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Scientific Discovery Through Fictionally Modelling Reality

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Abstract

How do scientific models represent in a way that enables us to discover new truths about reality and draw inferences about it? Contemporary accounts of scientific discovery answer this question by focusing on the cognitive mechanisms involved in the generation of new ideas and concepts in terms of a special sort of reasoning—or model-based reasoning—involving imagery. Alternatively, I argue that answering this question requires that we recognise the crucial role of the propositional imagination in the construction and development of models for the purpose of generating hypotheses that are plausible candidates for truth. I propose *simple fictionalism* as a new account of models as Waltonian games of make-believe and suggest that models can lead to genuine scientific discovery when they are used as representations that denote real world phenomena and generate two main kinds of theoretical hypotheses, model-world comparisons and direct attributions.

Keywords Scientific discovery · Scientific models · Scientific representation · Model-based reasoning · Make-believe · Fictionalism · Denotation · Theoretical hypotheses

1 Introduction

How do scientific models represent real world phenomena in ways that enable scientific discovery and inferences? In this paper I will argue that answering this question requires recognising the crucial role of the scientific imagination in the construction and development of models for the purpose of generating hypotheses that are plausible candidates for truth.

Imagination is integral to the ways in which contemporary scientific investigation enables scientific discovery and thereby produces new knowledge of reality. When scientists want to study a particular aspect of the world that is too complex to study directly they imagine a version of that system with simplifications and alterations, i.e. they study a scientific model. For example, the Lotka–Volterra model of predator–prey interaction is commonly identified with the following two differential equations:

$$dx/dt = Ax - Bxy$$

$$dy/dt = -Cy + Dxy$$

The equations model the growth rates of two imaginary populations, one prey and one predator, dynamically interacting with each other. However, the equations per se do not model anything unless they are used under a certain construal. The variables x and y in the equations are construed as standing in for prey and predator population respectively, t for time, A for the growth rate of prey, B for the predation rate coefficient, C for the predator mortality rate, and D for the rate at which predators increase by consuming prey. To enable mathematical treatment, the model makes a number of simplifying assumptions, including that prey have limitless supplies of food, that predators have infinite appetite, and that the environment never changes. Of course, each of these assumptions is false! The model describes two imaginary populations interacting with each other under imaginary conditions. Furthermore, the model enables the generation of certain hypotheses about the dynamic interaction of the imaginary prey and predator populations. The model predicts that the dynamic interaction between imaginary predators and prey will show a cyclical relationship in their numbers, and that the rates of increase and decrease of the predator population size generally tracks the rates of increase and decrease of the prey population size. These predictions can then be transferred onto reality through the generation of hypotheses that are about real predators and

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prey. Imagination thus seems to be vital both to the construction and development of the model and to the generation of its outcomes.

The traditional distinction between context of discovery and context of justification championed in different ways by Reichenbach (1938) and Popper (1961) undervalued the epistemic role of imagination. On this view, in the context of discovery we get ideas and formulate hypotheses, no matter how—dreams, reveries and any unconstrained uses of imagination will do. In the context of justification, we gather evidence from reality to assess scientific hypotheses and thereby gain knowledge. The context of justification is properly characterised as epistemic, i.e. it relates to knowledge. Epistemic standards—or standards of knowledge—do not apply to the context of discovery. They apply only to the context of justification. Imagination falls within the context of discovery and is therefore irrelevant to the context of justification.

The traditional distinction between discovery and justification has been challenged over the past few decades by upholders of deductive, evolutionary and cognitive theories of discovery (for a critical review see Ippoliti 2017, 2018). Deductive theories posit that there is a logic of discovery and that this is deductive logic (Dummett 1991; Hintikka 1973; Musgrave 1989); evolutionary theories claim that new ideas and hypotheses are formed through an evolutionary process of blind variation and selective retention (Campbell 1960; Hull 1988; Nickles 2009); cognitive theories hold that discovery is brought about by certain cognitive processes involved in ordinary problem-solving activities and heuristic reasoning (Simon and Newell 1971; Simon 1977). Deductive and evolutionary theories do not analyse the key role of imagination in the generation of new hypotheses about reality. But Magnani (2009) and Nersessian (2008, 2009) recently developed cognitive theories according to which conceptual change and innovation in science are achieved through a particular type of reasoning—or model-based reasoning—which involves imagery. These cognitive theories based on model-based reasoning focus on the cognitive operations performed on imagistic representations that, as I will argue below, are neither necessary nor sufficient for the generation of new hypotheses in scientific models.

My aim in this paper is to sketch a novel understanding of how scientific models enable the generation of new hypotheses through the scientific imagination. I identify make-believe as a variety of constrained imagination that is crucial to the construction and development of models. Make-believe emerges as a specific theoretical notion within Walton's (1990) theory of fiction and it has been deployed in contemporary fictionalist accounts of models as representation (Frigg 2010; Toon 2012). However, I will not have space to discuss these accounts here. Instead, I will present my own view, what I call *simple fictionalism*. Following

Salis and Frigg (forthcoming), I will construe make-believe as a social imaginative activity involving propositional imagination. I will then argue that models enable scientific discovery when they stand in a referential relation with real world phenomena and when they generate two main kinds of theoretical hypotheses about reality, model-world comparisons and direct attributions.

In what follows, I will critically assess Magnani's (2009) and Nersessian's (2008, 2009) cognitive accounts of scientific discovery (Sect. 2). I will sketch an account of models as make-believe based on Walton's (1990) theory and Salis and Frigg's (forthcoming) interpretation (Sect. 3). And I will advance simple fictionalism as an alternative account of model-based discovery (Sect. 4).

2 Scientific Innovation Through Model-Based Reasoning

In a series of works published since 1988, Nancy Nersessian developed a sophisticated and influential account of conceptual change and innovation in science. Her starting point is the distinction between two main types of mental representations, imagistic representations and linguistic and formulaic representations, enabling two distinct types of reasoning, model-based reasoning and sentential reasoning. Linguistic and formulaic representations enable sentential reasoning, i.e. logical and mathematical operations that are rule based and truth preserving. These representations 'are interpreted as referring to physical objects, structures, processes, or events descriptively' (Nersessian 2007, p. 132). Their relationship to what they refer to 'is truth, and thus the representation is evaluated as being true or false' (ibid., 132). Imagistic representations—what she calls 'iconic representations' or 'mental models'—enable model-based reasoning, including problem solving, analogical reasoning, mental simulation, probabilistic reasoning and causal reasoning. Iconic representations 'are interpreted as representing demonstratively' (ibid., 132). Their relationship to what they represent 'is similarity or goodness of fit [...] and [they] are thus evaluated as accurate or inaccurate' (ibid., 132). Mental models are analogues of real world phenomena. They are cognitive constructs that represent real phenomena as conceptual structures composed of imagistic symbols (iconic representations). Nersessian (2009) further identifies three specific forms of model-based reasoning, i.e. analogical modelling, visual modelling and simulative modelling (or thought experimenting). On her view, the generation of new ideas and hypotheses is explained in terms of model-based reasoning that enables the construction of new mental models under domain-specific constraints and through various forms of abstraction.

Partially inspired by this work, Magnani (2009) explains the process of forming new hypotheses in terms of the notion of *model-based abduction* that he distinguishes from sentential abduction. The notion of abduction was originally introduced by Peirce (1932/1963) as a form of inference that is distinct from deductive and inductive inference. More specifically, abductive inference is the process of generating an explanatory hypothesis. Magnani further elaborates this view through what he calls the *Select and Test model*. On this model, abduction generates a novel hypothesis that is a plausible candidate for being the best explanation of a certain phenomenon; deduction draws the consequences of the hypothesis in terms of logical implication; induction assesses the hypothesis on the basis of whether its consequences hold via comparisons with the facts. Sentential abduction generates explanations constituted by linguistic symbols (e.g. sentences of a logical language, neural and probabilistic frameworks) that enable deductive reasoning through logical implications. Model-based abduction operates on imagistic symbols (perceptual, diagrammatic, mnemonic) that enable analogical reasoning and simulative reasoning akin to Nersessian's simulative model-based reasoning. In sentential abduction a hypothesis is chosen from a finite set of a theory's entailments. In model-based abduction a hypothesis is formed as genuinely new. On this view, the generation of new hypotheses is best explained in terms of model-based abduction.

Both Nersessian and Magnani argue that mental models are imagistic representations. However, I doubt that imagery is either necessary or sufficient for the generation of new hypotheses in scientific models. Let me start by explaining why I think that mental images are not necessary. Our abilities to form mental images and perform the relevant kinds of cognitive operations are highly subjective and idiosyncratic. Yet, individuals with poor imagistic abilities are obviously not prevented from deriving model outcomes. Consider again the Lotka–Volterra model. No mental images are required to grasp the model's theoretical and mathematical background, to develop the equations and assign the relevant values to their variables. No mental images are required to grasp the mathematical constraints operating on the equations. No mental images are required to generate the hypothesis that imaginary predators and prey interact in a cyclical way. Of course, the results of the equations can be graphically represented with a diagram that facilitates a scientist's reasoning by making it more vivid. However, this is far from being necessary. One can form the hypothesis that predators and prey interact in a cyclical way by grasping the propositional content of the model description and by deploying the mathematical and theoretical principles that are relevant for this specific domain of enquiry. Model-based reasoning as the sort of reasoning that would be enabled exclusively by

imagistic representations therefore seems unnecessary for the generation of hypotheses in scientific models.

Second, I doubt that images are sufficient to draw model outcomes. Consider again the Lotka–Volterra model. We don't have an image of a prey population with infinite supplies of food or of a predator population with limitless appetite. For what sort of mental images would these be? Likewise, we cannot form an imagistic representation of the concept of dynamic interaction without having a theoretical definition, which is usually given in linguistic and formulaic symbols. What we really need to develop the model and derive its outcomes are theoretical knowledge of general mathematical principles and laws, mathematical abilities, and logical inferential abilities. We could not even begin to reason about the model and its domain of enquiry without the relevant theoretical, mathematical, and logical abilities. So, it is not surprising that when talking about similar issues in the practice of thought experimenting, Nersessian admits that '[i]nformation deriving from various representational formats, including language and mathematics, plays a role' (2007, p. 147). On her view, this form of sentential and mathematical reasoning is fundamentally different from model-based reasoning. But it is difficult to see how this fits into a view that places imagistic representations at the heart of conceptual change and innovation. Imagistic reasoning therefore seems also insufficient for the generation of hypotheses in scientific models.

The same considerations apply to Magnani's (2009) identification of model-based abduction as the only relevant sort of inferential reasoning leading to the generation of novel hypotheses. As I stated above, Magnani distinguishes between sentential abduction and model-based abduction in terms of different types of mental representations enabling different types of cognitive operations. Given what I argued for in the previous two paragraphs, I doubt that the generation of new hypotheses can be achieved through model-based abduction involving the manipulation of imagistic representations. More plausibly, sentential and mathematical symbols are involved both in the selection of a hypothesis among other available hypotheses and in the generation of novel hypotheses.

The upshot of this critical discussion is that we need to recognise an alternative notion of imagination that can contribute an explanation of the generation of new hypotheses in models in terms of the deployment of linguistic and mathematical symbols.

3 Models as Games of Make-Believe

To identify the right kind of imagination involved in the generation of hypotheses in models I will take on board a taxonomy of varieties of imagination recently developed in

Salis and Frigg (forthcoming). Here we distinguish between two main kinds of imaginative abilities, objectual imagination and propositional imagination. Objectual imagination is a mental relation to a representation of a (real or non-existent) object, and further divides into imagery—a relation to an imagistic representation—and conceptual imagination—a relation to a conceptual representation of an object that needs not involve any imagistic symbols, e.g. a concept of a chiliagon, which is a thousand-sided polygon and therefore cannot be visually represented in the mind.

Propositional imagination involves linguistic and formulaic symbols and is usually characterised as a mental relation to a proposition. We identify three main features of propositional imagination that emerge from the current literature on imagination in philosophy of mind and cognitive science, i.e. freedom, mirroring, and quarantining.

Freedom is the feature according to which we can imagine in ways that transcend reality (Currie and Ravenscroft 2002; Nichols and Stich 2000; Velleman 2000). We can imagine that predators have infinite supplies of food, that a pendulum bob is a point mass, that economic agents are perfectly rational etc. without being committed to the genuine truth of any these claims.

Mirroring is the feature according to which propositional imagination carries inferential commitments that are similar to those carried by belief (Gendler 2003; Leslie 1987; Perner 1991; Nichols and Stich 2000; Nichols 2004, 2006). We can engage in inferential reasoning of different kinds (deductive, inductive, abductive) both when we believe that p and when we imagine that p . In both cases inferences will depend on background information and on the particular purposes of our reasoning.

Quarantining is the feature according to which imagining that p does not entail believing that p and therefore does not guide action in the real world (Gendler 2003; Leslie 1987; Nichols and Stich 2000; Perner 1991). Thus, learning through the propositional imagination requires stepping out of the imagination by exporting what has been learned in the imagination in relevant ways (more on this below).

Propositional imagination divides into supposition, counterfactual reasoning and make-believe. Make-believe fits well with the social, normative and objective character of imagination in scientific models and artistic fictions and for this reason we identify this variety of propositional imagination as crucial to the construction and development of models and to the derivation of their outcomes.

Walton (1990) originally characterises make-believe as an imaginative activity involving props and submits that works of fiction function as props in games of make-believe. Props are ordinary objects that make propositions fictionally true in virtue of a prescription to imagine, i.e. a social convention explicitly stipulated or implicitly understood as being in force within a game. Fictional truth—or fictionality—is

a property of those propositions that are licensed by the prescriptions to imagine of a game (independently of whether they are in fact imagined). To call a proposition p fictional means that in a certain game F it is to be imagined that p . To avoid confusion, I will use the expression ‘ f -truth’ to refer to fictional truth.

F -truths divide into primary f -truths and implied f -truths. Primary f -truths are generated directly from the text of a fictional story (the prop). Implied f -truths are generated indirectly from the primary f -truths via principles of generation. Walton identifies two main principles of generation, the reality principle, which keeps the world of the fiction as close as possible to the real world, and the mutual-belief principle, which is directed toward the mutual beliefs of the members of the community in which the story originated. Depending on disciplinary conventions and interpretative practices other principles are also possible.

Games of make-believe are *authorized* when they are constrained by the author’s prescriptions to imagine. They are *unofficial* when they are not licensed by an author’s prescriptions to imagine and the rules of generation constraining them are *ad hoc*. Furthermore, they can involve imaginings about real objects and fictional objects. But imaginings do not have any ontological import and do not commit us to postulate any fictional entities. The Waltonian framework is therefore compatible with both realism and antirealism about fictional entities, but Walton (1990, chap. 10–11) voices his preference for antirealism.

When we apply these ideas to scientific models we obtain the following picture. Models involve model descriptions—the props—that prescribe imagining that certain hypothetical systems are so and so. Consider, for example, the Lotka–Volterra model of dynamic interaction between predator and prey populations. The model is usually identified with the two differential equations presented in Sect. 1. The equations are the props that prescribe imagining that two hypothetical populations dynamically interact with each other according to certain mathematical constraints. The first equation prescribes imagining the growth of the prey population as the rate of increase in prey population ($dx = Ax dt$) proportional to the number of prey, minus the rate at which prey are destroyed by predators ($dx = - Bxy dt$). The second equation prescribes imagining the growth of the predator population as the rate of decrease of the number of predators ($dy = - Cy dt$) proportional to the number of predators, plus the rate at which predators consume prey ($dy = Dxy dt$).

As mentioned in the Introduction, the model description further prescribes imagining that predators have infinite appetite, that prey have limitless supplies of food, that the environment in which they interact does not change. We can imagine otherwise if we want, for example we can imagine that prey have only limited supplies of food, but this is in violation of the model’s prescriptions to imagine and thus it

is not among its *f*-truths. The content of the model is therefore normatively and objectively determined by the model's initial prescriptions to imagine and by the interpreted mathematical principles of the game independently of possible subjective idiosyncrasies in the actual imaginings of users of the model.

Furthermore, the model is developed by finding out what is implicitly true in it or implicitly *f*-true, which goes beyond what is explicitly stated in the original prescriptions to imagine. And this makes it possible that we can discover facts in the model—what we may call fictional facts or *f*-facts—that enable us to learn about the model and, eventually, also about reality. These implicit *f*-truths can be inferred according to certain principles of generation. However, as we emphasise in Salis and Frigg (forthcoming), neither the reality principle nor the mutual belief principle are privileged in scientific modelling. Scientific models make use of different principles that can vary depending on disciplinary conventions, interpretative practices and purpose of enquiry.¹ The Lotka–Volterra model is developed according to the mathematical constraints of the two differential equations to find out the rates of increase and decrease of the size of the imaginary prey and predator populations. The model predicts that when the number of predators increases (*y*), so does the rate at which predators consume prey (Dxy), which leads to an increase in their number. As a consequence, the number of prey (*x*) decreases, which leads to a decrease in the number of predators (*y*) and the rate at which predators consume prey (Dxy) also decreases. As the rate at which predators consume prey decreases, the number of prey (*x*) increases again, leading to an increase in the number of predators (*y*) starting again the cycle.

In this way we have discovered the mechanisms of dynamic interaction of two fictional populations. That is, we have discovered certain *f*-facts pertaining to a fictional system. Discovering the rates of increase and decrease in the size of *real* populations interacting with each other requires exporting what we have learned in the game of make-believe onto reality via the formulation of certain theoretical hypotheses. Specifically, it requires comparing the rates of increase and decrease of the size of fictional populations and the rates of increase and decrease of the size of real predator and prey populations with the aim of testing whether the first are shared by the second. Fictional populations do not really increase or decrease their size in dynamic interaction with each other. That is, they do not really have the sort of properties that they are supposed to share with real predators and prey. So, how can model-world comparisons involving apparent reference to fictional populations be true? Answering this question requires turning to Walton's analysis of

fictional discourse, i.e. discourse about fictional characters, events and situations. I will come back to this in Sect. 4.

4 Simple Fictionalism

From the current literature on the representational function of models emerge two main conditions that a model has to satisfy to be a representation of a real system that enables knowledge of reality, the *aboutness condition* (henceforth AC) and the *epistemic condition* (henceforth EC). AC is the condition that an object *x* has to satisfy to be a representation of a distinct object *y*. EC is the condition that an object *x* has to satisfy to be an epistemic representation of a distinct object *y*. In this section I will first focus on AC and then on EC.

4.1 Aboutness Condition or AC

Contemporary theories of models as representation identify denotation as the key to AC. Denotation is a dyadic relation between a token of a representational symbol and the particular or multiple objects it stands in for. Philosophers of language have spent a great deal of time developing different theories of denotation—or reference (they often use the two terms as synonyms). But while they take the nature of denoting symbols to be sufficiently clear not to worry too much about it, philosophers of science have spent quite a great deal of ink trying to understand the nature of models and what kind of objects they really are (see Frigg and Nguyen 2017 for a review of these different positions).

According to simple fictionalism, a model *M* is a complex object that is constituted by a model description D_M and its content C_M , so that $M = [D_M, C_M]$. Model descriptions are akin to the texts of fictional stories, they are props that prescribe imagining certain *f*-truths. The model content includes the explicit *f*-truths prescribed by the model description and the implied *f*-truths generated through the principles of generation. The relevant *f*-truths, as anticipated in Sect. 3, are nothing other than the propositions that are among the prescriptions to imagine generated by D_M . Model descriptions typically involve definite or indefinite descriptions and express propositions that are not about any concrete object. Simple fictionalism avoids the usual metaphysical controversies surrounding the nature of fictional entities by assuming fictional antirealism. On this view, there are no imaginary systems that model descriptions are about.

Nevertheless, model descriptions *seem* to prescribe imaginings *about* some particular systems. This is one important aspect of the phenomenology of models—or what Thomson-Jones (forthcoming) calls the *face-value practice*. He notices that a model description “has the surface appearance of an accurate description of an actual, concrete system (or kind of

¹ See Frigg and Nguyen (2016) for the sort of principles of generation involved in models.

system) from the domain of inquiry” (2010, p. 284). But how can model descriptions prescribe imaginings *about* model systems if there are no such systems? This is one particular instance of the more general problem of the object-directedness—or intentionality—of mental states.

Antirealists about intentionality argue that not every mental state that seems to be directed at some object needs an object. According to one increasingly popular idea, the object-directedness of our imagining is explained in terms of the notion of a mental file.² This notion is deeply rooted in our folk psychology and it is akin to the idea of a concept, a cognitive particular or a mental representation that stands in for an individual object. A mental file is a cognitive structure for the storage of information that a subject takes to be, internally, about one and the same object independently of whether the object exists. An architect refurbishing an old building will produce a description (including sentences, plans, blueprints) containing all sort of information that she takes to be about the building. An architect planning to construct a new building will do something very similar and will take the information stored in the file to be about one and the same building even though this does not yet exist. Similarly, the model description of the Lotka–Volterra model involves information that one takes to be about certain imaginary populations dynamically interacting with each other. The descriptive information generated through the prescriptions to imagine and the principles of generation is taken to be about the same imaginary populations. Of course, there are no real entities that this information is really about. So, this aboutness relation is not genuine aboutness but merely pretend aboutness. Yet internally, at the level of thought, these cases engage the same sort of cognitive resources and therefore have the same phenomenology.

Here is another aspect of the phenomenology of models that has been at the centre of heated debate.³ Often scientists seem to think and talk about model systems *as if* they were the vehicles of denotation. For example, they say things like ‘the imaginary prey population represents the rabbit population’, or ‘the imaginary dynamic interaction between imaginary predator and prey populations represents the real dynamic interaction between foxes and rabbits’. Those who have taken this *datum* at face value have argued that model systems really are the vehicles of denotation. To account

for this intuition, realists postulate that model systems are abstract entities that stand in a representation relation with real world targets.⁴ But what can antirealists say?

Antirealists will have to say something like the following. Scientists use model descriptions to specify, in the imagination, an imaginary system having these and these properties. Of course, they are merely engaging in pretence and this does not commit to the postulation of any imaginary systems as *bona fide* objects. While engaged in the very same pretence scientists also claim that model systems denote targets. As stated above, denotation is a relation between a referring symbol (the *denotans*) and an object (its *denotatum*). Philosophers of language have already focused on cases where there is a referring term (e.g. ‘the present king of France’, ‘Ulysses’) but no object that satisfies the reference-fixing condition associated to uses of the term. The problem that the antirealist about model systems faces is what I call the *inverse* problem of denotation, where we have a *denotatum* (the target) without *denotans* (the model system). On this antirealist interpretation of model systems, denotation fails because there is no vehicle of denotation. It follows that denotation between model systems and targets is only *pretend* denotation and therefore it is not denotation at all.

How can simple fictionalism explain AC coherently with antirealism about model systems? Simple fictionalism identifies the model M —the complex object constituted by the model description D_M and its content C_M —as the vehicle of denotation. Scientists construct and develop models in pretence just like authors of fiction construct and develop fictional stories in pretence. D_M do not denote any real targets just like fictional texts do not denote any real objects. Furthermore, they do not prescribe imaginings about any real systems, but rather prescribe imaginings about fictional systems without there being any such systems. M , as the complex object constituted by D_M and C_M , however, is a *bona fide* object that can stand in a genuine (rather than pretend) denotation with targets. Both D_M and C_M exist, and so the *whole* model M exists. Model systems, however, don’t exist—just like the fictional characters described in fictional stories don’t exist. Indeed, they are not part of the model at all. The intuition that model descriptions prescribe imagining propositions that seem to be about some particular model systems can be explained in terms of the deployment of mental files for the storage of information that they take to be about some particular object independently of whether the object exists or not. Mental files, however, are associated to the model without being part of it. Since both D_M and C_M exist, there can be genuine denotation relation between M and real target systems.

² Friend (2011, 2014) appeals to mental files to explain the phenomenon of intersubjective identification of fictional characters within an antirealist framework. Intersubjective identification of the same object, or co-identification, is further explained in terms of participation in the same information network (Friend 2011, 2014) or the same name-using practice (Salis 2013) which support the mental files.

³ See the current dispute between upholders of the so-called indirect fiction view (Frigg 2010) and the direct fiction view (Toon 2012) of models.

⁴ See, e.g., Giere (1988, 2004) and more recently Thomasson (forthcoming) and Thomson-Jones (forthcoming) for a defence of this view.

4.2 Epistemic Condition, or EC

Now let us move to EC, which is the real key to the problem of how models enable scientific discovery and knowledge of reality. Simple fictionalism can contribute an explanation of EC in terms of the generation of two main kinds of theoretical hypotheses about reality, comparative statements and direct attributions. It is through these testable hypotheses that models can enable genuine scientific discovery and inferences about reality. Let us start from model-world comparisons. Fictional objects do not have the sort of properties that they are supposed to share with real objects. So, how can model-world comparisons involving apparent reference to fictional objects be true? Answering this question requires turning to Walton's analysis of fictional discourse.⁵

When considering the Lotka–Volterra model of dynamic interaction between two populations we can say things like:

1. The prey population has unlimited supplies of food.

This can be interpreted in two different ways, as an instance of *intra-fictional discourse* that we perform from a perspective that is *internal* to the imagined context of the model or as an instance of *meta-fictional discourse* that we perform from a perspective that is *external* to the imagined context of the model. On the first interpretation, utterances of (1) are assertions (or pseudo-assertions) that are only *f*-true and the propositional attitude we have toward their content is imagination. On the second interpretation, utterances of (1) are genuine assertions that can be evaluated for genuine truth and the propositional attitude we have toward their content is belief. In this case, we need to read (1) as implicitly prefixed by an operator M_{LV} quantifying over the Lotka–Volterra model that is akin to Walton's (1990, 396 ff.) fictional operator:

2. According to M_{LV} , the prey population has unlimited supplies of food.

The proposition that 'according to M_{LV} , the prey population has unlimited supplies of food' (a general proposition that does not involve reference to any concrete population) is true even though there is no fictional prey population.⁶

We can claim to know things about the imaginary populations described in the Lotka–Volterra model and the

ways in which they interact. But what sort of knowledge is the one we claim to have in this case? These claims, call them K_f -claims (where 'K' stands in for 'knowledge' and 'f' stands in for imagination), involve imagination as the relevant mental attitude and they can only be assessed for *f*-truth. As such, they do not fit well with the traditional notion of knowledge as *justified true belief*. Addressing this issue requires developing an understanding of the epistemic constraints operating on imagination in models. Here I can only sketch what I believe to be the beginning of the right sort of answer. What makes a particular imagining justified is the possession of evidence that is provided by the objective *f*-truths generated by the original prescriptions to imagine of the model together with the principles of generation. It is this conformity with the original prescriptions to imagine and the principles of generation that guarantees that a particular imagining is the outcome of a reliable epistemic process. We are justified in imagining that the prey population has unlimited supplies of food or that predator and prey dynamically interact with each other in cyclical ways if this conforms to the prescriptions to imagine of the Lotka–Volterra model. In this way, we can explain how these claims can be objectively assessed in terms of the notion of *f*-truth.

Now consider a comparison between imaginary populations and real populations:

3. The dynamic interaction of the imaginary predator and prey populations is very similar to the dynamic interaction of real foxes and rabbits.

(3) is literally false (because there is no dynamic interaction between imaginary predators and prey). Walton (1990, 405 ff.) submits that such utterances should be understood as contributions to unofficial games of make-believe. On the internal reading, an utterance of (3) is interpreted within an unofficial game of make-believe that includes information about the dynamic interaction of imaginary populations and the dynamic interaction of real foxes and rabbits. On the external reading, we have to appeal to an operator UG_{LV} quantifying over the unofficial game of make-believe implied by comparing the dynamic interaction of imaginary populations and the dynamic interaction of real populations. Call this *AI* for Analysis-1. On this interpretation, (3) is replaced by

4. According to UG_{LV} , the dynamic interaction of the imaginary predator and prey populations is very similar to the dynamic interaction of foxes and rabbits.

While (3) is only *f*-true, (4) can be tested for genuine truth. Indeed, (3) has only fictional truth conditions—it is *f*-true in the unofficial game of make-believe—while (4) is genuinely true because the unofficial game of make-believe is real and (4) simply reports one of its prescriptions to imagine. Compare: 'it is fictional that *p*' with 'the game is such that *p*'.

⁵ See Salis (2016) for an extensive discussion of Walton's analysis of fictional discourse and model-world comparisons in relation to the current literature on models as fiction.

⁶ Walton rejects this interpretation for statements involving fictional names (which according to him express no propositions) and appeals instead to an analysis in terms of *kinds of pretence*. Friend (2011) argues that this is insufficient to distinguish different kinds of pretence that seem to be about different fictional objects. She and Salis (2013) offer an alternative analysis in terms of gappy propositions. Model descriptions, however, do not usually involve proper names. So, we should not worry about this particular problem here.

Some comparative claims, however, involve reference to degrees of properties, rates of increase and decrease of properties, and other mathematical entities that can be individuated on a scale of measurement:

5. The rate of increase in the size of the fictional prey population is very similar to the rate of increase in the size of the rabbit population.

The fictional prey population cannot instantiate any increase of size. On the internal reading, an utterance of (5) is interpreted as performed within an unofficial game of make-believe which includes information about the rates of increase of the size of the fictional prey population and the rates of increase of the size of the real rabbit population. (5), of course, is only *f*-true. On the external reading, we can appeal to quantification over rates of increase of the fictional prey population size and the operator M_{LV} quantifying over the Lotka–Volterra model. Call this A2 for Analysis-2. On this interpretation, (5) can be construed as:

6. There are some rates of increase in population size, i and j , such that $i \cong j$, according to M_{LV} the rate of increase of the prey population size is i , and the rate of increase of the rabbit population size is j .

(6) is a candidate for genuine truth on the assumption that there are certain rates of increase in population size i and j standing in a similarity relation, according to the Lotka–Volterra model i is instantiated by the (fictional) prey population, and j is instantiated by the real rabbit population. Of course, i is only fictionally instantiated by the imaginary prey population. But the relevant clause states that it is *according to the model* that i is instantiated. That is, the clause is a report of what the model prescribes to imagine.

How is the similarity relation between models and reality *justified*? To address this issue, we need to distinguish between generating and assessing a hypothesis as a plausible candidate for truth on the basis of evidence originated in the game of make-believe and assessing the hypothesis for truth and falsity in reality and therefore on the basis of empirical evidence. The relevant hypotheses become K_R -claims (where ‘ K ’ stands in for knowledge and ‘ R ’ stands in for reality) when they are assessed for truth in reality through rigorous and systematic procedures of observation and experimentation. I may compare the ways in which the fictional populations in the Lotka–Volterra model interact with the ways in which real predator and prey populations interact. They become K_R -claims when they are assessed in reality. However, comparative claims involve genuine reference to real world objects and apparent reference to non-existent objects. Model-world comparisons are therefore contributions to unofficial game of make-believe.

Unofficial games of make-believe raise the same issues raised by K_f -claims and are amenable to similar solutions.

One caveat is in order though. The truth-conditions of these claims are only partially constrained by the prescriptions to imagine of a certain game, i.e. those concerning features of the imaginary objects of the model. Imaginings about reality, however, are constrained by reality itself. For example, when I compare the ways in which the imaginary populations in the Lotka–Volterra model interact with the ways in which real predators and prey interact, I must assess the claim with respect to the model prescriptions to imagine and with respect to reality. If real populations do not behave in similar ways (if they do not instantiate the features that they are supposed to share with imaginary populations) then the comparative claim will be false.

Sometimes scientists do not engage in model-world comparisons but rather in comparisons between models, or what I would like to call *model–model comparisons*.⁷ For example, in some scientific contexts scientists compare models of different degrees of abstraction such as data-models and theoretical models about black-holes without comparing a model of a black-hole and a real black-hole. Depending on the specific sort of comparative claim, we could apply analysis A1 or A2 to these cases too. However, the similarity relation between models would be justified only in terms of the prescriptions to imagine in force in the games of make-believe and in the unofficial games of make-believe generated for the specific purposes of these special circumstances. As such, they raise the same issues raised by K_f -claims and are amenable to similar solutions.

Finally, scientists can also select and export information about the model system as testable hypotheses about the target when they directly attribute imagined properties of the fictional system to the target. So, for example, they can say things like:

7. The rates of increase and decrease of the real predator population size tracks the rates of increase and decrease of the size of the real prey population.

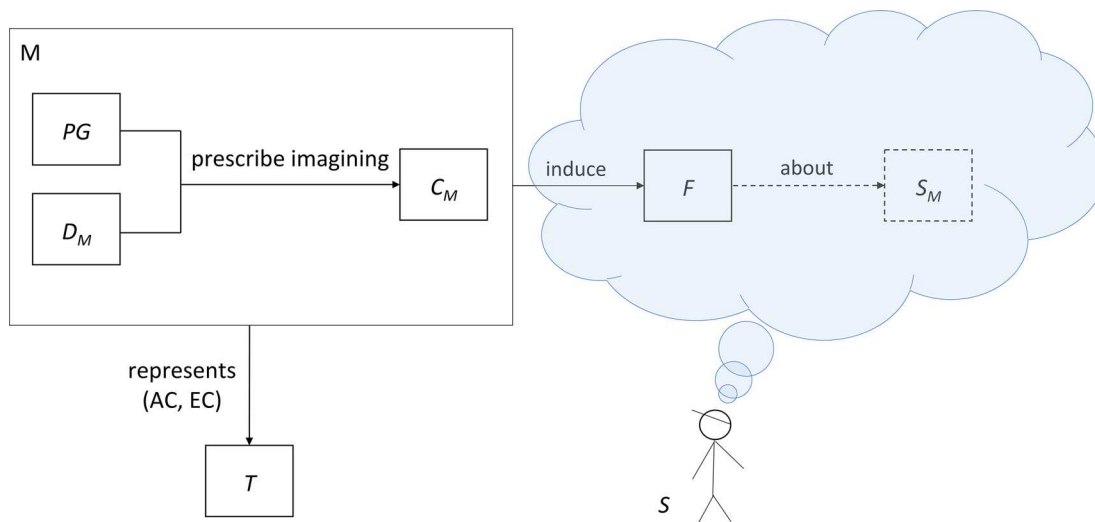
(7) is not a comparison but a direct attribution of a property of the fictional system (rates of increase and decrease of population size) to the real predators and prey. The generation of this kind of theoretical hypotheses can be explained in terms of interpretation keys converting facts about model systems into claims about targets.⁸ When the relevant key is identity the

⁷ Thanks to an anonymous referee for pointing out this different type of comparison.

⁸ Interpretation keys have been presented originally by Frigg (2010). On his view, model systems are analogous to maps that allow inferring facts about a certain territory from facts about the map and an interpretation key translating facts about the map into claims about the territory. See Salis (2016) for a critical discussion of this notion in the context of Frigg’s fictionalist proposal.

imagined properties of model systems and the real properties of targets can only be fictionally identical, or identical within a game of make-believe. That is, we can only have *imagined identity*. Exporting what we have learned about the model system requires that we assume an external perspective (either implicitly or explicitly) and state that this is how things are described *in the model* and then claim that this is also how things are (hypothetically) in the relevant physical system. Thus, an interpretation key is nothing other than a principle of exportation that needs to take into consideration the original fictional nature of the facts that are fictionally identical to those of

the relevant target. The key enables to export an *f*-fact about imaginary populations and rates of increase and decrease of population size, as described according to the model, outside of the game of make-believe into a claim about a real corresponding fact about real populations. It is by generating these direct attributions that we can achieve genuine scientific discovery: after a plausible hypothesis has been generated through the imagination via the constraints imposed by the model description, we can test the relevant hypothesis in reality to gain genuine knowledge of real world phenomena.



Simple fictionalism: The model description D_M prescribes imagining a certain propositional content C_M , which is composed of the primary *f*-truths of the model and the implied *f*-truths generated through the principles of generation PG . The information generated through the original prescriptions to imagine and the principles of generation is stored in a mental file F and taken to be, internally, about a model system S_M . There is, however, no model system. The model M , constituted by D_M and C_M , stands in the representation relation with the target T . This representation relation involves two different conditions, AC (the aboutness condition) and EC (the epistemic condition), that need to be satisfied for M to be a representation that enables scientific discovery and thereby knowledge about T .

5 Conclusions

In this paper I developed simple fictionalism as a novel account of scientific models as epistemic representations that enable scientific discovery. In doing this, I drew on Walton's influential theory of fiction as a game of make-believe. Following previous work done with Roman Frigg, I interpreted make-believe as a form of propositional imagination constrained by prescriptions to imagine and domain specific principles of generation. I advanced an explanation of AC starting from the identification of models as complex objects constituted by model descriptions (the props) and their content (a set of fictional propositions) and I argued that they are the vehicles of denotation. I explained EC in terms of the generation of theoretical hypotheses, i.e. model-world comparisons and direct attributions. The upshot is that scientific models can lead to genuine scientific discovery when they are used as representations that stand in a genuine denotation relation with the world and generate plausible hypotheses through make-believe.

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Compliance with Ethical Standards

Conflict of interest Author declares that she has no conflict of interest.

Ethical Approval This article does not contain any studies with human participants or animals performed by any of the authors.

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