid). Luhmann, too, was at pains to substitute out the human agent from his reflection on social systems.

« 7 » But while the authors do not here argue definitively for some human agent that would deliver polyocularity, it is less clear just what does perform the work of moving from first-order to second-order observation (and from there to a polyocular research framework). They write:

> "In a perspectivist view, science is observer-dependent to the core, and we see a growing recognition in science studies that all scientific knowledge is perspectival; i.e., that the context established by a scientific discipline is decisive for the kind of observations that can be made by that discipline. This development is connected to the development of radical constructivism, which suggests that we, including science, actively construct our world and that deeper insights in the knowledge constructions of science can be gained from cognitive sciences […]" (§9)

« 8 » But who or what is this "we"? Readers are initially led to believe that the work of perspective is undertaken by autopoietic systems and, presumably, their structural dynamics. Do autopoietic systems comprise the sort of "we" to whom the authors would feel comfortable ascribing knowledge constructions? But again, and more crucially, which, and whose, theory of autopoiesis are the authors talking about?

« 9 » Not sorting such issues out quickly bleeds into other curiosities in this otherwise compelling and original (where applications to wicked problems are concerned) research article. For instance, for Maturana, autopoietic systems are *living* systems; they are molecular/biological beings in essence (this was one of the reason he resisted calling society autopoietic: society does not contain living, biological, hence, autopoietic elements). Maturana has held steadfastly to this claim and has been at pains to clarify that social systems are not autopoietic systems (a position that he has softened over the years, but a definition against which he has maintained a great deal of skepticism). This fact might also put the authors' reliance on Maturana and Varela (the extent of this reliance is admittedly ill-defined, but this actually ramifies the problems addressed here) at odds with Maturana's own proposals for autopoietic systems, since, the authors say: "[t]he perspectives that we are mainly concerned with in this article are scientific perspectives, and the observers we look at are social systems" (§17). Yet what if observers/social systems are not properly autopoietic, following Maturana (including his early work with Varela)? To sort out this difficulty, the authors' ought at least to be clearer about how they distinguish Luhmann from Maturana (and Varela), again, since Luhmann has consistently identified with the conceptual underpinnings of their model of autopoietic systems. In sum, these finer points matter quite a bit because the authors tie perspective to autopoietic systems very tightly (while perspective is tied, in turn, very tightly to their concepts of observers and observation).

« 10 » Recall that, for the authors, a "scientific perspective is an autopoietic system that […] produces […] its own instruments for observation" (§18). It does appear, however, that the authors take a stronger turn to Luhmannian conceptual resources (despite the fact that these are difficult indeed to separate out from the Maturanian and early Varelian influences) and they do this, it seems, because for Luhmann, the properties of autopoietic systems *actually can be* assigned or generalized to social systems. Thus, on Luhmannian terms, it is possible to speak of a scientific discourse (set of distinctions) or community of observers autopoietically generating its own modes of observation. But identifying strongly with Luhmann here raises the question of just how it is that the authors really benefit by tying their conception of perspective to the autopoietic model of Maturana and Varela, vis-à-vis Luhmann. Again, the authors' use of the autopoietic model does not appear to reside in Maturana and Varela's characterization of autopoietic structural dynamics (based as they are on structure-determined, living, autopoietic systems under operational closure). I think the authors' best defense here is to declare that their reliance on Maturana and Varela is of the nature of a passing interest in an important conceptual precursor, and then to strengthen their account of how it is that a particularly Luhmannian social system can

constitute a perspective over and against the Maturanian and Varelian account. And to an extent, they do make this move. But clarifying the conceptual lines of departure between Maturana and Varela and Luhmann (ignoring the other references to autopoietic systems theory-types) would do the paper good.

« 11 » In sum:

1 | there remains a skepticism that a perspective is (or can be) an autopoietic system. There remains a lack of conceptual clarity concerning what sort of autopoietic system the authors have in mind such that they do not, in the end, adequately predicate the subject of their key claim ("a perspective is an autopoietic system") or provide the essential conceptual markers to distinguish a perhaps more Luhmannian version of social systems from its roots in Maturana and Varela's essential insights;

2 | there remains skepticism that autopoietic systems, even Luhmannian, might actually stand as a viable ground (ontological or epistemological) *for* a perspective (what is the ontology, for example, that supports the claim that "a perspective *is* an autopoietic system"?);

3 | there remains a skepticism that the dynamics of autopoietic systems actually do a sufficient job of supporting the notion of perspective and polyocularity that the authors' champion.

« 12 » Let us recall that for Maturana (and the early Varela), autopoietic systems are structurally open precisely as a consequence of their operational closure. Are perspectives operationally closed and autonomous because operationally closed? In a perspective, *what* operations are recursively generated in scientific systems? For a perspective to qualify as autopoietic, would it not have to be autonomous? But then what is the basis (some act of synthetic, if asymmetrical, or combinatory logic, … or otherwise) for a *poly*ocular scientific interdisciplinary research program capable of addressing wicked problems? This basis must lie in *some* synthetic agent compiling together – even if in a plurality that never reaches a unity – the first-order observations. But *who or what* does the synthesis of the multiple first-order observations? Who or what observes the observations? It seems that perspectives, left alone, could not do this kind of heavy lifting, since they are the constitutive pre-condition of first-order observations.

« 13 » Recall that the authors say, "[t]he only access for interdisciplinary science to studying a complex problem or complex phenomenon is through the (first-order) scientific perspectives that enter into the study" (§23). We know that the authors' answer to the question of how to generate polyocularity out of first-order perspectives lies in a reliance on the notion that perspectives belong to social systems, which are, for the authors, in fact autopoietic. The problem with leaving the answer at this level of generality, without specification of the dynamics of the autopoiesis, is that it prefigures results that are, in turn, a touch generic. Furthermore, in Maturana and Varela's framework of autopoiesis, changes in the structure of an autopoietic system emerge from external triggers and structural coupling. Do the author's maintain that the move from first-order observations to polyocularity is a result of triggers and structural coupling? It seems not. The move to a Luhmannian model, where the social processes of autopoietic systems are to account for (polyocular) communications, seems equally unsatisfactory, mainly because the authors do not specify the autopoietic dynamics through which first-order perspectives might, as communications, generate polyocularity. To be sure, the authors do suggest that it is the social system of scientific observers, observing their first order observations, that serves as a precondition for generating the second-order observations capable of generating polyocularity. But what if, as Maturana declares, autopoietic systems are of a different order of systems than social systems such that autopoietic systems do not actually maintain the power of synthesis that would be required to generate second-order observations, but would instead require some non-autopoietic, say, human, synthetic capacity or some capacity of languaging? If the latter is the case, if some human agent or languaging capacity must preside over the synthesis of perspectives (note that this synthesis does not imply a reduction of perspectives for the authors, but only implies the sort of combination that yields a viably *poly*-ocular perspective), then why rely on the autopoietic systems theory at all? This problem is magnified if, again, the human social system is not an autopoietic system in the first place.

« 14 » Finally, in this article the authors tend to *presuppose* the relation between perspective and autopoiesis, and so, it must follow for them that when the social system of science, with its multiple, synchronic perspectives, makes an observation, this will qualify *a-priori* as a form of autopoiesis. But what, one might ask, are the autopoietic, structural dynamics that generate polyocularity? Is there not a conflation of concepts here? Thus, some relatively intractable conceptual difficulties emerge in the authors' tying together of the concepts of perspective and autopoietic system. Do these difficulties raise significant challenges to the clarity and coherence of the polyocular framework and, by extension, to its capacity to treat wicked problems? It would appear so. But the exciting promise of a polyocular framework for wicked problems demands, one would hope, that the authors accept the burden of clarifying their concepts.

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Authors' Response: A Perspectivist View on the Perspectivist View of Interdisciplinary Science

Hugo F. Alrøe & Egon Noe

> Upshot • In our response we focus on five questions that point to important common themes in the commentaries: why start in wicked problems, what kind of system is a scientific perspective, what is the nature of second-order research processes, what does this mean for understanding interdisciplinary work, and how may polyocular research help make real-world decisions.

Introduction

« 1 » The commentaries on our target article are very diverse in their standpoint and focus. This diversity illustrates a main point in the article: perspectives determine what observers can and cannot observe (§17), and that goes as much for the reading of a scholarly article, particularly in an interdisciplinary context. Some are critical, some corroborate and elaborate on the ideas in the target article; but despite the diversity, there are some common themes running through the commentaries. We will focus on those in our reply, trying to reinforce some of the key points in our article, and hopefully make them clearer.

« 2 » The target article takes a perspectivist view of interdisciplinary research. Rick Szostak (§13) joins us in "urging a specific understanding of 'interdisciplinarity' centred on an appreciation of the importance of disciplinary perspective." Werner Callebaut (§4) agrees fully with our perspectivist grounding, and we agree with him that perspectivism is "needed everywhere" as a basic epistemological tenet. We do not, any more than Callebaut (§6), want to enter into a complex discussion here about whether our approach is "realist" and in what way, but we agree with him that "perspectivism is as much realism as you can get" (paraphrasing Ronald Giere, see §74). And we can answer Callebaut's question about what we mean by constructivism, by saying that we see perspectivism as most closely connected to radical constructivism (as we state in the article, §9), and not, e.g., the social constructivism that Callebaut mentions.

« 3 » As always in (radical) constructivist approaches, we cannot, and should not, avoid turning perspectivism on itself; we need to take a perspectivist approach to the perspectivist view of science. When in our reply we refer to different perspectives on what we are doing, this is therefore not an attempt to evade giving a straight answer, but an attempt to explain reflectively our (perspectivist) approach by including multiple different perspectives on the topic of interdisciplinary research.

« 4 » The themes we address in the following represent the full span of our approach, from the starting point in wicked problems and what kind of system a scientific perspective is, to the nature of second-order research processes, what this means for how interdisciplinary work is understood, and how polyocular research may help make real-world decisions.

Why take wicked problems as a starting point?

« 5 » Steve Fuller and Callebaut are critical of our starting point in wicked problems, whereas Michael Hoffmann and Robert Drury King agree with this starting point while being critical of other aspects. Fuller (§3) states that according to our article a wicked problem enjoys an autonomous existence, independent of whether it threatens anyone or is registered by any scientific discipline. This is far from our understanding of a wicked problem and from how it is described in greater detail by Hoffmann (§1). Fuller (§7) suggests a revised understanding of "wickedness," with reference to Louis Pasteur. However, we find that Pasteur is an example of a technical problem and a technical solution, rather than a wicked problem. The issue is not that wicked problems are independent of any particular framing, as Fuller puts it, but that "there is no definitive formulation of a wicked problem" because "every specification of the problem is a specification of the direction in which a treatment is considered," as Hoffmann (§1) states, with a quote from Horst Rittel & Melvin Webber (1973: 161). "To find the problem is thus the same thing as finding the solution; the problem can't be defined until the solution has been found," Rittel & Webber write. Yet, paradoxically, the solution cannot even be sought before some formulation of the problem has been made, and this paradox adds to the wickedness of wicked problems.

« 6 » We agree with Fuller's (§§5f) deviant standpoint on interdisciplinarity that "it is not merely that the normal disciplinarian knows more and more about less and less but that her very narrowness of vision distorts what she purports to see" (Fuller 2010: 53). But we do not agree with his ensuing argument that:

> "It follows that the deviant tends to treat the very presence of different disciplines as prima facie pathological, rather like neuroses, which Freud treated as mere coping mechanisms for a reality we cannot fully manage in its entirety." (ibid)

We see scientific specializations as an inevitable consequence of the quest for new insights. The problem is not specialization and differentiation in science as such, but how we can handle the ensuing increase of complexity. And we see Fuller's (2010) account of different deviant interdisciplinarities as examples of new allegedly integrating scientific perspectives that are merely specialized in another way than the disciplines they react against. His example of general systems theory as "the most ambitious form of deviant interdisciplinarity in recent times" (ibid: 60) brings this point home.

What kind of (autopoietic) system is a scientific perspective?

« 7 » Systems theory is sometimes posed as a paradigm for interdisciplinary science, but there are a range of very different systems perspectives that lead to very different understandings of the system in question and its environment (see, e.g., Noe & Alrøe 2003, Alrøe & Noe 2012). The commentaries illustrate this. Fuller (§8), on one hand, is concerned with "open systems," which are dubbed open systems in contradiction to the closed systems of classical science, focusing on whole-part relations and referring to Ludwig von Bertalanffy. King (and we), on the other hand, is concerned with operationally closed systems, focusing on self-organisation, autopoiesis and system-environment relations, which provide an entirely different take on system bound-

ary, and referring to the systems theories of Humberto Maturana & Francisco Varela and Niklas Luhmann. Perhaps this difference is why Fuller (§1) thinks the concept of "system" remains unclear in our article, despite our very clear references to the system theories we build on, and why he perceives polyocular vision as an ad hoc construction despite our efforts to substantiate and elaborate the polyocular framework.

« 8 » However, we agree with Fuller's point that network theories are a counter-image to system theories (§9). We think this juxtaposition is even more acute with regard to actor-network theory and self-organising systems (see, e.g., Noe & Alrøe 2006, 2012), and we take this as an example of the need for multiple perspectives to understand complex research objects more fully. Fuller further emphasizes that the images of the sciences as either systems or networks also play a role in the position of science in society (§10): "The more that science agrees to the network-based self-understanding, the greater science's struggle to define its own epistemic distinctiveness (aka system boundary) in society." We think this is a good point and an example of how scientific perspectives are intertwined with perspectives in society at large.

« 9 » King (§1) states that it is an intriguing philosophical claim that "a perspective, scientific or – presumably – otherwise, is an autopoietic system." It is indeed an intriguing idea that perspectives in general are autopoietic, but in the article we only pose the more modest claim that a *scientific perspective*, such as a discipline, is an autopoietic system. King (§3) continues by asking what concept of autopoietic system we refer to in this claim. This is a very relevant question, to which we have a simple and a not so simple answer. The simple answer is that in making this claim we consider scientific perspectives as social systems, and that, e.g., the differentiation of science into specialized disciplines supports this understanding of science (§17 and §12). This idea of disciplinary perspectives is supported by Szostak (§2), who states that it is central to the discourse in the Association for Interdisciplinary Studies and provides examples of the key elements of such scientific perspectives that are largely in accordance with ours.

« 10 » The not so simple but more adequate answer aims at developing the pluralistic approach to scientific perspectives that we indicated in our target article (§10) and that spurred King's question. Even if we agree to regard a scientific perspective as a self-organizing and in some sense autopoietic system, there are, as King (§3 and elsewhere) points out, at least two different understandings of autopoietic systems, originating in Maturana & Varela and in Luhmann. Maturana & Varela focus on organisms or living, cognitive systems, which reproduce their own constituent parts such as proteins, nucleic acids, organelles, etc. Luhmann focuses on social, communicative systems, systems that consists of communication, and which reproduce their own communication elements, processes and structures. We have discussed this difference, and related questions such as different concepts of observation, elsewhere in some detail (Alrøe & Noe 2012, 2014), as noted in footnotes 5 and 6.

« 11 » Overall, we employ a Luhmannian social systems approach to radicalize the existing perspectivist, cognitive approach to science (§10). Luhmann's theory of autopoietic, communicative social systems forms the basis for the polyocular framework that we suggest. In reply to King, we acknowledge the issue is more complex than that. But since we are dealing with scientific perspectives as social systems, Maturana & Varela's account of autopoietic systems is inadequate, and therefore we rely on the theory of social systems, which Luhmann and others have elaborated in great detail. That said, social systems theory is not the only perspective on science; elements of the systems theory of Maturana & Varela (and other perspectives) are needed to gain a better systems theoretical understanding of scientific perspectives.

« 12 » A scientific perspective, for instance a specialised discipline such as soil physics, can be observed as a purely communicative social system or as a more material, cognitive system analogous to an organism or a living system. As a communicative social system, it establishes and reproduces its own specialised scientific concepts, semantics, archetypical examples, argumentative logics, hypotheses, diagrams, models, theories, etc. In analogy with a living system, the scientific perspective reproduces key constituent elements of the system as a cognitive system, such as specialised researchers, observation instruments and methods, experimental facilities, research platforms, indicator systems, etc. This is often done through structural couplings with other systems and other scientific perspectives. A very prominent example is that of the very large high-tech instruments for experiments and observation established by high-energy physics in CERN and elsewhere. The scientific perspective also establishes and reproduces the organisational structures that support communication in the form of conferences, journals, peer review systems, educations, email discussion lists, web pages, etc. The key point is that scientific perspectives are operationally closed (cf. King §12); it is the perspective itself that determines what is, and what is not, needed and accepted, through a continuing process.

What is the nature of second-order polyocular research processes?

« 13 » How do we employ multiple perspectives? Here we approach the heart of the target article, the second-order polyocular research process, and a large part of the questions in the commentaries. For example, King (§2) asks: "How can polyocular research observe/not observe?" and (§6) "what it is that synthesizes first-order observations into something adequately polyocular?" We have several different, but equally important, answers to these and related questions.

« 14 » One key to understanding the idea of polyocular research is that there is no hope of a holistic perspective. The paradox of scientific expertise is that the growth of science leads to a fragmentation of science and scientific knowledge (Alrøe & Noe 2011). This is a consequence of the functional differentiation of science illuminated by social systems theory, which shows how differentiated social systems become independent and closed to each other. Practical experiences from interdisciplinary work support this closure and lack of insight between different perspectives, as indicated in the target article (§4) and backed up by Hoffmann (§§1–3), Szostak (§2), and Callebaut (§4); the latter two also fully agree on the prevalence of hegemony and lack of respect between the involved disciplines.

« 15 » So how can independent and mutually closed perspectives cooperate on observing some complex phenomena or wicked problem? Our answer is "second-order observation." This is not carried out by first-order perspectives, because these are all specialized in observing different aspects of the world and not each other (economics, for instance, can only observe the observations of biology in economic terms, such as valuation). Nor are we thinking of what might be called second-order science in the form of sociology of science, history of science, philosophy of science, etc. These perspectives have science as their research object, whereas the second-order observation of polyocular research has the same research object as the first-order perspectives involved. Disciplines do not "spontaneously generate their own second-order visions when encountering domains of reality currently outside their remit" as Fuller (§6) suggests. Unlike reflexive processes in general, polyocular second-order observation requires a very deliberately planned framework. But given the right conditions, polyocular perspectives are indeed self-organising and autopoietic, they are not determined from without.

« 16 » There is a reason for using the term "polyocular" to designate this second-order observation process, and not something more colloquial such as "multi-perspectival" (cf. Hoffmann §3). The analogy to binocular vision is deep, because it incorporates the idea of looking at something through multiple "oculars" without seeing directly what each ocular is seeing. The polyocular research process is not just a second-order process, it is a first-, second- and zeroth-order observation process (cf. Figure 2); it is observing a complex dynamic object that cannot be "observed as it is," but only through the observation of different perspectives' observations of it.

« 17 » The first- and second-order processes of polyocular research are separate, very different, and mutually dependent. There cannot be a second-order polyocular perspective without first-order perspectives. And first-order perspectives cannot proclaim to observe complex phenomena without a second-order, polyocular observation process that establishes that these different perspectives are even observing the same dynamical object, let alone gathering a multidimensional understanding of it.

« 18 » The gathering of aspects of this dynamical research object by a polyocular, second-order observation of the observations – or insights cf. Szostak (§4) – of a range of different first-order perspectives is thus not like the synthesis of observations that can be made within a single perspective. The second-order process must observe and communicate these first-order observations together with their perspectival context, just as binocular vision must operate with the distance between the two oculars and the matching of the two images to infer depth.

« 19 » Callebaut (§§8–10) objects to a "levels view" of science based on a naturalistic account of science. This objection is directed against our second-order approach, but we actually agree with Callebaut in this. We do not consider second-order science of interdisciplinarity to be based on a transcendental theory of knowledge (*sensu* Luhmann, quoted in Callebaut §10). And we agree with Callebaut (§9) that: "As a matter of principle, any naturalistic/scientific account of science must be reflexive, for otherwise one would 'get out of the system'." It is important to maintain that polyocular research is a research process like other research processes; it is part of science as a self-corrective activity (Callebaut §8) or a common learning process (Alrøe 2000), just like any other kind of research proper. We think of this in terms of the systems theoretical insight that such self-correction and learning is inherently a systems internal process due to the operational closure of scientific perspectives as autopoietic systems.

« 20 » Somewhat in the same vein, Hoffmann (§§5f) asks why the second-order science of interdisciplinary research is supposed to be a "science." Second-order polyocular research must always be concrete; it is a research process that is done in connection with a selection of (first-order) scientific perspectives. It is thus not a general institution or research community, to answer Hoffmann's (§5) questions; it is an approach to interdisciplinary research. We do not speak of polyocular research as "*a* science," but as "second-order science," that is, as a form of science that consists not only of first-order scientific observation, but of first-, second- and zeroth-order observation processes. The reason we speak not only of second-order research processes, but of second-order science, is that we (in line with the special issue that this article is part of) consider the development of methods for carrying out second-order processes in science – and the concomitant criteria for whether such methods are better or worse science – a very important development of science as such; equal in importance to the differentiation and fragmentation of science that motivates such second-order science.

« 21 » As an aside, Callebaut (§11) suggests sticking to "multi-perspectival" and avoiding the term "polyocular" because it "perpetuates the persistent bias toward vision in our scientific and philosophical understanding of human perception." However, since "perspective" comes from the Latin verb for "to see through" or "look closely" (*perspectiva ars* was the "science of optics"), we are not better off using "perspective" rather than "ocular" in this regard. Instead, we suggest emphasizing the evolution of these concepts to cover not only other forms of human perception than vision, but also other forms of the much broader variety of scientific observation, which are evidently much broader, just as we use, for example, "see" and "insight" in a broader sense than that of vision.

What does this mean for understanding interdisciplinary work?

« 22 » Turning from the theoretical to the more applied side of polyocular research as a framework for interdisciplinary work, we are happy to learn of the recent publication by O'Rourke et al. (2014), which, Szostak (§9) reports, is similar to our approach in addressing perspectival barriers to cross-disciplinary communication. We have not been able to read this publication yet, but according to Szostak, the findings from the Toolbox project seem to corroborate our own findings from projects where we have tried out multi-perspectival and polyocular methods.

« 23 » In the commentaries we received several questions concerning who is doing the second-order observing. Callebaut (§7) asks: "who are to be the polyocular problem solvers," and suggests that these should be first and foremost the researchers them-

selves and other involved stakeholders. King (§§12f) asks: "Who or what does the synthesis of the multiple first-order observations," and speculates that "some human agent or languaging capacity" may be needed. Here we must emphasize the distinction between a scientific perspective as an autopoietic, communicative social systems and the scientists, researchers, and other stakeholders that may play a part in that system. Strictly speaking, from a social systems perspective, humans are not part of scientific perspectives (be they first-order or second-order), but belong to the environment of the social system. That said, we agree with Callebaut that the researchers and others involved in the first-order perspectives can take part in the second-order observation process. Researchers can to some degree participate in more than one scientific perspective, and interact (communicate) with other specialized perspectives, depending on their degree of interactional expertise (insights into other perspectives, see §61). But interactional expertise does not in itself constitute second-order science (to answer the question in Hofmann §6), though interactional expertise can help researchers partake in the second-order processes of polyocular research. We also think there are benefits from the same researchers partaking in both first- and second-order polyocular research processes, in terms of avoiding new alienations, as Callebaut (§7) suggests, and in terms of bringing insights from first-order perspectives into the polyocular communication. But there is definitely also room for other kinds of researchers to take part in polyocular research, such as the body of interdisciplinary scholars suggested by Szostak (§12), who work symbiotically with disciplinary specialists but have quite different skills and attitudes.

« 24 » Fuller (§10) suggests that the state must intervene in the case of cross-disciplinary conflicts "as a fair arbiter of these contesting second-order perspectival claims." But this does not at all enter into our suggestion of a polyocular framework for interdisciplinary research. Fuller focuses on the political conditions and incentives to encourage or – in the case of the state – "force otherwise wayward disciplines to work together to address free-standing social problems" (§5). We focus on the conditions for interdisciplinarity within science: the paradoxical co-occurrence of, on the one hand, ubiquitous and continuing calls for interdisciplinarity to compensate for disciplinary specialization in the face of complex problems and, on the other hand, a general lack of recognition of the value of interdisciplinary work and lack of incentive structures that encourage interdisciplinary work.

« 25 » Focusing on how interdisciplinary research may work, Hoffmann (§10) states that "the crucial question is obviously […] how a shared, coordinated, or integrated perspective can be achieved." We disagree, because this question throws "integrated" together with "shared" and "coordinated," and we see those as very different. In the target article (we write with reference to Alrøe & Noe 2011):

> "The differentiation and specialization of science and expertise results in what we call perspectival knowledge asymmetries: different scientific perspectives see complex matters differently, and these differences cannot, and should not, be merged." (§12)

Hoffmann (§11) writes in response to this: "If this is indeed true, why should we engage in any polyocular research project? If first-order perspectives can never be merged, how should we ever be able to cope with wicked problems?" In a similar vein, Szostak (§10) states the "there seems very little about what I would see as the critical step of integration," pointing to Repko (2012) for "the value of finding some common ground: a concept or conceptual map or even a theory that all might potentially accept" (§10).

« 26 » This question about the need for integration is, we believe, a key point, and a point that many seem reluctant to accept. We will therefore try to explicate it in a little more detail here. We think that different scientific perspectives can in general be coordinated and that synchronization is a particular aim in polyocular research; we think that a shared problem is a precondition for polyocular research; and we think that shared research in form of polyocular contextual communication is crucial to polyocular research (§§59–65). But we think that the idea of finding common concepts and theories across very different scientific perspectives as a ground for interdisciplinarity is misguided. We are of course aware that integration or merging of first-order scientific perspectives takes place, mostly in the form of related perspectives spurring a new intermediate perspective (e.g., molecular biology) or in relation to the development of new technologies, and that it may well be a political goal, such as the "converging technologies" agendas that Fuller (§4) refers to. Our point is that such integrations remain first-order, that they therefore, in contrast to the aim of integration, contribute to further differentiation of science, and that they therefore cannot solve the problem of solving wicked problems.

« 27 » As Szostak (§8) notes, we think the Kuhnian incommensurability between consecutive paradigms corresponds to problems in integrating and communicating across perspectives in interdisciplinary work (§75). But we find a deeper perspectival source of such incommensurability than language barriers, residing in the different observational apparatuses and forms of interaction provided by them. In the case of such incommensurability, when the difference is not between rationality and non-rationality, but between completely different conceptions of rationality, levelling out the disagreement by transforming it into a continua, as suggested by Szostak (§11) will be a disservice to the effort to achieve a better understanding. In the same way, holistic and hegemonic interdisciplinarity tend to hide incommensurability, whereas we want to make it visible. The contextualised observation and communication that we see as essential for polyocular research does not remove the barriers of communication between scientific perspectives, but transcends them (in line with Niels Bohr's recommendations in quantum physics, see §§22 and 63).

« 28 » Unlike what Hoffmann (§3) states, we find our approach to be very far from the "model of planning as an argumentative process in the course of which an image of the problem and of the solution emerges gradually among the participants, as a product of incessant judgment, subjected to critical argument" suggested by Rittel & Webber (1973: 162), which Hoffmann (§10) has developed as an approach to "solving wicked problems by integrating a multitude of perspectives in practice." We do not wish to claim that first-order interdisciplinarity

never works, but we also note that Hoffmann works with an approach to understanding ill-structured problems in applied ethics education, which does not directly involve scientific perspectives, whereas our article is directed at actual interdisciplinary research.

« 29 » It is important to stress, however, that the existence, and relative importance, of interactional expertise (§61), local integrations in science, and the "interfield theories" that Callebaut (§4) refers to, does not contradict our claim that scientific perspectives cannot, and should not, *in general* be merged, and that the solution to wicked problems therefore relies on polyocular research processes.

How may polyocular research help make real-world decisions?

« 30 » Szostak (§10) finds our remark that "any deliberate approach to instigate change and transformation must take place through an established perspective" (§66) rather cryptic. However, this follows directly from a perspectivist understanding of science. The scientific repertoire of interaction with the world is perspectival: physics, ecology, economy, sociology, and psychology all have different ways of interacting with the world in their research, and therefore their means of addressing a problem are different and they point to different forms of interventions to solve a problem. There is no escaping this; all research-based solutions are subject to these conditions, the different ways to instigate change are connected to different scientific perspectives. Therefore the process of establishing a shared solution is a separate, difficult task in polyocular research, based on the multidimensional understanding that has been established (§§66f). And these perspectival conditions for how to instigate change are also crucial to understanding complex societal tasks such as the regulation of agroecosystems (Noe & Alrøe 2014b).

« 31 » Szostak (§8) writes that though we, the authors, are thoroughly "perspectival," we argue that one can "gain an 'unambiguous' description of a 'complex phenomenon' by looking at this from multiple perspectives (§22)." But this is a misunderstanding; what we advocate is "taking a *complex phenomenon* to mean a phenomenon where multiple perspectives are needed to give an unambiguous description of the phenomenon." The term "unambiguous description" is from Niels Bohr (see §22), meaning a description that does not contradict itself because it includes the observational context, and not some form of objective description in a classical sense.

« 32 » In relation to this, Callebaut (§5) states that a first priority of scientific perspectivism should be the elaboration of a *grammar of perspectives*, telling us how scientific perspectives can (and cannot) be meaningfully combined; a grammar to which we, the authors of the target article, have not begun to contribute. This aim is certainly important, and we do in fact suggest at least one element of such a grammar in the target article (§76); namely a typology of the forms of complementarity between scientific perspectives and their relation to the general conditions for observation. Based on such a typology, we write,

> "an analysis can be made of what role complementarity plays in cross-disciplinary research, how scientific disagreements may be connected to the complementarity of scientific perspectives, and what this means for the options to produce unambiguous descriptions of complex phenomena through second-order science." (ibid)

« 33 » Finally, Hoffmann (§11) somewhat challengingly asks how the polyocular framework "could help make good decisions when facing wicked problems." He elaborates:

> "We can talk forever about the multitude of perspectives that come into play when we want to build a highway […] But at the end of the day there needs to be a decision: should it be built or not?" (ibid)

« 34 » We agree with Szostak (§8) that "there is no value in interdisciplinarity unless it allows understandings that are in some way superior," and that we therefore need to answer Hoffmann's question. However, Szostak (§8) continues that "we cannot speak of scientific progress unless we can understand each other well enough to recognize progress collectively." And in this lies the seed to a reply. Hoffmann's question is posed in a frame that goes beyond the frame of research. The decision to build or not build the highway is a political decision, not a scientific one. The role of science is to provide the best possible basis for the political decision. And here we think polyocular research is better, because the alternatives are worse: advice from a range of disparate and blindly disagreeing experts, advice based on interdisciplinary research biased by the hegemony of a single discipline, self-proclaimed "holistic" advice that is blind to what this particular perspective is not able to observe, etc. There is a need for interdisciplinarity to address wicked problems, and the polyocular framework is, we believe, a way towards better interdisciplinary research.

Conclusion

« 35 » There is a large and continuing increase in complexity in society. Science is itself part of this complexity increase through the involvement of science in the development of new technologies and new ways of looking at the world. But science is also a means for society to handle the (wicked) problems that the growing complexity gives rise to. Second-order science, as we see it, is a different way to handle complexity. Instead of trying to reduce complexity in the form of new universal approaches that rely on the continuing growth in computing power, the polyocular approach aims to work with concrete problematics in the form of new arenas for handling observations: arenas that are based on second-order observation of the insights of first-order scientific perspectives. Polyocular research is thus an example of a new form of science, a second-order science that incorporates both first-order and second-order research processes.

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Combined References

Alrøe H. F. (2000) Science as systems learning: Some reflections on the cognitive and communicational aspects of science. Cybernetics and Human Knowing 7(4): 57–78.

Alrøe H. F. & Kristensen E. S. (2002) Towards a systemic research methodology in agriculture: Rethinking the role of values in science. Agriculture and Human Values 19(1): 3–23.

Alrøe H. F. & Noe E. (2008) What makes organic agriculture move – protest, meaning or market? A polyocular approach to the dynamics and governance of organic agriculture. International Journal of Agricultural Resources, Governance and Ecology 7(1/2): 5–22.

Alrøe H. F. & Noe E. (2011) The paradox of scientific expertise: A perspectivist approach to knowledge asymmetries. Fachsprache – International Journal of Specialized Communication Vol. XXXIV, 3–4/2011: 152–167.

Alrøe H. F. & Noe E. (2012) Observing environments. Constructivist Foundations 8(1): 39–62. Available at http://www.univie.ac.at/constructivism/journal/8/1/039.alroe

Alrøe H. F. & Noe E. (2014) Communication, autopoiesis and semiosis. Open Peer Commentary on "Social autopoiesis?" by Hugo Urrestarazu. Constructivist Foundations 9(2): 183–185. Online at http://www.univie.ac.at/constructivism/journal/9/2/183.alroe

Andersen E. S. (1991) Techno-economic paradigms as typical interfaces between producers and users. Journal of Evolutionary Economics 1(2): 119–144.

Andersen N. Å. (2003) Discursive analytical strategies: Understanding Foucault, Koselleck, Laclau, Luhmann. Policy Press, Bristol.

Andersen N. Å. (2008) Partnerships: Machines of possibility. Policy Press, Bristol.

Anderson R. L. (1998) Truth and objectivity in perspectivism. Synthese 115: 1–32.

Atlan H. (1986) A tort et à raison. Intercritique de la science et du mythe. Seuil, Paris.

Barwich A.-S. (2014) A sense so rare: Measuring olfactory experiences and making a case for a process perspective on sensory perception. Biological Theory 9(3): 258–268.

Bateson G. (1979) Mind and nature. A necessary unity. E. P. Dutton, New York.

Bohr N. (1985) Kundskabens enhed. In: Naturbeskrivelse og menneskelig erkendelse. Udvalgte artikler og foredrag fra årene 1927–1962. Rhodos, Copenhagen: 19–39. Danish original published in 1957. English translation: Bohr N. (1955) Science and the unity of knowledge. In: Bohr N., The unity of knowledge, Doubleday & Co., New York: 47–62.

Bracken L. J. & Oughton E. A. (2006) What do you mean? The importance of language in developing interdisciplinary research. Transactions of the Institute of British Geographers 31: 371–382

Börner K., Contractor N., Falk-Krzesinski H. J., Fiore S. M., Hall K. L., Keyton J. & Uzzi B. (2010) A multi-level systems perspective for the science of team science. Science Translational Medicine 2(49): 1–5.

Callebaut W. (2003) Lorenz's philosophical naturalism in the mirror of contemporary science studies. Ludus Vitalis 11(20): 27–55.

Callebaut W. (2007) Simon's silent revolution. Biological Theory 2(1): 76–87.

Callebaut W. (2010) The dialectics of dis/unity in the Evolutionary Synthesis and its extensions. In: Pigliucci P. & Müller G. B. (eds.) Evolution: The extended synthesis. MIT Press, Cambridge MA: 443–481.

Callebaut W. (2012) Scientific perspectivism: A philosopher of science's response to the challenge of big data biology. Studies in History and Philosophy of Biological and Biomedical Sciences 43(1): 69–80.

Caporael L., Griesemer J. R. & Wimsatt W. C. (eds.) (2013) Developing scaffolds in evolution, culture, and cognition. MIT Press, Cambridge MA.

Cartwright N. D. (1999) The dappled world: A study of the boundaries of science. Cambridge University Press, Cambridge.

Chen X. (1997) Thomas Kuhn's latest notion of incommensurability. Journal for General Philosophy of Science 28: 257–273.

Clark A. (2008) Supersizing the mind. Oxford University Press, Oxford.

Collins H. (2004) Interactional expertise as a third kind of knowledge. Phenomenology and the Cognitive Sciences 3: 125–143.

Collins H. (2010) Tacit and explicit knowledge. Chicago University Press, Chicago.

Collins H., Evans R. & Gorman M. (2007) Trading zones and interactional expertise. Studies in History and Philosophy of Science Part A, 38(4): 657–666.

Darden L. & Maull N. (1977) Interfield theories. Philosophy of Science 44(1): 43–64.

Dawkins R. (1982) The extended phenotype. Oxford University Press, Oxford.

Favrholdt D. (ed.) (1999) Niels Bohr – Collected works. Volume 10: Complementarity beyond physics (1928–1962). Elsevier, Amsterdam.

Foerster H. von (1981) Observing systems. Intersystems, Seaside CA.

Foerster H. von (2003) Understanding understanding. Essays on cybernetics and cognition. Springer, New York.

Folse H. J. (1985) The philosophy of Niels Bohr: The framework of complementarity. Elsevier Science Publishers, Amsterdam.

Fraassen B. C. van (2008) Scientific representation: Paradoxes of perspective. Oxford University Press, Oxford.

Fuller S. (1988) Social epistemology. Indiana University Press, Bloomington.

Fuller S. (1993) Philosophy of science and its discontents. Second edition. Guilford, New York. Originally published in 1989.

Fuller S. (2010) Deviant interdisciplinarity. In: Frodeman R., Klein J. T. & Mitcham C. (eds.) Oxford handbook of interdisciplinarity. Oxford University Press, Oxford: 50–64.

Fuller S. (2011) Humanity 2.0: What it means to be human past, present and future. Palgrave, London.

Funtowicz S. O. & Ravetz J. R. (1990) Uncertainty and quality in science for policy. Dordrecht, Kluwer.

Galison P. (1997) Images and logic: A material culture of micro-physics. University of Chicago Press, Chicago.

Giere R. N. (1988) Explaining science: A cognitive approach. University of Chicago Press, Chicago.

Giere R. N. (1999) Science without laws. University of Chicago Press, Chicago.

Giere R. N. (2006a) Scientific perspectivism. University of Chicago Press, Chicago.

Giere R. N. (2006b) Perspectival pluralism. In: Kellert. S. H., Longino H. E. & Waters C. K. (eds.) Scientific pluralism. University of Minnesota Press, Minneapolis: 26–41.

Griesemer J. (2002) Development, culture, and the units of inheritance. Philosophy of Science 67: S348–S368.

Hales S. D. & Welshon R. (2000) Nietzche's perspectivism. University of Illinois Press, Chicago.

Hardwick C. S. & Cook J. (eds.) (1977) Semiotic and significs: The correspondence between Charles S. Peirce and Victoria Lady Welby. Indiana University Press, Bloomington.

Harrison S., Massey D. & Richards K. (2008) Conversations across the divide. Geoforum 39(2): 549–551.

Hoffmann M. H. G. & Borenstein J. (2014). Understanding ill-structured engineering ethics problems through a collaborative learning and argument visualization approach. Science and Engineering Ethics 20(1): 261–276.

Holbrook J. B. (2013) What is interdisciplinary communication? Reflections on the very idea of disciplinary integration. Synthese 190(11): 1865–1879.

Hull D. L. (2000) The professionalization of science studies: Cutting some slack. Biology and Philosophy 15(1): 61–91.

Kellert S. H. (2006) Disciplinary pluralism for science studies. In: Kellert. S. H., Longino H. E. & Waters C. K. (eds.) Scientific pluralism. University of Minnesota Press, Minneapolis: 215–230.

Kitcher P. (1998) A plea for science studies. In: Koertge N. (ed.) A house built on sand: Exposing postmodern myths about science. Oxford University Press, New York: 22–56.

Klein J. T. (1996) Crossing boundaries: Knowledge, disciplinarities, and interdisciplinarities. University of Virginia Press, Charlottesville, VA.

Klein J. T. (2004) Interdisciplinarity and complexity: An evolving relationship. E:CO 6(1–2): 2–10.

Klein J. T. (2010) A taxonomy of interdisciplinarity. In: Frodeman R. (ed.) The Oxford handbook of interdisciplinarity. Oxford University Press, Oxford: 15–30.

Koskinen K. (2013) Knowledge production in organizations. Springer, New York.

Krishnan A. (2009) What are academic disciplines? Some observations on the disciplinarity vs. interdisciplinarity debate. National Centre for Research Methods Working Paper Series 03/09. Available at http://eprints.ncrm.ac.uk/783

Kuhn T. S. (1996) The structure of scientific revolutions. Third edition. The University of Chicago Press, Chicago. Originally published in 1962.

Kuhn T. S. (2000) The road since structure. The University of Chicago Press, Chicago.

Ladyman J., Lambert J. & Wiesner K. (2013) What is a complex system? European Journal for Philosophy of Science 3(1): 33–67.

Lakatos I. (1978) The methodology of scientific research programmes. Volume 1: Philosophical papers. Cambridge University Press, Cambridge UK.

Latour B. (1988) The pasteurization of France. Harvard University Press, Cambridge MA.

Levinson S. C. & Majid A. (2014) Differential ineffability and the senses. Mind & Language 29(4): 407–427.

Lipsey R. & Lancaster K. (1956) The general theory of second best. Review of Economic Studies 24(1): 11–32.

Longino H. E. (2006) Theoretical pluralism and the scientific study of behavior. In: Kellert. S. H., Longino H. E. & Waters C. K. (eds.) Scientific pluralism. University of Minnesota Press, Minneapolis: 102–131.

Luhmann N. (1989) Ecological communication. Polity Press, Cambridge, UK.

Luhmann N. (1990) Die Wissenschaft der Gesellschaft. Suhrkamp, Frankfurt am Main.

Luhmann N. (1992) The concept of society. Thesis Eleven 31: 67–80.

Luhmann N. (1995) Social systems. Stanford University Press, Stanford. German original published in 1985.

Luhmann N. (2000) Art as a Social System. Stanford University Press, Stanford.

Læssøe J., Ljungdalh A., Alrøe H. F., Noe E., Christensen T., Dubgaard A., Olsen S. B., Kærgård N. & Kastberg P. (2014) Three perspectives on motivation and multi criteria assessment of organic food systems. Ecology and Society 19(3): 7.

Maruyama M. (1974) Paradigmatology and its application to cross-disciplinary cross-professional and cross-cultural communication. Dialectica 28: 135–196.

Maruyama M. (2004) Peripheral vision – polyocular vision or subunderstanding. Organization Studies 25: 467–80.

Maturana H. R. (2014) Understanding social systems? Constructivist Foundations 9(2): 187–188. Available at http://www.univie.ac.at/constructivism/journal/9/2/187.maturana

Maturana H. R. & Varela F. J. (1980) Autopoiesis and cognition. The realization of the living. Reidel, Dordrecht.

Maturana H. R. & Varela F. J. (1987) The tree of knowledge: The biological roots of human understanding. Shambhala, Boston.

Mesarovic M. D. & Sreenath S. N. (2006) Beyond the flat earth perspective in systems biology. Biological Theory 1(1): 33–34.

Miller T. R., Baird T. D., Littlefield C. M., Kofinas G., Chapin F. III & Redman C. L. (2008) Epistemological pluralism: reorganizing interdisciplinary research. Ecology and Society 13(2): 46.

Mingers J. (2004) Can social systems be autopoietic? Bhaskar's and Giddens' social theories. Journal for the Theory of Social Behavior 34(4): 403–426.

Mitchell S. D. (2009) Unsimple truths: Science, complexity, and policy. University of Chicago Press, Chicago.

Moran J. (2010) Interdisciplinarity. Second Edition. Routledge, Oxon UK.

Müller H. F. J. (2007) Epistemology returns to its roots. Constructivist Foundations 2(2–3): 72–80. Available at http://www.univie.ac.at/constructivism/journal/2/2-3/072.muller

Müller K. H. (2014) Mapping a new and post-disciplinary research frontier – Science and cybernetics at the second-order level. In: Müller K. H., The new science of cybernetics. Volume 4. In press.

Noe E. & Alrøe H. F. (2003) Farm enterprises as self-organizing systems: A new transdisciplinary framework for studying farm enterprises? International Journal of Sociology of Agriculture and Food 11(1): 3–14.

Noe E. & Alrøe H. F. (2006) Combining Luhmann and Actor-Network Theory to see farm enterprises as self-organizing systems. Cybernetics and Human Knowing 13(1): 34–48.

Noe E. & Alrøe H. F. (2012) Observing farming systems: Insights from social systems theory. In: Darnhofer I., Gibbon D. & Dedieu B. (eds.) Farming systems research into the 21st century: The new dynamic. Springer, Dordrecht: 387–403.

Noe E. & Alrøe H. F. (2014a) Sustainable agriculture issues explained by differentiation and structural coupling using social systems analysis. Agronomy for Sustainable Development. Online first.

Noe E. & Alrøe H. F. (2014b) Agroecology and Social Sciences – Regulation of agroecosystems. In: Monteduro M., Buongiorno P., di Benedetto S. & Isoni A. (eds.) Law and Agroecology: A Transdisciplinary Dialogue. Springer. In press.

Noe E., Alrøe H. F. & Langvad A. M. S. (2008) A polyocular framework for research on multifunctional farming and rural development. Sociologia Ruralis 48(1): 1–15.

Norton B. G. (2012) The ways of wickedness. Analyzing messiness with messy tools. Journal of Agricultural and Environmental Ethics 25: 447–465.

Nöth W. (2011) Some neglected semiotic premises of some radically constructivist conclusions. Constructivist Foundations 7(2): 12–14. Available at http://www.univie.ac.at/constructivism/journal/7/2/12.noeth

Ortega y Gasset J. (1961) The modern theme. Edited by James Cleugh. Harper & Row, New York. Spanish original published in 1923.

O'Rourke M., Crowley S., Eigenbrode S. D. & Wulfhorst J. D. (eds.) (2014) Enhancing communication and collaboration in interdisciplinary research. Sage, Thousand Oaks CA.

Palmer C. L. (2001) Work at the boundaries of science: Information and the interdisciplinary research process. Kluwer Academic Publishers, Dordrecht.

Palmquist S. (1993) Kant's system of perspectives: An architectonic interpretation of the critical philosophy. University Press of America, Lanham MD.

Peirce C. S. (1998) Excerpts from letters to Lady Welby. In: The essential Peirce Volume 2. Indiana University Press, Bloomington: 477–491.

Pennington D. D. (2008) Cross-disciplinary collaboration and learning. Ecology and Society 13(2): 8.

Repko A. F. (2012) Interdisciplinary research: Process and theory. Second edition. Sage, Thousand Oaks CA.

Riegler A. (2001) Towards a radical constructivist understanding of science. Foundations of Science 6: 1–30. Available at http://www.univie.ac.at/constructivism/riegler/20

Riegler A. (2005) Inclusive worldviews: Interdisciplinary research from a radical constructivist perspective. In: Aerts D., D'Hooghe B. & Note N. (eds.) Worldviews, science and us: Redemarcating knowledge and its social and ethical implications. World Scientific, Singapore. Available at http://www.univie.ac.at/constructivism/riegler/34

Riegler A. & Scholl A. (2012) Luhmann and the sociological turn in constructivism. Constructivist Foundations 8(1): 1–4. Available at http://www.univie.ac.at/constructivism/journal/8/1/001.riegler

Rittel H. W. J. & Webber M. M. (1973) Dilemmas in a general theory of planning. Policy Sciences 4: 155–169.

Rudolph L. (ed.) (2013) Qualitative mathematics for the social sciences. Routledge, London.

Schaeffer W. (ed.) (1984) Finalization in science. Kluwer, Dordrecht.

Scholl A. (2012) Between realism and constructivism? Luhmann's ambivalent epistemological standpoint. Constructivist Foundations 8(1): 5–12. Available at http://www.univie.ac.at/constructivism/journal/8/1/005.scholl

Sebeok T. (2001) Biosemiotics: Its roots, proliferation and prospects. Semiotica 134(1/4): 61–78.

Shapere D. (1984) Reason and the search for knowledge. D. Reidel, Dordrecht.

Simon H. (1977) Sciences of the artificial. Second edition. MIT Press, Cambridge MA. Originally published in 1969.

Star S. L. & Griesemer J. R. (1989) Institutional ecology, "translations" and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907–39. Social Studies of Science 19: 387–420.

Stichweh R. (1992) The sociology of scientific disciplines: On the genesis and stability of the disciplinary structure of modern science. Science in Context 5: 3–15.

Stokes D. (1997) Pasteur's quadrant – Basic science and technological innovation. Brookings Institution Press, Washington DC.

Strijbos S. (2010) Systems thinking. In: Frodeman R., Klein J. T. & Mitcham C. (eds.) Oxford handbook of interdisciplinarity. Oxford University Press, Oxford: 453–469.

Suppes P. (1978) The plurality of science. PSA: Proceedings of the Biennial Meeting of the Philosophy of Science Association 1978(2): 3–16.

Szostak R. (2007) Modernism, postmodernism, and interdisciplinarity. Issues in Integrative Studies 26: 32–83.

Thorsøe M. H., Alrøe H. F. & Noe E. (2014) Observing the observers – uncovering the role of values in research assessments of organic food systems. Ecology and Society 19(2): 46.

Uexküll J. von (1982) The theory of meaning. Semiotica 42(1): 25–79. German original: Uexküll J. von (1940) Bedeutungslehre. J. A. Barth, Leipzig.

van Fraassen B. C. (2008) Scientific representation: Paradoxes of perspective. Oxford University Press, Oxford.

Varela F. J., Thompson E. & Rosch E. (1991) The embodied mind: Cognitive science and human experience. MIT Press, Cambridge MA.

Weingart P. (2010) A short history of knowledge formations. In: Frodeman R. (ed.) The Oxford handbook of interdisciplinarity. Oxford University Press, Oxford: 3–14.

Wimsatt W. C. (2007) Re-engineering philosophy for limited beings: Piecewise approximations to reality. Harvard University Press, Cambridge MA.