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Scientific Models as Abstract Epistemic Tools for Learning how to Reason

Los modelos científicos como herramientas epistémicas abstractas para aprender a razonar

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Abstract

The variety of scientific methodologies aimed at obtaining knowledge, generating beliefs, and promoting action is very wide. Both philosophy of science and science education have been concerned with critically assessing the virtues of the various scientific methods, especially the inductive and deductive ones. However, the emergence of new procedures specific to non-academic sciences has encouraged the development of new reflective perspectives that can analyze those virtues. From randomized controlled trials to epidemiological or clinical procedures, the Philosophy of Science has been concerned with examining the virtues and also the defects of their practical set-up. The article assumes that modeling based on empirical evidence is a practice of high interest in linguistics. In order to substantiate this assumption, two philosophical approaches to scientific modeling distinguished by their respective research lines on the notion of representation are compared: the Representational and the Pragmatic. These accounts are then illustrated with a brief case taken from linguistics called "language parsing", aimed at examining several particular samples collected as evidence in early stages of experimental modeling. By way of conclusion, it is emphasized that both philosophical accounts provide analytical elements that are relevant for the kind of scientific reasoning around models and whose scope in science education may be of great practical interest.

Keywords

Scientific Modeling, Representation, Language, Education, Pragmatics, Epistemic Tool.

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Resumen

La variedad de metodologías científicas dedicadas a obtener conocimiento, generar creencias y motivar la acción es amplia. La filosofía de la ciencia y de la educación ha valorado críticamente las virtudes de los diversos métodos científicos, en especial de los inductivos y deductivos. Sin embargo, la aparición de nuevos procedimientos vinculados a ciencias no académicas ha promovido el desarrollo de nuevas perspectivas reflexivas que analicen dichas virtudes. Desde los métodos controlados aleatorios hasta los procedimientos epidemiológicos o clínicos, la filosofía ha examinado las virtudes y también los defectos de su puesta en práctica. El presente artículo asume que la modelación basada en evidencias empíricas es una práctica de alto interés en lingüística. Con el fin de sustanciar tal asunción, se comparan dos enfoques filosóficos de la modelación científica distinguidos por sus respectivas líneas de investigación en torno a la noción de representación: el representacional y el pragmático. Los enfoques se ilustran posteriormente con un caso de la lingüística denominado "análisis sintáctico del lenguaje", dirigido a examinar muestras particulares recogidas como evidencias en fases iniciales de la modelación experimental. Como conclusión, se enfatiza que ambos enfoques filosóficos aportan elementos analíticos realmente pertinentes para el tipo de razonamiento científico que pivota en torno a modelos y cuyo alcance en la enseñanza de las ciencias puede resultar de gran interés práctico.

Palabras clave

Modelación científica, representación, lenguaje, educación, pragmática, herramienta epistémica.

Introduction

The methodological diversity in the epistemic and educational fields is a fact that philosophy, especially the philosophy of science, has analyzed during the last decades. The inductive method, always important in everyday life and in the not so theoretically advanced phases of empirical science, presents some inability to create new and not purely empirical concepts (Bunge, 1963, p. 141). Deductive and abductive alternatives have become key ingredients to understand the types of argumentations in epistemology and in educational settings, but they involve their own weaknesses. All these proposals are participants in the new methods and procedures for obtaining and creating beliefs and knowledge, since, as is well known, induction is used when formulating certain hypotheses—formal or factual—in science and when validating factual theories. As Bunge pointed out (1963, p. 149), the mere mention of statistical inference should suffice.[1]

The epistemic procedures updated to the new scientific and technological needs are, as we said, diverse. In medicine (Sackett *et al.*, 1996), pharmacology, nutrition (Bengoetxea & Todt, 2021) or education (Cartwright, 2015; Cartwright & Hardy, 2012), as well as in almost all regulatory sciences, it is common to resort to evidence-based procedures that employ formal tools of inference. They have their own methodological hierarchies (organized according to their reliability and other epistemic

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values) and their preferred norms. A crucial procedure is the so-called "randomized controlled trial" or "clinical trial" (RCT), initially rooted in experimentation in medicine and pharmacology, but extended to other fields. In such a characterized context, it is important to distinguish the *most traditional or academic sciences*, in which the conditions of study and knowledge are closer to experimental laboratory standards, from *decision-oriented sciences*, sometimes called "regulatory sciences" (Bengoetxea & Todt, 2021, p. 43). Both areas are basic to obtain knowledge, project beliefs and motivate actions that, at least, can be characterized as reasonable.[2] The methodology aimed at obtaining knowledge in science, as we pointed out, is not only inductive, although this is common in empirical science. Influencing this in the classroom seems to be a crucial pedagogical aspect in an era in which unfounded skepticism and various "negationisms" advance at will, as, for example, Adrian Bardon (2020) rightly shows through his study of "motivated reasoning" linked to the beliefs and attitudes of "denial".

By contrast, the idealized experimental configuration of RCTs does not seem to be a sufficient basis for making definitive regulatory decisions. Some procedural shortcomings have already been detected (Trusswell, 2001), as well as a strongly reductionist bias that insists on the primacy of RCT experimentation as an ideal applicable to all areas of research. This generates a practical problem (many RCTs are not viable) that forces us to suggest methodological alternatives applicable to other areas of knowledge. A direct objective of this text is to show a methodological procedure related to modeling and reasoning operations, especially in the field of linguistics. For its possible elucidation, we propose to analyze it in order to understand the generation of knowledge and certain forms of reasoning in this field of the human sciences. We will call it "modeling-based reasoning." Models, also scientific ones, can have diverse types (material, abstract, scale, analog, etc.). In this text, we start from a general notion, according to which a model is the tool built by scientists with which the theory (its laws, principles, concepts) is put in contact (through mediation and interaction) with the empirical field of which it deals, in order to act on it or learn from it representationally. Underlying this, first and foremost, is the mediating notion of modeling found in Morgan and Morrison (1999) and in the proposals of Nancy Cartwright (2022). This idea of reasoning in terms of modeling will require confronting and analyzing two fundamental epistemological conceptions in current debates, within the empirical disciplines, research in the teaching of science and philosophy: the *representational* and the *pragmatic*.

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Experimental modeling in the study of language is an activity of enormous relevance as language is influenced by various cognitive functions with a crucial value for education and teaching, from memory and perception to the control and monitoring of the subject and its actions. We have witnessed for decades an unprecedented advance in scientific hypotheses about linguistic methodology (McKinley & Rose, 2020), so that, from epistemology and the philosophy of science, it is urgent to examine this type of hypothesis from a naturalistic and pragmatic approach (Schulz, 2014), beyond conjecturing hypotheses intuitively (McMullin, 2014). Scientific modeling is therefore the crucial issue underlying the text. In particular, it is the general modeling elaborated in the disciplines that deal with the study of language but focused from a pragmatic perspective that makes it possible to conceive the models as epistemic tools generated in experimental practices and whose objective partly aims at improving the learning procedures in the classrooms or in the manuals. Both the understanding of material content (scientific, linguistic) and the learning of better methods and practices of reasoning constitute an essential undertaking that students, teachers and researchers should develop if science teaching is really a fundamental objective of regulated education.

In this sense, it is necessary to understand that scientific-linguistic practice is both empirical and conceptual (Bunge, 1984, p. 163). This makes it interesting to investigate whether or not the data and experimental evidence of language acquisition, understanding and production contribute in any way to modeling and its working hypotheses (Baggio *et al*., 2012; Glymour, 2000). The present method, therefore, will consist in the use of certain advances of the own empirical linguistics in order to propose two philosophical concepts (modeling and representation) within a framework in which to examine real scientific practices,[3] not merely idealized prototypes that, supposedly, would have to "respect" certain normative codes of the own philosophy. The study of these concepts, based on bibliographic references linked to them, has the ultimate objective to show the validity, importance and reality of cientific models to help teach and educate in classrooms, seminars and laboratories.

The text is structured into five sections, including this introduction (sec. 1). In Sec. 2 we emphasize the importance of the study of modeling in evidence-based linguistics (LBE, hereinafter), of an empirical and experimental nature at times. Sec. 3 is devoted to countering two fundamental philosophical approaches to scientific modeling distinguished by their corresponding treatments and uses of the notion of representation: representational and pragmatic. We present as an application a brief case of linguis-

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tics ("syntactic analysis of language") aimed at examining modeling with evidence and using representational tools (sec. 4). The conclusion emphasizes the interest of the two previously developed philosophical approaches to model-based scientific reasoning and to science teaching (sec. 5).

Data and evidence versus intuitions in linguistics

Since the middle of the 20th century, generative grammar and formal semantics began to point to a risky aspect of linguistic competence theories: these appeared surrounded by a protective belt against the data provided by certain empirical disciplines (neuroscience, experimental psychology) (Baggio *et al*., 2012; Derwing, 1979). Generative linguistics was supposed to deal primarily with a specific model of real speech—the more general model (language)—that did not address the particular (physiological and social) circumstances of specific linguistic actions or their "complexity" (Bunge, 1984, p. 165). Today we know that this is not entirely correct or advisable. Chomsky did not oppose this objection and what he and other generativists did in fact was to clarify and defend that it is the syntactic component (opposite, for example, to the pragmatic one) that sheds more and better light on the characteristics of what they termed "language faculty" (Chomsky & Miller, 1963).

This does not concern the philosophy of linguistics. What happens is that the tension that has always motivated and strengthened this idea of generative grammar may be somewhat problematic insofar as it has relatively inhibited the advancement of experimental linguistics. Since linguistics is intended to account for conceptualized competence based on performance (*performance*) information – i.e., through standardized records of linguistic behavior – the Chomskians accepted that such data were indeed relevant to theoretical linguistic activity. However, the important thing was to find out from what kind of action the empirical basis of "competition theories" could be derived (Baggio *et al*., 2012, p. 328).

Under the generativist prism, the evidence base of linguistics would be that formed basically by introspective judgments. It seemed that Chomskian approaches rejected the speaker's own intuitions and demanded performative information with the aim of imposing certain constraints on competition theory (Baggio *et al*., 2012). The question about the empirical basis of competition theories remained on hold, however: ¿how should we obtain information about a speaker-listener's competence? According to Chomsky (1976, p. 20), we would obtain it by virtue of the

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linguistic performance and introspection of a native speaker or a native linguist. These would be the means that would provide the linguist with the data with which to show the adequacy of the hypothesis about the linguistic structure underlying the faculty of language.

It seems clear that the generativists did not take into consideration the data obtained by controlled (experimental) observation and statistical inference. According to them, these methodologies were ineffective for the purposes of a theory of linguistic competence. Definitely, the types of data that could influence such a theory were reduced to *insightful intuitions* of the linguist.[4] Supposedly, experimental research sought to reach evidence that ultimately referred to *introspective data*. Therefore, they argued that linguistic theory was based on the intuitions of native speakers (Baggio *et al*., 2012, p. 331).

Linguistics does not model or perform experiments of the same type or design as those of the natural sciences (in general terms), but this is not necessary for it either. In the cases of Ilse Lehiste's phonology (Bunge, 1984, p. 167), psycholinguistics (Prideaux, 1979), multivariate comparative studies (Fine *et al*., 2011) or the field of complex networks (Bengoetxea, 2024), no attempt is made to evaluate an alleged ideal nature of experimentation or modeling (Radder, 2003). Rather, it is assumed that the genuine basic feature of these two activities is the modification of variables (modifying the tone and speed of speech, for example, to see if understanding depends critically on any of the changes made) and their comparison with control groups (Bunge, 1984; De Regt, 2017; Knuuttila & Merz, 2009). That is, it is an experimental modeling activity.

From this perspective, the emerging question is this: does LBE provide anything to our understanding of scientific modeling? Does linguistics contribute anything to the general scheme of science and to the scientific philosophical and educational fields? The philosophy of science accepts that linguistics sometimes does contribute to a better understanding of scientific modeling, albeit with a non-negligible nuance: the philosophy of science continues to consider that the immaturity of linguistics—due to its lack of laws and a supposed lack of explanations (Egré, 2015) 'is what places it in the background when compared to the natural sciences. But requiring the management of one's own laws and an offer of explanations is a criterion inherited from an overly positivist, if not controversial, view of science. The notion of law could be understood in terms of Hume's philosophy, as regularity (a systematic pattern) and thus as a possible pathway to an establishment of (probabilistic) laws in linguistics. Moreover, until not so long ago the notion of explanation in philosophy had received a

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fairly biased treatment in favor of the natural sciences (Bengoetxea, 2023). Therefore, we suggest focussing aspects of linguistics that project a manageable and alternative image to that of the natural sciences with the aim of better understanding how it can be reasoned through the use of integrated models in real practices of linguistics. As has been pointed out, modeling and representation are two crucial notions here, the latter being the origin of the theoretical bifurcation between pragmatic currents, closer to the empirical disciplines, and the more ontological and epistemological ones, closer to properly philosophical activities.

Modeling and representation for reasoning in science

A model can be built in many ways. The model is not a copy of the phenomenon under examination or description, but an abstraction, more or less elevated, of it. A model of Ecuadorian Spanish speakers is not made up of all speakers. Models are incomplete because they are idealized. Some consider them "falsehoods" (Bokulich, 2012) or only "partial" truths (Bueno & French, 2018). This feature of the models has motivated several philosophical questions about their epistemic virtues, such as their reliability, their replication capacity and their validity (Magnani & Bertolotti, 2017; Abbuhl *et al*., 2013, p. 116). Beyond these interesting virtues, here we will deal solely with the possibilities opened by considering the instrumental nature versus the purely representational nature of modeling in scientific and educational practices, as well as in philosophy.

What usually serves as a model of an empirical domain (a *phenomenon or target system*) is a system constructed by abstractions, idealizations, analogies or computational simulations. The phenomenon or target system may be something existing or not empirically, since it may be fictional or simulated.[5] And if it exists, it may in turn be something constructed—for example, by technologies—without needing to be a fact of a natural genre (Bird, 1998). In any case, the construction of the model of the phenomenon will go through at least two distinct phases (Weisberg, 2013; Bailer-Jones, 2009; Bokulich, 2012; Bokulich, 2017; Bueno & French, 2018):

1. *Modeling is carried out through a specific constructive process*. Scientists seek to access the world's empirical systems in a way that enables them to generate reasoning and gain knowledge (or beliefs for action). Specificity is crucial here. This is achieved because the models are constituted in a constrained way to provide us with knowledge aimed at studying

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or examining issues (or hypotheses) of interest. It is in this sense that it can be said that models are tools aimed at reasoning, artificial systems, built and constrained, oriented to answer fundamental questions of research.

This image of models is pragmatic and does not insist on the representation of a target system or empirical phenomena external to the model, since models are not conceived as separate entities that have to be connected to the systems of phenomena of the world through a representation relationship. In this sense, they already appear immersed in our knowledge of the world. Therefore, it is important to emphasize that the very construction of a model can facilitate (by analogy or by some other relationship between the structure of that model under construction and the phenomena of the real world studied) the examination that is made of the different elements (and the possible relations and functions established between them) postulated or given in an experimental configuration.

Constriction is crucial and is related to idealization in modeling. Without idealization, some empirical systems would be mathematically or computationally intractable –social phenomena are complex systems with many variables, for example– (Thagard, 1993) and could not be designed in order to isolate certain relevant or differential traits from the target system by rejecting the rest (Mäki, 2011). In linguistics, populations of speakers are ideally treated because not all the properties of a population are susceptible to be taken into account. For example, when working with speech samples, linguists do not attend to all the syntactic relationships between words (Buchstaller & Khattab, 2013). Researchers select a scientifically important subset of the properties of a studied phenomenon, and this will constitute the target system.[6]

However, the regulation of the types of permissible idealizations is not a simple matter (Weisberg, 2013). To avoid arbitrariness, general principles (in reality, constraints) adapted to the empirical work of the discipline are proposed. These principles guide a continuous and dynamic process of gradual tuning in the modeling process (Zielińska, 2007), which is partially sustained through already established resources (theoretical, empirical, mathematical, computational, and representational) and is the result of the triangulation of different media: other models, experiments, observations, background theories.

2. *From a theoretical perspective, it is argued that the model must have representational capacity*. There are two ways to understand this ability. The most philosophical (representational approach) conceives it as a *general fit* between model and target system. The target system has been sketched or designed (a population sample, for example)[7] with a series

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of selected elements and with some question and hypothesis at hand in the experimental configuration. A potential difficulty of this procedure lies in the fact that, *although the target empirical system is an abstracted entity, the properties of the system are actually concrete—as is the case with corpus* samples of speakers (Stubbs, 2006). If modelers employ mathematical and/or computational tools, it is important to know if the model can be compared in any way with its target. ¿Can any analogy or similarity be drawn? (Eco 1995, p. 59). The standard way to respond to this is to reconstruct the phenomenon itself in formal (mathematical, computational) terms and then compare it with the empirical model, i.e., two models are confronted to detect some possible mutual resemblance (or an isomorphism, a partial homomorphism, etc.). In this way, a computational model, for example, will also adopt a certain material (in a computer), autonomous and concrete nature (Hausser, 2006). Model and target will be distinguished by the modeler by freely choosing the structure of the formal (or computational) model, while the target system is a constrained entity belonging to the world.[8]

The other way to understand representational capacity is pragmatic. Modeling is a process of interaction with the *representational tools* available to scientists. The model is designed with a purpose and serves as an artificial epistemic tool. It is common for the scientist—linguist—to have no interest whatsoever in a realistic description of any system of speakers, but simply to prefer to examine a series of interactions between elements and causes internal to the model itself.

Among the representational tools are in mathematics the differential calculus, graphs, networks, or diagrams, and in computing certain computer programs. The author has developed this question, applied to the study of language, elsewhere (Bengoetxea, 2023); there he specified the use of resources and representational tools in the modeling work of experimental linguists, for example, before the question of how the development of language can be compared in children without linguistic problems detected and children with some syndrome (Down, Williams), experimental modeling and the use of representational tools included corpus collected from the CHILDES database (http://childes.psy.cmu.edu/), transcribed conversations of three subcorpus of language (German, Dutch and Spanish), the SAN tool (high-speed local network formed by storage devices) to solve outstanding problems in previous modeling that combined scripts materials with software, the Netlang software —an integration platform that operates as a service to streamline the application connection process (www.netlang.com)— to collect data and evidence from speech sampling,

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and in order to computationally model the experiment, the Cytoscape network software (Shannon et *al., 2003) thanks to which the data collected in various phases of experimental modeling are processed.*

This case serves to illustrate the fact that conceiving models as tools can be highly recommended for the teaching of science and reasoning with models. Models can be tools that motivate students to reflect on existing phenomena, but also on new phenomena, rather than understanding them as literal projections of what an empirical phenomenon actually looks like. In this way, it would even promote the construction of multiple models of mutually related phenomena with the objective of solving problems that the professor initially raised around some theory, previous knowledge and working hypotheses (Reith and Nehring, 2020).[9]

Formal representation and pragmatic representation

The previous sections allow to establish the state of the philosophical question around scientific modeling on the basis of a current debate: either the models are used as tools aimed at reasoning and solving practical problems that arise in a scientific context, or they are used for more philosophical and ontological purposes in search of some reality that the models supposedly represent. To discredit either option, which is often done, would in fact constitute denying the very value of the discipline that would perform the analysis of such a shaping task.

In the philosophy of science, these two general ways of interpreting representation (Contessa, 2011) have adopted a formal register, whose objective has been to identify and elucidate the nature of scientific models (syntactic conception and semantic conception) (Chakravartty, 2010), and a pragmatic one, according to which the roles that models play in real scientific practices and reasoning (generation of beliefs and knowledge, puzzle solving) must be examined.[10] Both registers have employed real-case studies. For example (Bueno,2014; Bueno & French, 2018) project modeling using a *partial structures* approach, while Suárez (2015) proposes an *inferential conception* in which the models built are machines that produce inferences. However, from a pragmatic perspective, these proposals have been criticized by not sufficiently emphasize that analyzing the process of model construction and manipulation—as we have already mentioned—is an indispensable requirement to study modeling oriented to gain knowledge and reason.[11] As Knuuttila and Voutilainen (2003) point out:

> While proponents of semantic conception seek to represent models of science as relatively stable and prefabricated entities, proponents of

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practice-oriented conception are interested in the modeling process and explaining why and how models are employed in scientific work (p. S 1485) (own translation).

The pragmatist alternative of Knuuttila (2006) presents a case of modeling as opposed to merely representational and serves to illustrate the idea of models as tools to study language. It is the "syntactic analysis of language".[12] Knuuttila proposes to conceive models as epistemic tools that highlight the material and instrumental role (tools) of models. This way of conceiving models seeks to identify how they are constructed, used and "imagined" in the various scientific activities—among them, those dedicated to teaching how science is done—since the variety of models existing in the sciences is very wide. In this sense, Knuuttila's appreciation is correct that the attempt by the philosophy of science (syntactic and semantic conceptions, first and foremost) to provide a general theory of representation based on modeling is a titanic and unrealistic undertaking.[13] Compatibilizing this desire with a naturalized and pragmatic project would be more advisable.

The idea of a model construction (which is the basis of reasoning) is crucial here because the dynamic and continued notion of a model in scientific practice was barely considered in the philosophy of science of the 20th century (Rost & Knuuttila, 2022). Models are not stable, stopped entities, which only act as mediators (still) between a formal and an empirical construct (Morgan & Morrison, 1999). The problem is that models of science are more complex than what Morgan and Morrison admit, which is partly because the phenomena they represent are complex entities as well. The former are not formed solely by theory, data and empirical evidence, but also by analogies, metaphors, theoretical notions, mathematical concepts, formal techniques and other pragmatic elements (Boumans, 1999), i.e., triangulation of the modeling task is a complex and arduous undertaking. Therefore, beyond the most common image of the modeler as a theoretical agent, we could project the image of the researcher as an enriched agent with characteristics more typical of the "know-how" (Stanley, 2011), such as skills and experience or expertise.

This new conception of modeling and the modeling agent makes us see with good eyes the productive and dynamic approach of models understood as "epistemic artifacts" (Knuuttila & Merz, 2009), although without approving the rejection of any notion of substantial philosophical representation that pragmatists profess. It is convenient not to conceive modeling as an activity that passively represents, it is true, but the philosophy of science will always have the right to defend a space for deeper

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reflection about the nature of the models. This, of course, is not very useful in terms of understanding actual practices or educational approaches to the sciences. Hence, we separate the two objectives. From a practical perspective, we insist and accept that modeling is a substantial part of a process of understanding and knowledge of epistemic procedures that interest scientists (linguists, chemists, physicists, economists), since the practice of creating models and using them can help to understand more deeply those same practices (Svetlova, 2015). In this sense, to affirm that models are epistemic artifacts is equivalent to saying that they are concrete things that have their own way of functioning, without the need to represent (ontologically) any target empirical structure, no empirical phenomenon (Baird, 2004). In short, they are "concrete models" (Knuuttila & Merz, 2009, p. 150). This fits well with the idea of modeling processes in terms of tools located within experimentally designed assemblies (Rouse, 2015) or "social aggregates" (Latour, 2008, p. 57).

Modeling tools around language

From a close perspective to the pragmatic approach outlined above (Knuuttila, 2021; Rost & Knuuttila, 2022), it can be suggested that in modeling the supposed distinction between representing and producing without the need for a fit between model and target phenomenon becomes blurred (Boon & Knuuttila, 2009). Work with computational models, for example, is a partially virtual work in which substitutes (*surrogates*) are employed whereby researchers have the option to reason and construct inferences. Even if the representational value of modeling had been re-examined in pragmatic terms (Bailer-Jones, 2009; French, 2013; Giere, 2004), thereby improving previous models of representation *per se* (naive realist notion) (Hughes, 2010; Teller, 2001), this "mixed" perspective would still not sufficiently estimate the great importance of the productive (creative), practical and dynamic aspects of modeling and the reasoning generated by it (Humphreys, 2004), aimed at acting and gaining knowledge (Knuuttila & Loettgers, 201 2). This aspect must be taken into account because it is key to teach students to reason and to produce inferences with models to answer questions posed by initial hypotheses linked to the theories handled.

This can be clearly seen in the case of computational models, especially when designing and applying simulations. The approaches, idealizations and even the "falsifications" of modeling are linked to certain

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constraints and *affordances* applied to a material and concrete object: the computer (Zuidema & de Boer, 2013). The representation genre implemented in computational modeling can be seen, first and foremost, in the modeling results and not so much in the passive structure of the models that supposedly reflect the structure of the empirical phenomenon studied (Rost & Knuuttila, 2022). In the case of syntactic analysis of language, the criterion for their valuation is more pragmatic than representationalist, since the linguist and the computational programmer represent completely different things, despite being constructing the same. The linguist seeks to represent the world as faithfully as possible; the programmer instead values the program-analyzer (*parser*) for what it produces (Knuuttila, 2006, p. 42). Consequently, it seems appropriate to argue that prefabricated, prefinished models that supposedly represent (*stand for*) phenomena do not configure the concept of model or modeling more interesting in the processes of modeling production aimed at generating reasoning, beliefs-knowledge, and actions.

Parsing by artifact modeling

Syntactic analysis is a linguistic procedure that has received open samples of theoretical interest in the philosophy of scientific modeling. From a philosophy that looks at scientific practices and not ideal prototypes of science, Knuuttila (2006) has dedicated himself to analyze the computational-experimental task surrounding the technological construction of models of syntactic analysis (Karlsson *et al*., 1995). It can be suggested, therefore, that this line of research is highly interesting to understand some reasoning practices and generation of linguistic knowledge aimed at teaching in science.

Syntactic analysis (*parsing*) is a grammatical procedure of describing words or sentences, or parts of a speech made up of words with their own shared grammatical features (nouns, verbs, adverbs, adjectives, conjunctions, etc.). This type of analysis automatically assigns a morphological and syntactic structure—without a semantic interpretation—to input texts of varying length and complexity (Knuuttila, 2006, p. 43; Karlsson *et al*., 1995). It is, therefore, a techno-linguistic device or program aimed at producing a syntactically analyzed text, and serves as an illustration to see how the construction of models can help both to scientifically understand the phenomena studied and to produce useful results.

There are two general approaches to parsing: on the one hand, the grammar-based approach, of a linguistic and descriptive nature; on the

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other, the data-driven approach, of a statistical and probabilistic nature, which includes *corpus*-based learning rules, hidden Markov models and machine learning conceptions (Knuuttila & Merz, 2009, p. 160). The particular case of "Constriction Grammar Analysis" (CGP) —well developed in the philosophy of modeling in linguistics—combines a grammatical basis with the handling of experimental features, and is grounded in linguistic *corpus*. It remains completely at the level of the surface structure and, instead of stipulating rules for well-formed expressions (as the universal Chomskian generative grammar did during its early years), it is constituted according to constrictions that reject inappropriate sentences (Knuuttila, 2006, p. 43). However, syntactic analysis does not realistically describe or "represent" human language competence, nor does it pretend to. The scientific understanding it provides does not derive from a supposed "real" image of an empirical system, but rather is something dynamic and inherent to the linguist's expertise in the process of model construction—expertise with the handling and knowledge of language, cognitive elements, and the "technological artifacts" employed in practice—(Knuuttila & Merz, 2009, p. 159).

Syntactic analysis aims to computationally model some aspect of the language using a tool consisting of a computer program. Constriction grammar is a formalism of syntactic analysis that provides a correct grammatical interpretation of each word in a functional text, as well as enriching each word with additional syntactic information. In this way, the CGP is based on a previous methodological analysis carried out using a morphological and synthetic analyzer (Knuuttila, 2006, p. 43; Knuuttila & Merz, 2009, p. 160).

The words normally used by speakers are such that their shape (e.g. "square") is interpreted differently depending on the context of their use, i.e., many words are ambiguous. The CGP then seeks to select which of the interpretations is appropriate in the context of lexical occurrence, usually in a text or in a spoken discourse. This is called "disambiguation" (DeRose 1988; Knuuttila 2006, p. 44). This search for some interpretation is one of the most interesting ways to model language and to obtain relatively satisfactory and world-adjustable results (Eco, 1995).

A CGP proceeds in three stages (Knuuttila, 2006), in which what is expressed as "interpretation" can be translated into "modeling" in our most philosophical lexicon:

- Once the morphological analyzer has provided all the admissible morphological interpretations, the CGP checks which ones are

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appropriate. It does this by applying morphological constraints that take advantage of contextual knowledge or *neighborliness of each word*. For example, if a word has a substantive and a verbal interpretation, and if it is preceded by an article, the relevant constraints subtract the verbal interpretations about that word.

- Once the character of morphologically ambiguous words has been elucidated, it is time to analyze them superficially and syntactically. The result of the morphological disambiguation module becomes *input* for the following module: namely, it will be a syntactic mapping. It will assign all possible surface syntactic functions to each accepted morphological interpretation. Again, the shape of a word can have different syntactic functions (subject, object or direct complement, indirect object or complement, etc.), so that in order to grant each word its correct syntactic interpretation, the linguist will apply syntactic constraints after mapping and discard assignments to contextually incorrect or illegitimate syntactic functions.
- The final stage is a direct consequence of CGP namely, it is a text in which, in the best of scenarios, each word will be assigned with its corresponding correct morphological interpretation and appropriate syntactic function.

Two crucial tasks here are how to represent "rule sets" of language (Knuuttila, 2006, p. 45; Karlsson *et al*., 1995) and the implementation of grammar as a computer program. This challenge is very delicate, since the linguist generates the models with the objective of describing the world and computing attempts to produce it, build it and modify it in a dynamic and interventionist way (Knuuttila, 2006; Hacking, 1983, p. 220). This model construction is a continuous process of modeling involving distinct (representational) layers and replicated checks of various *corpus* (Knuuttila, 2006, p. 45). Three necessary steps of this type of active and productive modeling that employs representational tools are the following:

- The writing of the CG grammar for a *corpus*. It is based on a morphologically analyzed text, for which the constraints that disambiguate the words are established.
- After applying the resulting grammar to a manually disambiguated *corpus* (linguist's empirical task), the system *software* generates an applicative statistic for each of the constrictions.
- From this statistic and after identifying the wrong predictions, the linguist (grammarian) either corrects and, or, dismisses

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> previous constrictions, or creates new ones. This cycle is repeated by using the evidence of new *corpus* until the grammar is close enough to the "human action" (Knuuttila & Merz, 2009, pp. 160).

As seen, the construction of a syntactic analysis of this type opens an interesting way to the notions of modeling and representation, which move away from the traditional and static idea of the philosophy of science, rather occupied with the relationship between a type of prefabricated model and a real target system. According to this type of philosophy of science and epistemology, a model is epistemically useful if it provides a broad picture of the object or phenomenon studied. But if an approach is adopted, if possible, closer to the productive and pragmatic idea of Knuttila—and even if the syntactic analysis is the result of certain uses of representational tools—such an approach will be valued basically by what it produces according to what the agents have proposed (questions), and not according to the ontological reflection of a postulated reality.

Reasoning, believing and knowing through models to educate in science

It is convenient to analytically nuance the function of the modeling company. On the one hand, it should be noted that in scientific research models are conceived without the need for ontological assignments, i.e., as epistemic tools aimed at solving problems. It is the most radically pragmatic form. In the educational field of science, it would also be useful to project the pragmatic nature of modeling so that students learn to reason with a view to their goals: answering practical scientific questions, solving puzzles, etc. However, it is also possible to leave a space for philosophical questions related to modeling, so that it is not so enigmatic, given the millennial Western philosophical tradition to ask about the nature of what is being modeled. Not allowing this would have a disastrous consequence for many philosophers in fields close to the philosophy of science, namely their expertise and lack of preparation in empirical activities in which they would often act as mere guests. The supposed role of sociologist, political scientist, policy expert, regulator, or pedagogue, which many philosophers take for granted on the pretext that purely philosophical questions do not concern a field like modeling, should – if we praise sincerity – send them into unemployment.

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Fox-Keller (2000), as well as Gouvea and Passmore (2017, p. 50), among others, distinguish two interesting interpretations: the "models of" and the "models for". They argue that "models of knowledge", located in an environment of substantive philosophical representation, are always accompanied by "models for learning" because scientific models are tools for understanding, explaining and predicting, and not only in research itself, but also in classroom teaching. They consider that "models of" are less able to support the epistemic agency of experimenters and students when doing science, since they tend to treat models as representations of what we already know, instead of acting as tools that are used to generate new knowledge and reasoning (Gouvea & Passmore, 2017).

But philosophical analysis of practices also has its *raison d'être*. It must be recognized that conceiving models as tools and artifacts built to reason and generate knowledge is not something that necessarily has to start from assuming that there has to be a direct representation of an empirical system. It may be the case, and it often is, that if a teacher wanted to present how scientific modeling works, surrogate reasoning based on a simplified correspondence between, say, molecules and a material model of balls and sticks, or between language and an inherently human faculty of language, would not add any value to the learning environment (the classroom or the laboratory) unless the teacher worked out that supposed correspondence much better. In such a case, the key to the exercise would be to understand the hypothetical and practical nature of the model. However, from a more philosophical and humanity view, the understanding and interpretation of the notion of representation can be a source of interesting questions for scientific and educational environments.

Conclusions

The text endeavored to set out the two poles of the debate and to respect to a certain extent the possibilities which each opens up. For this, it has been considered that the modeling work must start from issues of interest, previous theoretical knowledge, and empirical knowledge, as well as a collection of data and evidence that allow to construct successive models, continuously, of the (idealized) system chosen as an object of study. A philosophical examination of this practice aimed at reasoning and useful in scientific research and science teaching has allowed us to distinguish the concepts of modeling and representation, and project, within the current philosophical debate, two basic approaches, *representational* and

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pragmatic, as well as their mutual connections. Finally, an outline of the application of the proposed reflections to the modeling study of language and to the case of syntactic analysis has been suggested. The final conclusion, therefore, intends to leave room for proper philosophical reflection, without undermining pragmatics, in which the various representational tools (symbolic, semiotic or material resources) also play an educational role with their own character.

Notes

1 There are several papers dedicated to the methodology of the sciences written from a philosophical and introductory perspective. I recommend the classic, original 1976, *What's That Thing Called Science?* by Alan F. Chalmers (1993) and the more novel and very enjoyable *A Philosopher Looks at Science*, by Nancy Cartwright (2022).

2 It should be noted that the use of empirical evidence is dictated, at least in part, by axiological considerations (pragmatic and epistemic, for example) in order to make decisions that may affect regulations in public policy, food, health (drugs) or—among other clearly important fields—education (Cartwright & Hardy, 2012).

3 These practices include activities related to research in science education. In this regard, some interesting references are Krell *et al*. (2020) and Matthews (2007).

4 Linguistic research thus advanced one of the most fashionable topics in the philosophy of science: the debate between intuitive (armchair) obtaining and experimental obtaining of data and evidence to generate reasoning (see Sytsma & Buckwalter, 2016).

5 About modeling without target phenomenon, see, for example, Weisberg (2013, pp. 129–131).

6 An example of this in linguistics is that of *corpus*, whose prototypical cases are those that pretend to be representative of a particular language, of a variety of this or of some of its records (Gries & Newman, 2013; Kepser & Reis, 2005).

7 It should be noted that the configuration and extension of a sample depends on the judgment, background knowledge and representational tools of the experimental linguist, but not so much on an automated statistical algorithm.

8 This is the underlying theme of the debate between Eco and Rorty (Eco, 1995) around interpretation. This, and modeling also, by analogy, may be a purely pragmatic activity, aimed at reasoning to solve practical (scientific) problems that have little to do with what is in the world (Rorty) or, instead, may depend on ontological and epistemological assumptions of a philosophical nature that are occasionally disparagingly labeled as "naive realists".

9 Although it is to criticize them for not properly characterizing the notion of representation, Rost and Knuuttila (2022) review some pragmatic representational proposals applied to the field of education, among them Cheng *et al*. (2019) (tools to explain the mechanisms underlying target systems), Stieff *et al*. (2016) (specific molecular models) and Oliva *et al*. (2015) (competence of high school students in modeling chemical transformations).

10 The distinction between analytical (substantive) and pragmatic approaches to representation —some call it in other ways: "informational-functional" (Chakravartty,

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2010) or "informational-deflationary" (Poznic, 2015)— establishes two research agendas that can be distinguished thanks to their relative hypothetical connection to the study of real scientific activities (Suárez, 2015). Analytical approaches seek to elucidate basic relationships between theory and the world, while pragmatists attempt to account for the scientific practice of model construction (Boon & Knuuttila, 2009; Bueno & French, 2018; Chakravartty, 2010; Suárez, 2015; van Fraassen, 2008; Weisberg, 2007).

11 Rost and Knuuttila (2022) criticize, one by one, each representationist-pragmatic proposal because none of these characterize or adequately define the notion of representation. Apparently, as we will argue in the last section, this serves them to disqualify the philosophical enterprise (representationalist, ontologistic, epistemological) that tries to give an answer to the question of the nature of knowledge through scientific modeling.

12 Knuuttila argues that models are epistemic artifacts (tools) created to meet or achieve certain specific goals and that they are made productive through human work and manipulation within particular scientific practices (Svetlova, 2015).

13 For a brief critical analysis of some fundamental aspects (as well as some puzzles) of the general theory of representation, see Frigg (2006, pp. 50–52).

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Author	**Contributions**
Juan Bautista Bengoetxea Cousillas	As it is a single author, the total contribution corresponds to the same author. The content presented in the article is the sole responsibility of the author

Artificial Intelligence Use Statement
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