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COMPLEX NETWORKS, STRUCTURAL EXPLANATIONS, AND THE ROLE OF VALUES IN EXPERIMENTAL LINGUISTICS

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Abstract. First, a brief state of the art on the role of values in science is presented. The main points of the critique of the ideal of a free-value science are depicted (Sec. 2), followed by a framework of four phases in the development of scientific activity that allows us to better assess the influence of values in science. The basic thesis of the present text criticizes the conception close to Heather Douglas' thesis, according to which values, including cognitive values, can only play an indirect role in science (Sec. 3). In order to show that, at certain phases of science, the explanatory power (a cognitive value) can play a direct role, we propose an examination of structural explanation, as distinguished from mechanistic explanation, in a case of experimental linguistics related to language acquisition (Sec. 4). The conclusion is presented in the last section.

Keywords: complex networks • structural explanation • experimental linguistics • cognitive values

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1. Introduction

The social relevance of philosophy continues to be a topic of debate in our discipline. According to Kitcher (2023, p.27), the philosophy of science and the epistemology of science would be quite well placed on this landscape, which unfortunately shows a shift away from public interest in philosophical products. Haack (2016) argues that interest could be revived precisely if we were to place philosophy in contexts of more social relevance. In this respect, she agrees with the results projected by authors such as Douglas (2009b, 2014), Lacey (2004, 2011), Martins Dos Reis and De Patta Pillar (2018), to mention a few cases of a philosophy directly linked to issues whose interest goes beyond the boundaries of the academy.

Obtaining and managing reliable knowledge is an inherent human goal and its social relevance is actually very important. If we consider that the highest form of doing this is the scientific one, its products, generally speaking (theories, hypotheses, models, technologies), will have to be reliable to be used in our task of understanding phenomena, explaining and predicting facts and hypotheses, intervening and influencing research domains with a minimum guarantee, or controlling various variables in these domains (experimentation) (see Hacking 1983, p.149–52; Douglas 2009b, p.93–4, 100–2, 112–3; Cartwright et al. 2022). In the case we are concerned with here, scientific explanation, its targets (*explananda*) depend to a large extent on all these products of science and also on the values underlying the scientific enterprise in situations—all or almost all—in which uncertainty and risk are part and parcel of the work that must be done (Douglas 2014). In these very common circumstances, researchers, regulators and science policy makers have to choose certain research pathways from a wider range of options. It is therefore very usual to wonder about the criteria, the interest or the objective that makes scientific research focus on one object or another, on one strategy or another, with such social weight.

Any response will undoubtedly take the form of a value judgement or depend on value judgements.[1] The ideal of a value-free science had a major impact on the philosophy of science and the epistemology of science for decades (see Rezaee & Bikaraan-Behesht 2023). However, that ideal was put into crisis and a major shift towards the examination of non-epistemic and non-cognitive values was undertaken (see Lacey 1999, 2004; Douglas 2009b). This change led to the almost consensual endorsement of the belief that ethical and social values (these would be the non-epistemic/non-cognitive ones) do influence scientific activity. Current issues as important for science and society as regulation and decision making, in addition to drawing on scientific work based on data and evidence, must take into account the influence of values and interests of the stakeholders involved.[2]

The shift away from the ideal of a value-free science has, however, led us to radically opposed positions, to the extent that the role of epistemic and cognitive values as such has been largely downplayed. It seems that the shift towards the study of ethical and social values has been excessively skewed towards certain biases and even positions that deny or greatly reduce the role of epistemic and cognitive values (Harding 1986, Longino 1990, see Haack 1998). This could call into question the very nature of the scientific enterprise. From a moderately pro-epistemic and pro-cognitive approach (see Risjord 2023), we consider it important to partially return to a defence of the positive role of epistemic and cognitive values, especially in a human science such as linguistics (Sec. 4).

To ponder the plausibility of the thesis that ethical and social values dominate in the social and human sciences, we first look at an epistemological proposal, specific to the philosophy of science, which projects an image of science as constituted in four phases (Lacey 1999, Martins Dos Reis & De Patta Pillar 2018, Douglas 2009b).[3] It is within these phases that we can inquire into the role of epistemic, cognitive and social values, and into which, if any, are strongest in each phase. The interest of this lies in the fact that we are interested in assessing scientific activity in a social and human science such as linguistics, a field in which, according to the advocates of the role of social and ethical values, these acquire even greater importance, if possible.

However, here we want to argue that it is precisely epistemic and cognitive values, in particular the explanatory capacity, that play a crucial role in this science, and that they dispel some of misunderstandings surrounding the multiplicity of interpretations and the weakness of the evidence used. Building on Douglas's (2009a, 2009b) dissection of the (direct and indirect) role of values in science, our analysis of the case of structural explanation in linguistics seeks to nuance that response and to re-emphasize the direct role of some cognitive values in scientific activity, especially that of explanatory power (see Cartwright et al. 2022).

2. A science with social value

Despite the aforementioned shift towards the study of non-epistemic and non-cognitive values, it is still possible to argue that there are epistemic and cognitive values that influence scientific activity in a very relevant way. Heather Douglas (2009b, p.92) starts from an interesting typology of values. According to her, we can distinguish between ethical values and social values on the one hand, and epistemic values and cognitive values, on the other. The latter two types differ in that epistemic values as such are not really values, but criteria that any scientific enterprise must meet. These are established because science is valued *as such*. They therefore fix the scope of science from the outside, and do not act as values within science. Cognitive values, on the other hand, constitute something more precise than a loose grouping of acceptable values in science (this is what is often equated with epistemic values). Cognitive values, he points out, are those elements of scientific work that helps us to reflect on the evidential and inferential features of theories and data that scientists hold (Douglas 2009b, p.93). They would be assistants to the cognitive work of scientists. In short, if cognitive values are concerned with the fruitfulness of research, epistemic values are concerned with the starting or basic goal of research, namely the true or, more usually, *reliable* knowledge. Furthermore, and importantly, cognitive, social and ethical values should never claim to play a *direct* role in science. That is, they should not be equated with the evidence and data used by scientists.

We see, therefore, that a value of high epistemic incidence is the reliability of the products of science. Cartwright et al. (2022, Part I, 3), in the wake of an idea of Otto Neurath, point out that reliability is an umbrella concept or *Ballung*. The concepts linked to cognitive values (scope, simplicity, explanatory capacity, consistency) would be deployed alongside it.[4] Science, among other things, would seek to propose coherent models, hypotheses or theories, or to offer adequate or useful theories. But we also know that theories and the scientific practices associated with them have degrees of uncertainty and are fallible and provisional (see Shrader-Frechette 1993), a fallibility that scientific practices and theories seek to reduce. What does seem to be accepted is that there is no such thing as a value-free science (whether or not that ideal is upheld), on the one hand, and that, although it is value-laden, science still has its own virtuous features (reliability, truth) without which science would cease to be science and research would cease to be research. In addition to those mentioned by Douglas (see endnote 4), we find precision, clarity, justification, objectivity, truth, empirical adequacy (see van Fraassen 1980; Lacey 1997, p.7), respect for evidence, as well as the effort to minimize fallibility and uncertainty (Douglas 2009b, p.95).

Ethical and social values also influence science. Ethical values are concerned with what is good or right, and are very important in examining the consequences of scientific errors for the general public. Among other things, they help us to weigh up whether potential benefits are actually potential dangers to be taken into account or not, whether there are dangers to be assumed without any price, etc. (Douglas 2009b, p.92). Social values arise from what a particular society values: justice, privacy, freedom, social stability, innovation, etc. (Lacey 1999, p.28–9).

Taking these different types of values seriously has promoted the aforementioned critique of the ideal of a value-free science (Kincaid; Dupré; Wylie 2007), which has changed the overall scope of the debate. Both the supremacy of the old value-free ideal and the exclusive interest in epistemic values (McMullin 1982; Laudan 1984) of scientific research have been called into question (Douglas 2009b, p.89). At the present it is social, political or ethical values that are of considerable interest in recent axiological debates (Koskinen & Rolin 2022; McMullin 1982). The efforts to overcome the ideal of a science free of values has been made in order to adopt an increasingly pluralistic scientific attitude, both in natural and social sciences (Kellert; Longino; Waters 2006). This new attitude is based on the basic idea that scientific research is a human activity that is goal-oriented and highly influenced by non-epistemic values and norms of research settings (contexts) (González 2013, p.1505). The four most prominent lines of criticism of the ideal of a value-free science can be summarized as follows:

[1] Philosophers sought to 'unmask' the so-called epistemic values that are in fact non-epistemic ones. Longino (1996) has argued that so-called 'epistemic' values are not in fact exclusively epistemic, for their use assumes political and social values in contexts of scientific judgement. There are values that underlie scientific judgement and they are not always, or even usually, politically neutral. Longino proposes to juxtapose these values with values (including many of a feminist nature) such as novelty, ontological heterogeneity, mutuality of interaction, applicability to human needs and diffusion of power. Failure to recognise this axiological richness and variety can lead to bias and adverse research outcomes (Wilholt 2009, p.96).

[2] Richard Rudner's (1953) now classic critique (see Resnik & Elliott 2023, Lacey 1999, p.71–4) questioned the idea that any decision about a scientific theory or hypothesis can be value-free (Douglas 2009b, p.51-2). According to him, any acceptance or rejection of a hypothesis is set against a background of knowledge and priorities (Rudner 1953, p.2), and a scientific hypothesis is never confirmed beyond reasonable doubt: there is always the possibility of a decision being wrong (Resnik & Elliott 2023, p.7). The decision to accept or reject a hypothesis implies a value judgement (at least implicitly); one has to judge which of the consequences of an erroneous decision is more acceptable.[5] Hence, non-epistemic (moral, social) values are a necessary part of the scientist's core activity of accepting and rejecting hypotheses.

[3] Moreover, using a strategy similar to Longino's (1996), Putnam (2002, p.140–2) rejects the possibility of a value-free science by means of a *semantic* argument that attacks the neutrality of scientific theories. Putnam (2002) points out that among non-epistemic and non-cognitive concepts, especially among ethical ones, there are values that can be considered both normative and descriptive depending on the perspective adopted. These are cases like 'cruel', 'dirty' or the like. He calls them 'thick' concepts and uses them precisely to provide counterexamples to the fact/value distinction or, in our context, non-epistemic value/epistemic value.[6] If the use of terms such as these intertwining facts and values is unavoidable in scientific practice and reasoning, any proposal of scientific hypotheses and results can hardly be value-free. This seems to undermine any thesis advocating the impartiality of science and the neutrality of its values.[7]

[4] Some philosophers of science argue that non-epistemic values have an indispensable legitimate role to play in assessing the risks involved in the acceptance of scientific hypotheses and decisions (the argument from *inductive risk*) (Elliott & Richards 2017; Elliott & Steel 2017, Part III; Brown 2013; Douglas 2000, 2009b, p.58; Rolin 2015, p.161; Steel 2010; Wilholt 2009; see Rudner 1953, p.2). One of its premises is that the acceptance or rejection of hypotheses (the usual task of scientists) involves uncertainty. In doing so, a scientist has to decide whether the available evidence is strong enough to warrant acceptance. This decision depends on the risks involved. If scientists accept a false hypothesis, there may be a cost associated with this type of error. If they reject a true hypothesis, the cost will be of a different kind. The key premise of this critique is that the assessment of the costs involved in both types of errors is a matter of moral value judgement (Rudner 1953, p.3).

As can be seen, it is assumed that defending the role of non-epistemic and non-cognitive values in attempting scientific hypotheses or theories does not necessarily rule out the possibility of creating regulatory frameworks in which beneficial and harmful consequences of such values could be distinguished (Crespo 2019; Diekmann & Peterson 2013). This makes it possible to propose alternatives, sometimes quite complex, to the ideal according to which science is *free of values*. Those would be alternatives that should redefine and distinctly locate several epistemic notions such as reliability, objectivity, and rationality (Douglas 2009b, Chapter 6; Koskinen 2021; Catwright 2022).[8] These epistemic values guide the task performed together with cognitive values, including the explanatory power (Cartwright et al. 2022; Pritchard 2021, p.5523; Intemann 2015; see Psillos 2015; Koskinen & Rolin 2022, p.193). The combined form of all the products derived from taking these values into consideration would be that of a *network*. The location of values, in turn, would not be given by the classical distinction between epistemic and cognitive versus social and ethical values, but rather by the role played by each type or each *token*: direct or indirect (Douglas 2009b, p.95–7). But we point out the relevance of the 'token' precisely because, contrary to what Douglas claims, we consider that the role of the explanatory power of scientific theories (understood as a cognitive value) cannot be labelled as 'indirect' *tout court*. Both mechanistic explanations and (mathematic-like) structural explanations in experimental linguistics will serve as an illustrative case for our critique of Douglas.

In order to locate and seek to understand this critique, we must see that the acceptability of scientific activity would therefore be based on its reliability, related to the use of evidence, together with the assessment of the lack of bias, the significance of scientific theories and all their products, their completeness, their consistency and other cognitive values. The constant consideration of these epistemic and cognitive values in scientific activity is not exempt from the participation of social and ethical values as well. The network in which they play a part is complex and tangled, and it is therefore useful to unravel, at least partially, those phases of the scientific enterprise where the use of values is more or less direct. The complex nature of scientific activity should be emphasised if we were to understand its products in any of the phases in which it takes place. Understanding this kind of complexity is linked to the reliability we expect from science from the very moment we begin to develop it (Cartwright et al. 2022; Brigandt 2015; Potter 2006; Lacey 1999, p.38–9).

3. Values into scientific research fundamental phases

Values are inherent in scientific practice aimed at providing reliable knowledge (McIntyre 2019, p.230; Douglas 2009b, p.113–4; Potter 2006, p.78).[9] How to articulate such reliability rolled in values, including social and ethical ones, is a pressing goal for the philosophy of science (see Cartwright et al. 2022, Part II, 4). If values, therefore, cannot be refused from scientific activity, then reliability or, as it may be, approximation to truth, would have to be obtained through different strategies in scientific research.[10] One consists of recognizing the plurality of values at the different stages of research, from the very beginning, when researchers select their goals and working methods—theory-guessing, making conjectures or hypotheses, and so on (Vilhalemm 2016; Popper 1994, p.95))—, to the final implementation stage. In all these stages, the weight of values can be estimated in some way, and their linkage to properly epistemic strategies based on evidence and data can be calibrated.

It is interesting to critically examine the roles that values can play in scientific activities (Lacey 2011; Lacey & Mariconda 2014).[11] This examination starts from the understanding that scientific activity can be structured in phases, specifically in four ('Ph' onwards) (see Douglas 2009b, p.88–9): [Ph-1] Adoption and development of a research strategy; [Ph-2] gathering data; [Ph-3] cognitive and/or epistemic evaluation of the theories, models or hypotheses proposed to solve some problem identified in the initial adoption; and [Ph-4] implementation of the obtained scientific knowledge.

[Ph-1] *Adoption and development of a research strategy*: The first decision concerns the research strategy; the research topic must be decided. One usual starting point of a research is to propose some conjecture, hypothesis, problem or theory (Cartwright 2022, p.19–20). That point serves to select and shape the phenomena that scientists intend to investigate. In order to do this, researchers irremediably take non-cognitive values into account. Adopting a research strategy is similar to propose a complex framework of scientific inquiry made up of various elements, among which the identification of an initial problem and of a working guide hypothesis helping to solve the former are two remarkable ones (Lacey & Mariconda 2014, p.647). This initial guide to scientific inquiry is crucial in order to establish the relevant types of empirical data, the appropriate descriptive categories for making observational reports, as well as the theories linked to data. The link between data and theories, it must be emphasized, requires the adoption of a strategy from the beginning.

[Ph-2] *Gathering data*: Once the object of research has been determined, scientists enter the justification phase, in which data and evidence are collected and accumulated,[12] attempts are made to justify certain hypotheses, to explain facts in the field studied or, in some cases, to predict those facts. The ways of collecting evidence can be very varied if we compare the natural sciences with the social sciences. In the latter, it is very common to appeal to interviews, reports, field work and, in general, to tools that are foreign to most of the natural sciences (Douglas 2009b, p.88).

[Ph-3] *Epistemic evaluation of theories (models, hypotheses)*: Once the necessary efforts have been made to confirm and verify (or disprove or falsify) certain hypotheses, the strongest or the best supported hypothesis is chosen. To confirm a hypothesis is to find evidence or reasons for it and not against it, so that the hypothesis likelihood increases. However, at this stage, contrary to what Douglas (2009b) advocates, cognitive values can act as criteria for epistemic evaluation and be independent from non-cognitive values (McIntyre 2019, Landes 2020). As theories or hypotheses tend to be accepted or refuted more clearly according to some criterion of reliability, a theory will be accepted for a field of phenomena if it exhibits its own cognitive values (scope, accuracy, explanatory power, predictive power, etc.) not shown by any alternative theory—or shown by the latter in a lesser degree. This is always made in the light of empirical data and the relevant and sufficient evidence collected from observation, experimentation or even simulations, and always on the basis of the used theory and of the phenomena to be studied. Non-cognitive values and certain non-empirical (metaphysical, speculative) convictions play no role in the 'Ph-3' of the theory assessment choice. This kind of values hardly, or not at all, determines the investigation in Ph-3 (see Betz 2013, p.212).

[Ph-4] *The implementation of knowledge*: To the extent that a hypothesis or theory is consolidated in a scientific discipline, and depending on researchers' interests and values, the conclusions and the practical, applicable and even regulatory options are analyzed and selected for decision-making in science policy (see Bengoetxea & Todt 2021, p.57–62; Bengoetxea 2024, p.113). This is also called 'the phase of implementation' of science (see González 2013). It may adopt the form of a transition from the natural sciences' context to the context of social sciences (from biochemistry to regulation, typically). By applying scientific knowledge, some ideals are projected and researchers serve certain interests that reflect specific non-cognitive values. Science is applied because scientists both expect some benefits stimulated by their initial research interests and assume to overcome some *potential* negative consequences of scientific applications (Lacey & Mariconda 2014).

It is not a necessary condition that these four phases develop in a successive order (for example, Ph-2 and Ph-3 could influence Ph-1, or the processes in Ph-4 could (allegedly) affect previous phases). Since the processes of obtaining scientific knowledge and its application are subject to varying degrees of uncertainty, science is assumed to be *fallible* (this is also a condition for doing science today). It means that scientists sometimes have to make decisions (or hypotheses) under risky conditions (Elliott & Richards 2017, p.2). In doing so, it is most usual to think about the (also social) interests of the cognitive enterprise, as well as the possible errors of such decisions. Thinking about consequences requires taking into account social, political, ethical and economic values, all of which can influence the process of verification and justification of a hypothesis by the scientific community. Therefore, it seems to us that the Ph-1/Ph-4 scheme is a good tool that could make easier the representation of the cognitive processes established and developed in science. The case study of structural explanation (section 4) is proposed to support this hypothesis. In the case of experimental linguistics, structural explanatory techniques involve introducing a cognitive value (explanatory power) in Ph-2 and Ph-3 as a fundamental element. This does not preclude the need to resort to non-cognitive values in some cases. In this sense, as we approach the social or human sciences, where human behavior is the object of research, it is more difficult to avoid the influence of non-cognitive values. Human language is a very complex phenomenon with many edges. Therefore, the articulation and evaluation of evidence and hypotheses turns out to be very complex and allows for different interpretations that may be motivated by multiple values or interests, at least in principle, although the main goal is their reliability as an epistemic value that conditions scientific activity. But explanatory power—conceived as a cognitive value playing a *direct* role in Ph-2 and Ph-3—is located in a complex *network* along with other values—cognitive, ethical, and social—and can help develop a more reliable and more integral science (Douglas 2009b, p.95), also in the case of experimental linguistics.

4. Complex networks, structural explanations and the study of some features of language

Hempel's nomological-deductive model of explanation ceased to be the quintessential approach in disciplines such as biology and neurosciences studying living and cognitive systems (Kitcher 1989; Douglas 2010; Hempel 1965; see Diez; Khalifa; Leuridan 2013; Douglas 2009a, p.449; Salmon 1989, p.94–101; Friedman 1974). Instead of seeking universally applicable laws or predictive models, researchers into these fields have sought to understand the behavior of living organisms by analyzing them in parts (structures). This explanation strategy was based on the study of mechanisms (Machamer; Darden; Craver 2000; Moreno & Suárez 2020, p.146).

However, mechanistic explanation is a type of explanation that cannot always account for certain aspects of the biology of organisms (development, reproduction, etc.) (Alleva; Díez; Federico 2017) nor deal with other properties of complex systems that are better explained by tools from complexity sciences (Huneman 2018, Brigandt; Green; O'Malley 2017). Something can be said to be *complex* if it is made up of interconnected parts and if the understanding of its behavior requires comprehending not only the behavior of its parts, but also the way in which they mutually act to give rise to an overall behavior. Global description requires describing the parts, and these in turn are described in terms of the whole (Bar-Yam 1997, p.1).

The most important characteristics to be taken into account of complex systems can be summarized as follows (Bar-Yam 1997, p.5): (1) the elements or entities of a system (and their quantity), (2) the interactions among them (and their strength), (3) their formation and function, (4) their diversity, (5) their environment, and (6) their activities. But what is complexity? To detail a description of a complex system, it is useful to understand how the concept of complexity is related to that of emergence (Bar-Yam 1997, p.6).

The concepts of complexity and emergence constitute the context in which the general properties of complex systems emerge and in which general phenomena can be better understood. A complex system is a system made up of many components whose behavior is emergent; that is, the behavior of the system cannot be inferred directly from the behavior of its components (Bar-Yam 1997, p.9). The amount of information needed to describe the behavior of such a system would be the measure of its complexity. Emergence arises because collective behavior is not understood from the behavior of its parts (Bar-Yam 1997, p.10). We can speak of emergence when we take into consideration a set of elements and the properties of the collective behavior of those elements.

Therefore, a complex system can be characterized as a co-evolving network of many levels. Thurner, Hanel and Klimek (2018, p.22–3) articulate an intuitive picture of this concept as follows: (1) complex systems are composed of many elements, (2) those elements interact with each other through one or more interaction types, (3) interactions are not static but change over time, (4) elements are characterized by states (states can be scalar; if an element has various independent states, it will be described by a state vector or a state tensor; and states are not static but evolve with time), (5) complex systems are characterized by the fact that states and interactions are often not independent but evolve together by mutually influencing each other (states and interactions *co-evolve*), (6) the dynamics of co-evolving networks is usually highly non-linear (see Hooker 2011, p.842–3), (7) complex systems are context-dependent (networks provide that context and thus offer the possibility of a self-consistent description of complex systems), and (8) complex systems often have memory (information about the past can be stored in nodes, if they have a memory, or in the network structure of the various layers).

4.1. Complex networks and structural explanation

The mechanistic strategy introduced by Bechtel and Richardson (1993), Glennan (1996) and finally Machamer, Darden and Craver (2000), among others, holds that it is possible to analytically decompose a complex system into its simplest components to methodologically isolate a few parts, so that causal mappings can be established between specific functional operations and their distinguishable structural components (Moreno & Suárez 2020, p.145). Thus, explaining would amount to providing a mechanism whose action is causally responsible for creating the phenomenon to be explained. What plays the explanatory role is the specification of the mechanism itself and not a set of physico-chemical laws of nature.

After the publication of the article by Machamer, Darden and Craver (2000), the mechanistic approach became one of the main lines for accounting for scientific explanation. However, in the field of the philosophy of biology, criticism has arisen because the mechanistic approach has two faults: on the one hand, it seems unable to account for some aspects of the biology of organisms (development, reproduction, etc.) (Alleva; Díez; Federico 2017) and, on the other hand, it is not able to deal with other properties of complex systems that are explained by the tools of the Complexity Sciences (Huneman 2018; Brigandt; Green; O'Malley 2017; Deulofeu; Suárez; Pérez-Cervera 2021). Faced with this, the structural explanatory alternative arose (Huneman 2018).

This alternative serves to propose explanatory strategies that employ mathematical tools and formalisms that can be conceived as 'network modeling' (e.g., cellular automata, Boolean networks, chaotic and dynamical systems theory, topology, graph theory, etc.) (see Huneman 2010, p.217; 2018, p.665, 692–3), which can constitute accurate means for examining emergent properties of complex systems. They can do so in a different way from mechanistic models, since the structural explanation is obtained as a consequence of *identity* relations between the empirical system and the mathematical system, independently of the causal mechanisms that give raise to the properties in the empirical system.[13] This kind of structuralism does not deny, however, that the final result produced in these systems is a result due to the action of causes. What we assert is that, whatever the causes are, they are not mechanistically structured and knowing them is not necessary to explain the properties of the complex system.[14]

A crucial feature of structural explanation is that it is not based on the mechanism that causally produces some phenomenon, but rather on the mathematical network properties of the system. This is something crucial for explaining complex systems. At this point, we are basically interested in discovering the organizational features generating an emergent property in a system, in spite of all the possible range of activities that could modify its mechanistic details. Structural explanations account for properties of complex systems as a consequence of the way these systems are organized (Huneman 2018); they are based on kinds of mathematical properties in an empirical system: its topology, its trend to find an equilibrium point, etc. (Moreno & Suárez 2020, p.149). The explanation is made possible by this abstraction and the tendency of the system to realize some property just because of its mathematical structure. We think that this approach can be extrapolated to other fields; for example, to parts of experimental linguistics.

4.2. Some basic ingredients of structural explanations

Mechanistic explanations cannot fully account for linguistic phenomena either. Experimental linguistic systems are made up of many entities that interact locally and in a relatively simple way, but can nevertheless give rise to quite complex behaviors. What happens holistically cannot be explained by a functional—or causal—decontextualized decomposition.

Complex linguistic systems can be conceived as networks (Moreno & Suárez 2020, p.154; Barabási 2002). One defining feature of a network is *recursion*, which implies the closure of interaction paths on themselves. Thus, a linguistic network, for example, would be a network that represents a sociolinguistic structure by mapping a graph: if two elements of the set of actors (individuals, utterances, etc.) are mutually related according to some criterion (massive use of the term 'that', being English speakers, some physiological-linguistic condition X, etc.), then a line is drawn connecting the nodes representing those elements (Seoane & Solé 2018). When these nodes become dense cores, *hubs* emerge (Barabási 2002, p.58).

One of the crucial features of networks is their systematic holism, namely their global behavior cannot be explained by detailed knowledge of the behavior of each unit (Green & Jones 2016). The importance of holistic processes is great in linguistic systems, although until recently there were no quantitative methods to deal with complex holistic systems. Today, by contrast, the study of networks has been greatly developed by means of computer simulations and other mathematical developments. 'Graph theory' studies the relationship between network architectures and their dynamics, and allows scientists to study complex holistic systems with strongly interacting and recurring components that show that, despite their variety, they share certain generic properties.

The scientific approach to complex holistic systems consists basically in the quantitative study of the conditions under which some sets of components, once they exceed a critical point or mass of interconnections, lead to the emergence of new global properties (hubs are a way of representing them). What is particularly interesting about this phenomenon is that, although the complexity of the dynamics leading to the overall behavior of the network cannot be dealt with analytically, there are ways of predicting that behavior that are based solely on the degree of interconnections between the parts of the system (Moreno & Suárez 2020, p.155; Huneman 2010, p.214). While mechanistic explanation sought to establish links between different empirical systems having the same mathematical structure (e.g., linguistic networks, computers, social networks, genetic networks, metabolic networks), structural explanation has the advantage of focusing its analysis on the specifically *dynamic* properties of a complex empirical system. This is one of the main reasons to understand that networks are systems susceptible to structural explanation (Seoane & Solé 2018; see Moreno & Suárez 2020, p.157). Given the existence of a high number of observables in any network, it is more feasible to handle different local rules—rather than a universal law—depending on the sort of network one is working with (random, small-world, scale-free, and so on) (Keller 2005a, p.7-8; Keller 2005b).[15]

4.3. Design in experimental linguistics

The ability to elaborate explanations in our case (linguistics) combines structural explanations with mechanistic explanations to generate answers to 'why' questions of interest (Barceló-Cobjlin; Corominas-Murtra; Gomila 2012; Barceló-Cobjlin et al. 2017). The work in both experimental design and the elicitation of an explanatory capacity based on complex networks turns to some basic elements:

[i] The design of the operational procedures of experimental linguistics takes into account both qualitative and quantitative elements. Their starting point is data collection and statistical analyses of the latter (Abbuhl; Gass; Mackey 2013, p.116; Gries & Newman 2013). From an epistemological point of view, this procedure attempts to satisfy three goals of the design: its validity, reliability and replicability (Radder 2003, p.156–8). This occurs in Ph-2 and Ph-3.

[ii] Any study can be internally or externally valid. When researchers conclude that a stimulus (a learning therapy in phonetics, for example) is responsible for the observed effects, we say that it is internally valid (it belongs to a small-world). Validity is external, by contrast, if the results can be generalized beyond the employed sample of experimental subjects (beyond a small-world) (Zuidema & de Boer 2013, p.430). External validity highlights that the results of an experiment are valid not only for the subjects studied, but also for a larger portion of the population (Cartwright & Hardy 2012) beyond the particular experimental setup. The *reliability* of the experiment depends on the consistency of its observations and measurements. Consistency should occur both between different evaluators and between the different instruments used to measure or collect data (*instrumental reliability*). This also occurs in Ph-2 and Ph-3.

[iii] It is crucial for the reliability of a study that it can be replicated. Replicability occurs when its outcomes can be repeated with alternative populations and in different contexts. Collecting and selecting representative and reliable bases of different sorts of data is understood to be a major empirical task for linguists (Abbuhl; Gass; Mackey 2013, p.117). The main goal of the data collection is to explore whether there is any similarity or any important difference related to the working hypothesis that researchers are handling.

4.4. The case of language acquisition

Consider the attempt to provide a structural explanation of *language acquisition*. Experimental linguists tend to propose some computational technique capable of capturing the complexity of a speaker's ability to syntactically combine lexical items (see Corominas-Murtra; Valverde; Solé 2009). Classically, the basis of these procedures has been the different theories of language acquisition, which have disagreed about their starting hypothesis:

[1] Chomskyan or classical linguists conjecture that infants enter this process equipped with some innate linguistic predisposition (Chomsky & Miller 1963).

[2] Michael Tomasello's (2003) alternative argues for the existence of certain general, non-innate, learning abilities that can account for this process.

[3] Some experimental linguists (see Corominas-Murtra 2007) have opened new paths of research aimed at overcoming this discrepancy. Ninio (2006), for example, has shown that the acquisition of syntactic patterns challenges Tomasello's *usage*-based hypothesis that infants learn the lexicon *in contexts*. What Ninio conjectures is that infants learn language because they are sensitive to categories and syntactic dependencies.

Each alternative to the problem of language acquisition explains its own target on the basis of a different theoretical hypothesis. Regarding [3], the alternative most directly linked to what we are dealing with here, Barceló-Coblijn, Corominas-Murtra and Gomila (2012) qualify two aspects of Ninio's statement: they argue that infants are not sensitive to syntax at the beginning of their language use (two years old) and that different languages, moreover, differ in their syntactic structuring. To conjecture and present evidence for their hypothesis, they have analyzed a pattern of syntactic development (occurring in the infant's third year of life) to see whether it is universal or simply a language-dependent pattern. Their purpose, therefore, is to discern patterns of syntactic development or, as in the case of the evidence-weighting problem, to propose evidence for different explanations.

To do this, they have presented a dynamic modeling of complex networks combined with longitudinal studies. To build such a model, previously, Barceló-Coblijn, Corominas-Murtra and Gomila (2012, p.431) had selected evidence in three phases. On the one hand, they analyzed three corpora taken from the CHILDES database,[16] each containing at least ten transcribed conversations (texts). On the other hand, they selected three corpora of specific natural languages (German, Dutch and Spanish). Finally, they followed three criteria to choose the instances of each corpus: (i) each had to have at least ten transcripts, (ii) each had to cover at least 300 days of the infant's life, especially those from 20 to 30 months, and (iii) the transcripts had to be qualified on a regular basis (cf. http://childes.psy.cmu.edu/).

The dynamic character of this design can be captured by the use of SAN[17] software in order to solve certain recurring problems in previous computational modeling that combined material scripts with software. The linguists employed a graph of lexical dependencies to model the syntactic structure constructed from the data collected from the samples (syntactic structure graph). This modeling exhibits a procedure that tracks the most widespread network linking lexical items in each infant's speech. Linguists call this a 'GCC network' (giant connected component) and it is nothing more than the connected component of a network containing a constant fraction of the nodes of the complete network (Barabási 2002, p.58). It is a non-static modeling, therefore, and is intended to examine the evolution of the GCC over time, in the way of an idealized modeling intended to explain the infants' syntactic abilities.

It should be kept in mind that the explanatory virtue of this type of design and modeling depends on the data and evidence with which it operates, not so much on the identification of a causal path, as mechanistic explanation aims to do (Deulofeu; Suárez; Pérez-Cervera 2021, p.2016).

4.5. A moderate direct role for the explanation as a cognitive value

Computation therefore makes it possible to assign some kind of formal structure to the target phenomenon (graphs, networks, hubs) by means of a program whose goal is to model aspects of the linguistic structure through those graphs and complex networks. This is a clear case of dynamic and processual modeling, carried out in different phases of a research program extended over time. In any case, the method is statistical and data-driven, in addition to being based on background (syntactic) learning rules based on corpora and various samples (Gries & Newman 2013, p.258–260).

The core of this computational task consists of representing the dynamic monitoring of the larger network that unifies the lexical items of each infant's speech through the use of networks. The goal of the GCC network was to operate as an idealized modeler that sought to represent infant's syntactic ability (Barceló-Coblijn; Corominas-Murtra; Gomila 2012, p.232). It is a sort of dynamic modeling that in turn serves as a device for making inferences, generating hypotheses and structurally explaining relevant results linked to the working hypothesis (on language acquisition). Specifically, the linguists (1) confirmed their results in the case of English, (2) were able to infer the hypothesis that there are universal patterns in language acquisition—with an inference from the studied cases to the general human population—, and (3) were able to infer 'confounding effects' related to syntactic productivity (McNamara 2006).

This whole structural explanatory strategy is based on the network configuration of the linguistic system under study. From an epistemological perspective, it is a structural explanation that does not depend on the explicitness of any causal (mechanistic) structure of some given phenomenon (Deulofeu; Suárez; Pérez-Cervera 2021). It is based only on the mathematical or formal-computational organization of the system. The ontological perspective is not so decisive here, since the nature of those elements, how they operate, or the causal trajectories they follow are largely irrelevant. According to this, a structural explanation results from linking an empirical (linguistic, in this case) system to a mathematical structure and attributing properties of the mathematical structure to that empirical system (see Huneman 2010, 2018).

Douglas argues that it is dangerous to employ any value, cognitive or social, in its direct role in accepting or rejecting a hypothesis (Douglas 2009b, p.110). She claims that neither cognitive nor social values are a good reason by themselves to accept or not accept some theory. We partially disagree with this statement. The explanatory power of a linguistic theory is one element among others (always combined with other elements (see Cartwright et al. 2022)) that sometimes plays only an *indirect* role (guiding and supporting decision-making by researchers or regulatory scientists),[18] but at other times can act directly because scientific explanatory power, unlike other cognitive values, is based on the development of explanations themselves, which is directly linked to working evidence and data. This normally occurs in phases Ph-2 and Ph-3, although it is related to the other phases. What we do not demand here is that the explanation has to be based on mechanisms, in general, nor on causal mechanisms, in particular. A structural explanation, based on mathematical topology, can provide a representation of an *explanandum* that reflects a network and that can be added to help solve several problems.

5. Conclusion

The openness of philosophy to other fields of interest takes the form of a focus on issues of both social and scientific interest. To this end, it is essential to work hand in hand with scientists themselves (Douglas 2010, p.317). Some philosophers have claimed that philosophy of science should regularly get engaged into scientific practices in order to understand their underlying philosophical issues (see Kitcher 2023, p.16). It is about a kind of social relevance that we might describe as 'being philosophically attentive' to those aspects of science that are particularly important to society.

Given the *desideratum* that philosophy should obtain greater relevance among scientists and the general public (Kitcher 2023, p.16), we have considered one nexus connecting just the three domains of values. The values—whether epistemic, cognitive, social, or ethical—were initially conceived (according to the ideal of a value-free science) as an undesirable influence on the scientific enterprise and on its integrity, objectivity, and reliability. However, these concepts themselves already took the form of values, at least epistemic and cognitive ones. A space was made for them, but not for the supposedly harmful 'social and ethical values'. This image was soon superseded in the philosophy of science by a series of well-established critical arguments, originated by Rudner in 1953, so that more detailed and complex approaches, such as that of Heather Douglas or Hugh Lacey, among others, established phases of science in which the integration of values gradually varied. Thanks to this new sharing of the complex procedures of making theories and practices in science, it has been possible to understand that the role of values is located in some combined processes similar to what Neurath meant with his '*Ballung* concepts'. In these circumstances, Douglas further incorporated the interesting idea that values, of whatever kind, may influence various phases of science, but will never play a direct role (Douglas 2010, p.328; 2009b, p.96, 112).

Well, this is precisely the thesis that we criticize here. The cognitive value 'explanatory power' is essential to support the epistemic value 'reliability'. And scientific explanation is not limited to playing an indirect guiding role in decision making, but, in the sense of the *Ballung* mentioned above, it is developed together with the handling of data, evidence and other properly scientific products and means. We have tried to show this in the case of experimental linguistics. We have proposed the notion of structural explanation, based on mathematics, which serves as a complement to many results of mechanistic explanations, since structural explanations are not conceived as mere 'aids' for decision making in the central phases of science (Ph-2 and Ph-3, for example).

Later we have moved towards those three desiderata through the application of a structural explanatory approach. The task of elaborating a notion of scientific explanation is properly philosophical and, in order to carry it out, we have also taken into account an approach based on a direct role of cognitive values. We have presented a case from experimental linguistics with which we work in close proximity to values and evidences linked to language acquisition. We think that this is a sufficient demonstration, at the moment, to positively value the scientific (linguistic) and social advances of an experimental science in continuous progress and helped by a philosophy of science, epistemologically rooted, that attempts to adequately conceptualize it.

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Notes

[1]On the multiple lines of research adoptable in medicine, as a field of high scientific and social interest, see for example Barker and Kitcher 2014, p.153–4.

[2]Advocates of the ideal of a value-free science might object that the influence of values, if any, is always prior to any research. This is the seminal idea of Reichenbach (1938) when he proposed the distinction between the context of *discovery* and that of *justification*, according to which, the mission of the scientist would be to seek and find this justification, to establish a hypothesis well, to justify it, corroborate it and verify it in such a way that non-epistemic values do not intervene in these procedures. This is precisely what is not accepted *tout court* today.

[3]Although we follow the four-phase pattern, closer to Douglas and Lacey, other authors, as is the case of Martins Dos Reis & De Patta Pillar (2018, p.464–8), analyze the roles that values exert in five phases of scientific activity: *adoption* of the research strategy, *development* of that strategy, cognitive *evaluation* of hypotheses and theories, *spread* of scientific results, and *application* of scientific knowledge.

[4]Douglas (2009b, p.93) mentions as cognitive values simplicity, scope, consistency, predictive accuracy, fecundity and—the one that interests us most here—explanatory power. Lacey (1999, p.58–60), on the other hand, speaks of empirical adequacy, explanatory and unifying power, encapsulation of possibilities, internal consistency, consonance, support between theories, and the capacity to solve puzzles.

[5]For example, the fact that some individuals die due to the side effects of a drug wrongly considered safe, or that other individuals die from a disease because they did not have access to a treatment wrongly considered unsafe.

[6]Putnam's *thick* concepts are quite similar to Neurath-Cartwright's *Ballung* concepts, although the former are specifically placed in the ethical debate.

[7]John Dupré (2007) openly claims that thick ethical terms cannot be eliminated from science, at least from certain parts of it. Scientific hypotheses, theories and results concern us just because they affect our human interests, which makes it necessary to express them with a vocabulary flecked with thick ethical concepts. And while it is sometimes possible to translate 'thickness' into 'impartiality' and 'neutrality', the consequence of this always results in some loss of certain human interests, since there are always, more or less surreptitiously, interests of this kind at stake. "If most or all of physics is value free, it is not because physics is science but because most of physics simply doesn't matter to us", Dupré (2007, p.31) provocatively says.

[8]Anyway, this perspective is not unanimous in the philosophy of science. Betz (2013), for example, demands more precision in the treatment of the role of (non-epistemic) values in the context of a criticism of a science without values. According to him, this criticism is tantamount to just flogging a dead horse (see Pritchard 2021, Pournari 2008).

[9]As McIntyre (2019, p.230) writes, "while it is true that we should not let our hopes, wishes, beliefs, and 'values' colour our inquiry into the 'facts' about human behaviour, this does not mean that values are unimportant. Indeed, as it turns out, our commitment to the scientific attitude is an essential value in conducting scientific inquiry".

[10]Such a strategy would be the explanatory one, for example, aimed at obtaining its own results thanks to "a dense interwoven net of scientific constructions that constrain and support each other (...) ideas, concepts, theories, experiments, measures, middle-level principles, models, methods of inference, research traditions, data, narratives" (Cartwright 2022, p.12, 20; see also Cartwright et al. 2022), and so on. Among them, we conclude that also values (cognitive, epistemic and non-epistemic) must be introduced.

[11]We follow the standard format of the four phases and leave out one phase that Lacey and Mariconda (2014, p.645) do take into account: spreading scientific results. We think that this and 'our' Ph-4 can be unified. In any case, this does not affect the goal of our article.

[12]Mahner (2022, p.68) qualifies the slight difference between the concept of *data* and that of *evidence*. According to him, data are the result (expressed linguistically) of an empirical operation (observation, measurement, experiment), but they are not evidences. As such, data do not say anything by themselves. A datum *d* becomes evidence only in relation to a hypothesis *h* or theory *t*. This is important in many epistemological contexts, but here we will treat both concepts equivalently because the slight difference does not interfere with our working thesis.

[13]For cases of weaker relationships such as isomorphism or homomorphism, see Bueno (2011, p.253–4).

[14]Deulofeu, Suárez and Pérez-Cervera (2021, p.2010–1) present a structural, not mechanistic, explanation of the stability behavior of the microbiome. They point out that, although Coyte¸ Schluter and Foster (2015) appear to provide a model of the mechanism defined in terms of entities, activities, and their organization, the details of the *causal* pathway that cause the stable behavior are actually diluted in the complexity of a mathematical analysis.

[15]In mathematics and physics, a *small-world* network is a kind of network for which most of the nodes are not neighbors of each other, although, nevertheless, almost all of them can be reached from any source node through a relatively short number of steps between them (Barabási 2002, p.53). That is, the construction of a small-world network depends on (1) the existence of a small-world phenomenon as such (any two nodes in the network communicate over a relatively small intermediate node path (small number of nodes), since the maximum distance between two nodes grows logarithmically along with the total number of nodes in the network), and (2) that it possesses high *clustering coefficients* or, in other words, the indication that, if two nodes are not directly connected to each other, there is a high probability that they connect through the intervention of other nodes. Therefore, it is a property of a small world that it presents networks in which, despite the existence of a large number of nodes, it is possible to find short communication paths between them. On the other hand, a *scale-free* network is a specific kind of complex network. In a scale-free network, some nodes are highly connected, i.e., they have a large number of links to other nodes,

although the degree of connection of almost all other nodes is quite low. Barabási (2002, p.58) points out that the Web, for example, does not have a distribution of the usual degree of connectivity. Instead, a few nodes, which are called *hubs*, are much more connected than the rest. An example is the case of networks of neurons in organisms with nervous systems. In these, it is quite normal to use very frequently a fraction of the neurons while leaving most of the rest of the neurons barely utilized.

[16]CHILDES (*Child Language Data Exchange System*) is a corpus (as of 2015 it had contents–transcripts, audio, and video—in 26 languages from 230 different corpora) to serve as a central repository for data of first language acquisition. See MacWhinney and Snow (1990).

[17]A SAN software is a high-speed local network that contains multiple sets of block storage devices. Among some of its features, SAN can consolidate storage devices (eases management), efficiently pools storage devices, improves performance by reducing storage latency, improves application availability through redundancy, simplifies data backup (no server interaction), and supports multiple kinds of storage devices.

[18]Douglas (2009b, p.108–12) analyzes the *indirect* role of values (cognitive and social) in the case of diethylstilbestrol (DES) (a compound that operated as an estrogen). According to her, the explanatory value in this case only plays an *orienting* role in decision making. However, as Coyte, Schluter and Foster (2015), Deulofeu, Suárez and Pérez-Cervera (2021), and Moreno and Suárez (2022) point out, there are other cases in which the explanation adopts more complex forms, as in the case of the microdiome. We think that these more complex explanations, which are sometimes of a structural-mathematical nature or, also, integrated with a mechanistic explanation format (Deulofeu; Suárez; Pérez-Cervera 2021, p.2022), do play a *direct* role, as we have tried to show in the case of experimental linguistics.

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