The New Fiction View of Models

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Abstract

How do models represent reality? There are two conditions that scientific models must satisfy to be representations of real systems, the aboutness condition and the epistemic condition. In this article, I critically assess the two main fictionalist theories of models as representations, the indirect fiction view and the direct fiction view, with respect to these conditions. And I develop a novel proposal, what I call 'the new fiction view of models'. On this view, models are akin to fictional stories; they represent real-world phenomena if they stand in a denotation relation with reality; and they enable knowledge of reality via the generation of theoretical hypotheses, model–world comparisons and direct attributions.

Keywords: scientific models; scientific representation; make-believe; denotation; theoretical hypotheses; mental files

1 Introduction

Modern science crucially relies on descriptions of imaginary systems—or model systems—that scientists study to learn about certain parts or aspects of the world—or target systems. An imaginary system is chosen as the object of study because it is less complex than its target and because by studying the model system we can learn about the target. This prompts the question of how scientific models represent. That is, what turns a description of an imaginary system into a representation that enables drawing inferences about reality. In this article, I develop a new theory of model representations coherent with the original insight of the fiction view of models. The fiction view started from a natural analogy with the imaginary objects of literary fictions. Godfrey-Smith originally emphasized that 'modelers often treat model systems in a "concrete" way that suggests a strong analogy with ordinary fictions' ([2006], p. 739), and that they often think of themselves as describing 'imaginary biological populations, imaginary neural networks, or imaginary economies' that 'might be treated as similar to [...] the imagined objects of literary fiction' ([2006], p. 735).

The main motivation for the fiction view is a theoretical requirement that Frigg ([2010]) calls 'naturalism'. According to naturalism, any account of how scientists learn with models should be able to explain scientific practice, or what Thomson-Jones ([2010]) calls the 'face-value practice' of modelling. Thomson-Jones emphasizes that a model description 'has the surface appearance of an accurate description of an actual, concrete system (or kind of system) from the domain of inquiry' (Thomson-Jones [2010], p. 284). There is no actual concrete object that fits the description and competent scientists know that. For example, the model description of the ideal pendulum seems to specify an imaginary system that is composed of a point mass and a string that is massless and unstretchable. The model description involves the attribution of properties that only concrete objects can have, such as being pulled, being released, and engaging in oscillatory movement. The model description seems to be about a particular concrete object, but there is no real object that satisfies the descriptive conditions stipulated by scientists. Yet, scientists think and talk as if there were such an imaginary object to be studied and explored and as if this imaginary object were a representation of some physical system.

The main contemporary versions of the fiction view of models recognize the central role of imagination in the modelling practice and build on Walton's ([1990]) notion of make-believe as a social imaginative activity (Frigg [2010]; Levy [2015]; Toon [2012]). Imagination is often construed as imagery, which is an ability to conjure up a perception-like state, such as forming a mental image. However, Salis and Frigg ([forthcoming]) argue that the relevant sort of imagination involved in scientific models is make-believe, which they specifically construe as a variety of propositional imagination. Propositional imagination is an ability to conjure up alternative states of affairs, possibilities (or even impossibilities), and scenarios, which can but need not be accompanied by mental images. For example, when considering the model of the simple pendulum, one imagines that a point mass is suspended to a massless string, that the point mass oscillates in a uniform gravitational field, and that the point mass is not slowed down by friction. While imagining these propositions one need not also form mental images of a point mass, massless string, uniform gravitational field, or frictionless motion. All these notions are grasped through specific theoretical concepts that do not involve any mental images.

There are two main strands of the fiction view, the indirect fiction view and the direct fiction view. The indirect view posits that model descriptions prescribe imagining about model systems, that model systems are akin to fictional characters, and that model systems are representations of physical systems (Frigg [2010]; Thomasson [forthcoming]; Thomson-Jones [forthcoming]). The direct view posits that model descriptions prescribe imaginings about physical systems without the mediation of a model system, and that model descriptions are representations of physical systems (Toon [2012]; Levy [2015]). The indirect fiction view and the direct fiction view incur different internal problems and, as I will argue, they do not successfully explain the representational function of models. For these reasons, I will formulate an alternative account, what I call the 'new fiction view of models'.

In recent years, several different theories of model representations have been developed.[1] The fiction view falls under a broad pragmatic account that sees models as objects that acquire a representational function when used in certain ways (Bailer-Jones [2003]; Currie [2017]; Frigg [2006], [2010]; Giere [2004]; Godfrey-Smith [2006]; Mäki [2009]; Parker [2011]; Suárez [2004], [2010]; van Fraassen [2008]).[2] While these theories disagree on several issues, most of them tend to converge on the recognition of two main conditions of adequacy that a model has to satisfy to be a scientific representation of real-world phenomena, the aboutness condition and the epistemic condition.[3] The aboutness condition is the condition that an object *x* has to satisfy to be a representation of a distinct object *y*. The epistemic condition is the condition that an object *x* has to satisfy to be an epistemic representation of a distinct object *y*, that is, a representation that enables knowledge of reality. These conditions raise some particularly difficult problems for the fiction view of models.

Let us focus on the aboutness condition first. Models enable us to learn about reality only when they are used as stand-ins for the particular aspects of the world we investigate. Without this condition, there would be no representation relation between a model and the real-world phenomena we want to understand. This raises an important question: in virtue of what does a model represent its target? Frigg refers to this as the 'enigma of representation' (Frigg [2006], p. 50), Morrison ([2008], p. 70) calls it 'the crux of the problem of representation', and Suárez ([2003], p. 230) specifically draws attention to the problem of

[1] See (Frigg and Nguyen [2017]) for a detailed review of these theories.

[2] Pragmatic approaches are sometime also called 'deflationary' (Giere [2004]; Knuuttila [2005]; Suárez [2010]) or 'functional' (Chakravartty [2010]), and are often opposed to 'strong accounts' (Knuuttila [2011], p. 265) based on some kind of morphism, including isomorphism (da Costa and French [2000]; French [2003]; Suppe [1974]; van Fraassen [1980]), homomorphism (Bartels [2006]; Lloyd [1988]), and partial isomorphism (Bueno [1997]; da Costa and French [2003]).

[3] In his critical discussion of representationalism, de Oliveira ([forthcoming]) identifies two main components of representation, an ontological component and an epistemic component, that correspond to the aboutness condition and the epistemic condition respectively.

how to understand this particular relation between models and targets. To appreciate the importance of the question it is useful to look at how the same problem is raised in the different context of pictorial representation.[4] When seeing Leonardo's *Monna Lisa*, we immediately recognize that the painting depicts a woman (Monna Lisa). The painting, however, is a flat canvas covered in paint. So, how can it represent anything beyond itself? Analogously, models represent solar systems, biological populations, and economies. But they are none of these things themselves. Models are equations and descriptions that represent other things beyond themselves. How do they do that? Many contemporary theories of model representations answer this question by appealing to the notion of denotation. Denotation is a dyadic relation between object *x* (a denoting symbol) and object *y* (a denoted object). According to the DDI (denotation, demonstration, interpretation) theory, denotation establishes the representation relation between models and reality (Hugues [1997]); some interpretations of the structuralist theory construe the relation between models and reality in terms of denotation (Contessa [2007]); the similarity theory holds that modellers generate hypotheses that denote targets (Giere [2010]); some versions of the fiction view of models posit that representation involves a denotation condition on models (Frigg [2010]); and the DEKI (denotation, exemplification, keying-up, imputation) account of models recognize denotation as essential (Frigg and Nguyen [2016]).

These theories also converge on the claim that models are used as the vehicles of denotation. That is, models are the symbols standing in the denotation relation with targets. Philosophers have largely disagreed on the ontology of models, and hence on the nature of the vehicles of denotation. This raises a fundamental challenge to any account of model representations: what objects are they and how do we identify them? Call this the

[4] A similar comparison with pictorial representation is made by Frigg ([2006], p. 50), who points out that in the context of pictorial representation, Flint Schier ([1986], p. 1). referred to the same problem as 'the enigma of depiction'.

‘identification problem’. In the previous paragraph, I said that denotation is a dyadic relation between a denoting symbol and a denoted object. Only existing objects can enter into relations. This raises a particularly strong version of the identification problem for the fiction view of models. According to this view, models are akin to fictional characters. So, what sort of objects are they and how can they possibly enter into a denotation relation with their targets?

Now let us move to the epistemic condition. Model representations are objects that are studied and developed for the purpose of learning about their targets. This is what makes them epistemic representations, namely, representations that facilitate the acquisition of knowledge. It is generally agreed that models represent in ways that enable the formulation of hypotheses about their targets. For example, Swoyer ([1991]) emphasizes that models are surrogate systems that scientists study with the aim of learning about real-world systems; Bolinska ([2013]) and Contessa ([2007]) describe models as ‘epistemic representations’; Frigg ([2006]) argues that an essential requirement of any theory of model representations is that it explains how they enable knowledge of reality; Godfrey-Smith ([2006]) posits that models have a distinctive epistemic role in science; Suárez ([2003]) claims that models license inferences about their targets; and Weisberg ([2013]) recognizes that the model–world relation is one that enables knowledge. So, how do models represent in ways that facilitate knowledge of reality? Call this the ‘epistemic problem’.

Many contemporary theories of models, including the ones mentioned above, posit that answering the epistemic problem requires the recognition that learning with models involves two steps. First, scientists study a model system to elicit new information about its properties and generate certain claims about the model system. Second, they convert what they have learned about the model system into knowledge of the target system via a set of comparative claims based on a relation of similarity. Usually, similarity is spelled out in terms of the sharing of properties in some respects and to certain degrees (Giere [1988], [2010]). For example, scientists compare idealized populations and biological populations, imaginary economies and real economies, the simple pendulum with physical pendulums, and they formulate certain claims about the relevant similarities between them.

Comparative claims are theoretical hypotheses, which are candidates for truth. But the current dispute about the ontology of models raises a particular problem concerning the truth conditions of model–world comparisons. Call this the 'problem of truth conditions'. Only concrete objects can have the sort of properties that model systems and target systems supposedly share. But model systems are not concrete. On the fiction view, they are merely imaginary systems. So, how can they share any properties with any physical systems and what would ground the truth conditions of model–world comparisons?

In what follows, I propose a new solution to the identification problem and the problem of truth conditions for model representations. This view remains coherent with the original insight of the fiction view and, like the indirect and the direct fiction views, it also draws on Walton's theory of make-believe. However, the new fiction view offers an original analysis of model representations and different responses to the identification problem and the problem of truth conditions. Concerning the identification problem, the new fiction view holds that models are akin to fictional stories, and that it is they (rather than model systems or model descriptions) that stand in a representation relation with targets. Concerning the problem of truth conditions, the new fiction view develops the Waltonian analysis of fictional discourse into an analysis of comparative claims. Furthermore, it recognizes that comparative claims can be only true in the context of a game of make-believe, and that the ultimate key to the epistemic condition is in the generation of direct attributions that export what has been learned about the model into theoretical hypotheses about reality. The new fiction view therefore posits that learning with models involves two different kinds of theoretical hypotheses, that is, model–world comparisons and direct attributions.

The plan of the article is the following: First, I will illustrate how the Waltonian notion of make-believe applies to scientific models (Section 2). Second, I will critically discuss the indirect view and the direct view (Section 3). Third, I will present the new fiction view of models (Section 4), and I will show how this can answer the identification problem and the problem of truth conditions (Section 5).

2 Models as Games of Make-Believe

Walton ([1990]) introduces the notion of a game of make-believe as a social imaginative activity involving props and further argues that works of fiction are props in the relevant games. Props are ordinary objects that make propositions fictionally true—or *f*-true—in virtue of certain prescriptions to imagine. Fictional truth—or *f*-truth—coincides with the notion of fictionality*,* which is a property of the propositions that are among the prescriptions to imagine of the game. The notion of fictionality is normative and objective to the extent that a proposition, *p*, is fictional when in a certain game it is to be imagined that *p*, independently of whether one actually imagines that *p*.

These initial ideas apply to scientific models in the following way. Models involve model descriptions—the props—that prescribe imagining that certain fictional systems are so and so. Model descriptions can be sentences, graphs, mathematical formulae, and so on. Consider, for example, the simple pendulum model, which is often used to represent familiar phenomena such as a person moving on a swing or a pendulum clock. The model describes the oscillatory movement of a bob suspended by a string. When the bob is displaced from its equilibrium position and then released, it oscillates back and forth on the arc of a circle with a radius that is identical to the length of the string. The model is usually identified with the following differential equation:

$$\frac{d^2\theta}{dt^2} + \frac{g}{L}\sin\theta = 0.$$

To be clear, the equation itself is not a model of anything. In fact, a mathematician could develop the equation independently of any particular reference to any physical system. The equation becomes a simple pendulum model when it is construed as describing a particular type of system. That is, when its variables are construed as standing in for certain objects. Under the relevant construal, the equation describes the oscillatory motion of a bob suspended by a string, where θ is the angular displacement, L is the length of the string, and g is the restoring force acting on the bob, which is gravity. The differential equation is difficult to solve analytically. However, when the amplitude of the angular displacement is small (usually when $\theta_0 < 1$), the equation effectively provides that of a harmonic oscillator and an analytical solution can be easily obtained:

$$\frac{d^2\theta}{dt^2} + \frac{g}{L}\theta = 0.$$

To enable this mathematical treatment, the model makes a number of idealizing assumptions, including that the string is massless and unstretchable and that the bob is a point mass; that the oscillatory motion occurs only in two dimensions (rather than three) and therefore that the point mass (the bob) moves along an arc (rather than an ellipsis); that the gravitational field is uniform; that motion does not lose energy to friction or to air resistance. Of course, these assumptions are false! They do not merely describe a type of system (a bob suspended by a string). They describe an imaginary object (a point mass) suspended by an imaginary string under imaginary conditions. That is, they describe an imaginary—or fictional—system. We can imagine otherwise if we want, but this does not conform to the prescriptions to imagine in force in the model and therefore it is not part of the model's *f*-truths, which means that it is not part of the model's content.

Now we can add another element from Walton's theory to further explain how the model is developed, and hence how we can learn about it. *F*-truths divide between primary *f*-truths and implied *f*-truths. Primary *f*-truths are generated directly from the props. Implied *f*-truths are generated indirectly from the primary *f*-truths via principles of generation. The simple pendulum model is studied and developed by eliciting what is implicitly true in it—or *f*-true. This requires going beyond the initial premises through certain principles of generation. Following Lewis ([1978]), Walton identifies two principles of generation, the reality principle and the mutual-belief principle. The reality principle imports truths about the real world into the world of the fiction so as to keep it as close as possible to the real world. The mutual belief principle imports the mutual beliefs of the community wherein the story was generated into the world of the fiction. However, neither the reality principle nor the mutual belief principle is privileged in modelling. We do not import facts from reality into the model like we would when imaginatively engaging with a realistic fiction. For example, we do not import real physical facts into the model of the simple pendulum (or, for that matter, any real facts, including chemical, biological, historical, and more). Instead, different principles apply depending on disciplinary conventions and purposes of enquiry. In the case we are discussing, the relevant principles are mathematical and they are provided by calculus. For example, one can ask: what is the frequency of the bob's periodic oscillations? That is, what is the number of vibrations that the bob makes in one second? Through calculus, we get the following equation:

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{L}},$$

where f is frequency, π is a constant, and the other variables inherit the assignments they had in the original equation. What is the period of the bob's oscillations? That is, how much time does the bob need to complete one oscillation? Here again, calculus yields the following equation:

$$T = 2\pi\sqrt{\frac{L}{g}},$$

where T stands in for period, the other variables have the same assignments and π is the same constant as in the previous equation. To obtain any specific results we need to assign specific values to the variables. For example, when L is 1.000 m and g is 9.800 m/s^2, the frequency, f, is 0.4983 Hz and the period, T, is 2.007 s.[5]

In this way one learns about the oscillatory movement of a fictional bob oscillating from a fictional spring. That is, one learns about a fictional system. Learning about the oscillatory movement of real systems, however, requires exporting what one has learned about the fictional system outside of the make-believe and onto reality via the formulation of theoretical hypotheses. As I will argue in Section 5, the relevant hypotheses are of two kinds, model–world comparisons and direct attributions. The Waltonian analysis of fictional discourse will be useful to understand the nature of model–world comparisons and the sort of truth conditions they have.

But before I do that, let me clarify that the Waltonian theory is compatible with both realism and anti-realism about fictional entities, and hence also about the imaginary systems

[5] This example is in (Young and Freedman [2011], p. 455).

specified by model descriptions. Imaginings do not have any ontological import and do not commit to any fictional entities. Walton ([1990]) dismisses realism because, as I will explain below, his analysis offers the theoretical tools to dispense with it. But those who, for independent reasons, prefer a realist ontology of fictional entities and model systems can endorse the Waltonian analysis without giving away realism.

3 Standard Fiction Views of Models

In this section, I turn to the two main accounts that occupy centre stage in the current debate on models as fictions, the indirect fiction view and the direct fiction view of models.

3.1 The indirect fiction view

Originally, Godfrey-Smith ([2006], [2009]) presents the indirect fiction view by suggesting that model descriptions specify model systems, that model systems are akin to fictional characters, and that model systems represent targets. We can distinguish two main versions of the indirect view depending upon whether one endorses anti-realism or realism about model systems.

Frigg ([2010]) originally develops the analogy in terms of Walton's theory of fiction as a game of make-believe.[6] He submits that model descriptions are props that prescribe imagining about model systems, and that model systems are the vehicles of representation of targets (what he calls 't-representation'); see Figure 1.

[6] Frigg and Nguyen ([2016]) introduce a version of the indirect fiction view that combines Goodman's ([1976]) and Elgin's ([2010], [2017]) notion of representation-as with the Waltonian account. This version shares with the original account the main problems that I will describe below.

Figure 1.

Frigg construes model systems as analogous to maps that allow inferring facts about a territory from facts about the map through a key translating facts about the map into claims about the territory. On his view, '*X* t-represents *Y* iff: (R1) *X* denotes *Y*. (R2) *X* comes with a key *K* specifying how facts about *X* are to be translated into claims about *Y*' ([2010], p. 126). (R1) responds to the aboutness condition since it establishes the aboutness of *X*. (R2) responds to the epistemic condition since it establishes the cognitive relevance of *X* for *Y* by imputing properties of *X* to *Y*. Frigg assumes anti-realism about model systems and submits that comparing non-existent objects and real objects 'does not seem to make sense' ([2010], p. 119). He interprets model–world comparisons as comparisons between properties of model systems with properties of real systems. On his interpretation, 'when I say that the population of rabbits in a certain ecosystem behaves very much like the population in the Fibonacci model, what I assert is that these populations possess certain relevant properties which are similar in relevant respects' ([2010], p. 119).

This proposal faces four difficulties. First, Toon ([2012], p. 58) notices that if model systems do not exist then they cannot denote anything—and this raises the identification problem. Second, Toon ([2012], p. 58) and Levy ([2015], pp. 789–90) submit that if model systems do not exist they cannot instantiate any properties and therefore there cannot be any facts about model systems to be translated into claims about targets. Third, Godfrey-Smith ([2009], p. 113) argues that since Frigg is suspicious of comparisons between non-existent objects and real objects he should also be suspicious of comparisons between uninstantiated properties and real properties. Fourth, I should also emphasize that model–world comparisons are candidates for truth, but statements involving apparent reference to non-existent objects and/or uninstantiated properties cannot be literally true—and this raises the problem of truth conditions.

These problems follow from Frigg's assumption of anti-realism about model systems. Can the indirect view be better off by assuming fictional realism? Thomasson ([forthcoming]) and Thomson-Jones ([forthcoming]) argue that model systems are best construed as abstract artefacts created through the imaginative activities of scientists. This responds to the identification problem by positing that model systems are abstract objects that represent things beyond themselves. However, Thomasson ([forthcoming]) recognizes that abstract objects cannot really have properties such as being a biological population or feeding on a prey population. Instead, they can only have such properties within a fictional context—or, in Walton's terms, a game of make-believe. She further accepts Frigg's ([2010]) analysis of comparative claims as comparisons between properties. But she overcomes Godfrey-Smith's concern by adding that the existence of these properties can be argued for 'by making pleonastic inferences'—for example, by moving from '"The wand is not magical" to "the property of magicalness is not possessed by the wand" to infer that there is a property of magicalness that the wand (indeed everything) lacks' (Thomasson [forthcoming]). This move, however, does not respond to the problem of truth conditions. Even if the relevant properties exist, abstract objects cannot instantiate them. At most, they can fictionally instantiate them, or instantiate them within a fictional context. The statement

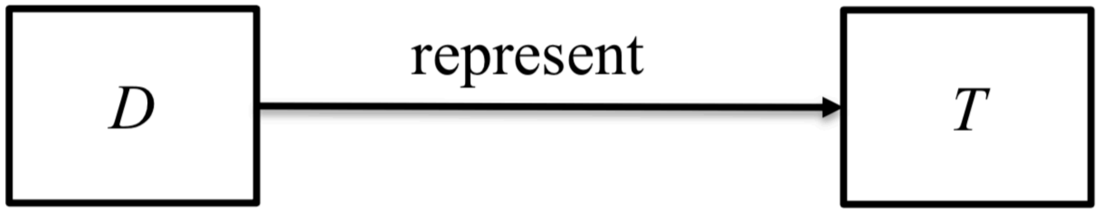

Figure 2.

'the real rabbit population and the imaginary prey population possess certain relevant properties which are similar in relevant respects' cannot be literally true and the problem of truth conditions remains unsolved.

3.2 The direct fiction view

To avoid the usual controversies surrounding the nature of fictional entities, Toon ([2012]) and Levy ([2015]) argue in favour of the direct fiction view of models. On Toon's original version, model descriptions of models with targets prescribe imaginings about concrete targets. For example, the model description of the simple pendulum prescribes imagining of some concrete pendulum that it is different from the way it really is. Model descriptions of models without targets prescribe imagining about fictional systems. For instance, models of synthetic molecules that have not been created in a lab prescribe imagining about fictional molecules. Models with targets enable philosophers of science to defer controversies surrounding fictional entities to philosophers of fiction. Models without targets, however, present philosophers of science with the very same controversies. (See Figure 2.)

More radically, Levy ([2015]) argues that there are no targetless models. He discusses three different cases: non-committal models, generalized models, and purely targetless models. Non-committal models are 'meant to apply to a target, but the specific range and features it captures are not known for sure' ([2015], p. 796). It is only after the target is found that the model satisfies the direct account. Generalized models work as hubs anchoring specific models. A generalized model has a generalized target (for example, population growth in general) and the specific models anchoring to it have particular target systems. The direct account ultimately applies to these too. Models of the third type, the purely targetless models, 'are never applied to any target, not even in a generalized or roundabout way' ([2015], p. 797). This is the case that I think poses the greatest challenge to Levy's version of the direct view. Levy considers a few examples put forward by Weisberg ([2013]) against the direct view, including 'game of life' and other cellular automata. He submits that one shouldn't take these cases too seriously because, ultimately, they are not real models but bits of mathematics.

Perhaps Levy is right in rejecting Weisberg's particular examples. But there are other cases that fall under his characterization of purely targetless models and that his version of the direct view cannot account for. Consider the following cases. Models of synthetic molecules that are never synthesized in a lab, models of three-sex populations that are used to explore certain alternative states of affairs, and models of false scientific posits such as Maxwell's model of ether are purely targetless in the sense that they are never applied to any targets. One may argue that these models are non-representational, and for this reason they would pose no challenge to the direct view. But any theory of model representations must allow for the possibility of representation failure. The analogy with linguistic and pictorial representations will be useful. The name 'Lilliput' is a linguistic representation even though it does not represent anything (because there is no Lilliput). And Millais' painting *Ophelia* is a representation even though there is no Ophelia. Lilliput and Ophelia are fictions, and the representations used to describe them are representations that fail to represent any real objects simply because there are no such objects. Similarly, models of synthetic molecules, alternative possible systems, and false scientific posits are model representations that fail to represent because the corresponding targets do not exist. They are purely fictional.[7]

Here is a challenge to the idea that the direct view can really avoid controversies surrounding fictional entities. Model descriptions, just like the texts of literary fictions, involve apparent reference to objects of different kinds, including fictional things (point masses, massless strings), fictional populations (infinite populations, prey populations with infinite supplies of food), fictional processes (the constant increasing or decreasing of the size of some population, a frictionless oscillatory movement), fictional situations or states of affairs (a point mass suspended to a massless string, the availability of limitless supplies of food). Stating that model descriptions are about real objects does not dispense with fictional entities (and the controversies they generate) because model descriptions always involve apparent reference to some fictional objects.

Upholders of the direct view may insist that all they mean is that scientists' imaginings are about real objects. For example, they imagine that the actual string in front of them is massless. As a result, the argument goes, there is no need to posit a fictional massless string standing between the model description of the ideal pendulum and the world—any more than we need to posit new fictional objects every time we give a false description of something real. This reply, however, introduces a mismatch between what model descriptions prescribe to imagine and what scientists would purportedly imagine. We only need to look at the model description of the simple pendulum (Toon's preferred example) given in a standard physics textbook to realize that this does not involve reference to any real objects:

[7] For a different discussion of targetless models, see (Currie [2017]).

> A simple pendulum is an idealized model consisting of a point mass suspended by a massless, unstretchable string. When the point mass is pulled to one side of its straight-down equilibrium position and released, it oscillates about the equilibrium position. (Young and Freedman [2011], p. 453)

The model description of the ideal pendulum is not about any particular pendulum. It does not start with 'Imagine of this particular pendulum in front of you that it is a point mass suspended by a massless, unstretchable string'. Rather, it apparently refers to an imaginary system consisting of a point mass and a massless string and hence prescribes imagining about a fictional system. On a charitable interpretation, one could argue that while the model description prescribes imagining about a fictional system, a scientist using the model to learn about the oscillatory motion of a physical pendulum in a particular context may also imagine of the physical pendulum that is in front of her that it is a point mass suspended by a massless string. But this is not what the model description prescribes to imagine. The model description is independent of reality. Indeed, it is not a representation of reality.

Here is a different charitable interpretation. Suppose we give up the claim that model descriptions are about concrete individual systems. The direct theorist might claim that model descriptions are about certain types (or classes of types) of concrete objects—for example, all physical objects that satisfy a certain set of properties specified among the prescriptions to imagine of the model. On this interpretation, the model description of the simple pendulum would be about all physical systems that can be described as engaging in the sort of oscillatory motion specified by the model's equations. The problem with this interpretation is that the model description does not involve any reference to ordinary objects, not even as members of a type (or class of types). The model description does not say 'imagine of (or about) all concrete objects that engage in this kind of oscillatory motion (the one described by the simple pendulum) that they are a point mass suspended to a massless and unstretchable string'. And it does not say 'imagine of the abstract type including all concrete objects that engage in this kind of oscillatory motion (the one described by the simple pendulum) that it is a point mass suspended to a massless and unstretchable string'. The model description involves apparent reference to particular imaginary objects (a point mass, a massless and unstretchable string) engaging in oscillatory motion under imaginary conditions.

Now let us briefly consider how the direct view addresses the epistemic problem of how we learn with models. Toon ([2012], p. 67) suggests that this involves making 'an inference from the model to the system when we take what is fictional in the model to be true of the system'. Levy develops a similar idea in terms of Yablo's ([2014]) notion of partial truth, according to which a proposition is partly true if and only if it has parts that are wholly true. He suggests that model descriptions are partly true if some of the things they say about real systems are true. So, for example, when we consider the ideal gas model we evaluate the truth of parts of what the model description says about real gases and 'we find that it is partly true, that is, with respect to the role of the motion of particles; and partly untrue, that is, with respect to the role of collisions among particles' ([2015], p. 794). Real gas particles collide all the time, ideal gas particles never collide. This proposal inherits the problems mentioned above: model descriptions are not about any real systems and the model description of the ideal gas is not about any real gases.

4 The New Fiction View of Models

In this section I propose an alternative account of model representations, what I call the 'new fiction view of models'. Just like the indirect view and the direct view, the new fiction view draws on Walton's theory of make-believe. However, the new fiction view offers a different construal of the analogy between models and fictions. Upholders of the indirect fiction view and the direct fiction view respectively identify models with model systems and model descriptions. The new fiction view rejects both interpretations and reconceptualizes the notion of models as complex objects constituted by model descriptions and model contents.

The fiction view of models was originally motivated by the recognition that scientists think and talk about model systems just as ordinary people think and talk about the imaginary characters of fiction. The new fiction view recognizes the force of this analogy, but it also posits that there is a more fundamental analogy between theoretical models and literary fictions. Walton construes works of fiction as games of make-believe. Literary works of fiction are the products of an author's imaginative activity and the objects of an imaginative response. Analogously, models are the products of a scientist's imaginative activity and the objects of an imaginative response. The new fiction view departs from traditional analyses by holding that the fundamental analogy is between theoretical models and literary works of fiction. In this way, the proposal avoids most of the pitfalls of the traditional analyses that have been described above and, as I will argue below, it delivers a new and better understanding of the face-value practice of modellers and of model representations.

According to the new fiction view, model M is a complex object constituted by model description D and content C, so that $M = [D, C]$. From an ontological point of view, the model is analogous to a literary work of fiction; the model description is analogous to the text of a fictional story (the prop that prescribes imagining certain *f*-truths); and the model content is analogous to the content of a fictional story (it involves the primary *f*-truths prescribed by the model description and the implied *f*-truths generated through the principles of generation). The model description prescribes imagining about an imaginary system, such as a point mass suspended by a massless string. But imaginings do not commit to the existence of any fictional entities and the new fiction view is therefore compatible with anti-realism about model systems. More precisely, the new fiction view commits to fictional anti-realism. On this view, there are no model systems.

What is the relation between model description and model content? The model, *M*, is constituted by model description and model content, and these are distinct entities that only together constitute a particular model. The model description is a set of linguistic and mathematical symbols that prescribe particular imaginings under a construal. For example, as emphasized in Section 2, the model equation

$$\frac{d^2\theta}{dt^2} + \frac{g}{L}\sin\theta = 0$$

is a mere string of mathematical symbols that does not specify any particular *f*-truths until it is interpreted as describing the oscillatory movement of an ideal pendulum. That is, until the variables in the equation are interpreted as standing in for certain (fictional) objects (*L* for the length of the fictional string, *g* for the restoring force acting on the fictional bob). The model content is the set of *f*-truths of the model, including the primary *f*-truths prescribed by the model description and the implied *f*-truths generated through the principles of generation. Thus, the model description alone does not entail the entire model content. Model descriptions set the primary *f*-truths (the model's initial assumptions), while the principles of generation augment these by generating the model's implied *f*-truths. Furthermore, to a certain extent, model description and model content can vary independently of each other. For example, the model description may involve not only mathematical symbols (which, we assume, are generally shared through different contexts) but also linguistic symbols that may change without changing the content of the model (suppose you have a linguistic description of the ideal pendulum in English and another one in Chinese). Different model descriptions can specify the same content under the same interpretation or they can specify a different content under different interpretations (suppose a mathematician interprets the above equation as purely mathematical, without any reference to the oscillatory movement of an ideal pendulum).

Model descriptions are constitutive parts of models. This, however, seems to lead to the absurd consequence that every small change in the model description results in a new model. Fortunately, it does not. To explain this, I will rely on a distinction that has been put forward to avoid a similar objection to the syntactic view of theories.[8] The syntactic view of theories claims that theories are constituted by descriptions, that is, sets of sentences. The syntactic view, however, is not committed to the claim that sentences provide identity criteria for a theory. To understand this, we need to distinguish between theory and theory formulation. A theory is what a particular set of sentences expresses and the same theory can be expressed by different sets of sentences. A theory formulation is the particular expression of a theory through a particular set of sentences and sets of sentences provide identity criteria for theory formulations. As a consequence, any change in any given sentence results in a different theory formulation (a different set of sentences). Providing identity conditions for theories is more difficult and it goes beyond the scope of this article. But it is worth pointing out that several alternatives have been developed over the past decades, including definitional equivalence (Glymour [1970]), intertranslatability (Quine [1975]), and sameness of truth conditions (Hendry and Psillos [2007]).[9] Further work is needed to investigate how each of these different criteria could be used to provide identity

[8] See (Suppe [2000]) for an overview of the key steps of this debate.

[9] See (Barrett and Halvorson [2015]) for a recent critical discussion of Glymour's ([1970]) and Quine's ([1975]) proposals. See (Thomson-Jones [2012]) for an idea about models that is similar to the one defended by Hendry and Psillos ([2007]).

criteria for models having syntatically different yet theoretically equivalent descriptions. But it should be clear that construing model descriptions as constitutive of models does not entail absurd identity conditions because they do not provide identity conditions for models.

Principles of generation, obviously, are also independent of model description and model content. They depend upon the particular interpretative practices and traditions in which a scientist works. Principles of generation in models are poorly understood. As mentioned in Section 2, they can be of different types. Mathematical principles, theoretical principles, and some restricted versions of reality orientation are at work in different models. So, for example, Bechtel and Abrahamsen ([2010]) consider computational models in chronobiology and cognitive science and argue that computational models of circadian rhythm are grounded in empirical discoveries, while computational models in neuroscience typically do not involve direct empirical evidence but rather generate indirect evidence that a certain mechanism may adequately produce particular behavioural data. This implies that some types of models (in chronobiology) may be constrained in a reality-oriented way for the derivation of certain implied *f*-truths and are categorized as realistic models. Some other models (in computational neuroscience) are less constrained by reality-orientation and therefore are categorized as less realistic. The divide between realistic and unrealistic models presents a fruitful opportunity to study the limits of reality-orientation and the further constraints that may operate on these different types of models. But exploring these limits will have to be the goal of another article.

The new fiction view develops a natural analogy between fictional models and fictional stories that preserves the original idea that scientists think and talk about model systems in ways that are similar to how ordinary people think and talk about the imaginary objects of fiction. This view can also deliver a better account of the face-value practice of modellers coherently with fictional anti-realism. In the rest of this section, I will focus on two key aspects of the practice: the attribution of properties to model systems, and the ability to think and talk about them.

How can modellers attribute properties to model systems if there are no model systems? An answer to this question can be offered in terms of model content. When scientists seem to attribute properties to model systems, they really make claims involving the predication of certain properties. They say things like, 'the bob is a point mass attached to a massless string' or 'the bob does not lose energy to friction'. These claims can be assessed as true in the model if they are part of its content. Indeed, eliciting the model's secrets, learning about its features, comes down to discovering new *f*-truths by drawing the inferences that correctly follow from the model's primary *f*-truths together with the principles of generation.

Model descriptions prescribe imaginings that seem to be about some particular system (the model system). However, the new fiction view assumes fictional anti-realism and holds that there are no model systems. This raises the following question: how can model descriptions prescribe imaginings about model systems if there are no such systems? This is one of the main worries raised by upholders of the direct fiction view against the anti-realist version of the indirect fiction view. But if one thinks carefully about it, it will immediately emerge that this is just a particular instance of the more general problem of the intentionality—or object-directedness—of mental states. Realists about intentionality argue that every mental state that seems to be directed at some object is really directed at an object and they offer different accounts of what this object could be (Meinong [1960]; Thomasson [1996], [1999]). Anti-realists about intentionality argue that not every mental state that seems to be directed at some object is really directed at an object (Friend [2011], [2014]; Sainsbury [2010]; Salis [2013]). Imagining a unicorn does not require that there really is a unicorn one is imagining. Analogously, imagining a point mass and imagining a massless string do not commit one to the existence of some particular point mass and massless string as the objects of those imaginings. In other words, thinking 'about something' does not automatically commit one to its existence.

Many contemporary anti-realists about intentionality appeal to the idea of a mental file to explain the phenomenology of thoughts apparently directed at objects that do not exist. Mental files are akin to the folk psychological notion of the concepts one has of particular objects. A mental file is a cognitive structure for the storage of information that one takes to be about some object independently of whether the object exists or not.[10] This information is usually identified with a list of predicates expressing properties that one takes as satisfied by a particular object. The information contained in the mental file, however, does not identify the file itself. Information stored in a mental file can be retrieved, updated, and deleted at any time without changing the identity of the file. Indeed, information stored in a mental file can be subjective and idiosyncratic to the extent that different individuals can list different information in their mental files for the same object.

Let me illustrate these ideas with an example. A team of engineers working on improving the stability of a particular bridge produces a project. The project is constituted by a set of descriptions (sentences, graphs, blueprints, notes, sketches) expressing a certain content. The city mayor, who needs to approve the project, gathers information about the bridge (such as structural features, building materials, existent damages) that is conveyed through the content. The mayor stores information that she takes to be about the bridge in a mental file and that is supposed to match the project content. However, she does not realize that, for example, the bridge has trusses built from structural steel and that it has a smaller beam connecting two cantilevers.

[10] Philosophers of mind and language originally introduced this notion under the label 'dossier' (Grice [1969]) and later introduced the term 'mental file' (Perry [1980]). Cognitive psychologists appeal to the same notion to theorize about belief representation in infancy (Perner *et al*. [2015]), and to the similar notion of object concepts to theorize about object representations in infancy (Carey [2009]).

Now let us change the example a little bit. Suppose that the team is designing a new bridge that does not yet exist. A project constituted by a set of descriptions expressing a certain content is produced and the mayor receives the project for approval. She reads the project and, as in the previous case, opens a mental file to store information that she takes to be satisfied by a particular bridge, the one that the engineers are designing. But there is no bridge that this information is really about. The bridge has not been built yet.

From a cognitive point of view, the two cases look very much alike. In the first case, the project involves a description expressing a certain content that induces a mental file about a particular bridge. In the second case, the project involves a description expressing a content that induces a mental file that seems to be about a particular object without being about any real object. In the former case, we have genuine aboutness. In the latter case, we have only the appearance of aboutness. For lack of a better word, I will call the latter 'imagined-aboutness'. The same cognitive resources (mental files) are deployed in both cases. In the first case, the mayor acquires and stores information that she takes to be about a particular object, and since there is a real object there is also genuine aboutness. In the second case, the mayor acquires and stores information that she takes to be about a particular object. But there is no such object and hence there is only imagined-aboutness.

Something similar to the latter happens with models. When one studies the simple pendulum model one gathers information from the model content (the primary *f*-truths and the implied *f*-truths) that is stored in a mental file for the simple pendulum. For example, coherently with the model content, one imagines that the bob is a point mass attached to a massless string. By doing this, one acquires information that seems to be about some particular bob (the one described in the model) without there being any such bob. Indeed, one gathers information that one imagines to be about some particular bob that the model describes. This information is stored in a mental file containing the predicates that one takes to be satisfied by the model bob. Among these are predicates that are involved in the primary *f*-truths of the model (being a point mass and being attached to a massless string), and among the implied *f*-truths of the model (having a frequency of 0.4983 Hz when the length of the string is 1.000 m and gravity is 9.800 m/s^2). But the competent model user includes also further information deriving from the predicates that characterize, or define, a point mass (being a geometric zero-dimensional point and having zero volume). Of course, one may also get the model content wrong. In this case, the information stored in a mental file for the model bob will have to be amended or deleted. Finally, it is worth noticing that the mental file is the subjective and psychological component of a scientist's individual imaginative engagement with the model. Hence, mental files contribute an explanation of the phenomenology of the modelling practice without being among the model constituents.

Let us take stock. The new fiction view develops a new analogy between models and fictions by reconceptualizing the notion of a model as akin to a literary work of fiction. On this view, the model is not the model system (as per the indirect fiction view) or the model description (as per the direct view). Rather, the model is the model description together with its content. Model description and model content are independent entities that together constitute a model. A model description is a set of symbols (mathematic, linguistic, pictorial) that expresses a particular content under an interpretation and that does not enter into the identity conditions of the model. The model content is composed of the primary *f*-truths prescribed by the model description and the implied *f*-truths of the model governed by the principles of generation. Furthermore, the new fiction view can explain the attribution of properties to model systems in terms of the predication of the same properties involved in the model content. And it can explain the apparent aboutness of scientists' discourse and thought about model systems in terms of the mental files that they deploy when imaginatively engaging with models. In this way, the new fiction view can offer a full explanation of the face-value practice of modellers without committing to the existence of any exotic entities.

5 Answering the Identification Problem and the Problem of Truth Conditions

With these new tools we can now address the identification problem concerning models as the vehicles of denotation and the problem of truth conditions concerning the theoretical hypotheses generated through models.

In Section 3, I noted that standard versions of the fiction view face different issues with respect to the identification problem. On the anti-realist version of the indirect fiction view, model systems do not exist yet they are supposed to stand in the denotation relation between models and targets. Given that denotation is a dyadic relation, this generates the odd consequence that denotation can only be pretend denotation. Upholders of the direct fiction view avoid this problem by arguing that it is not model systems, but rather model descriptions that are the vehicle of denotation standing in the relevant relation with targets. Model descriptions exist, hence there could be genuine denotation. However, as I argued in the same section, model descriptions do not denote any real systems and hence cannot directly denote any targets.

The new fiction view avoids both problems of systematic denotation failure and thus solves the identification problem by reconceptualizing the notion of model. On this view, the vehicle of denotation is the model, *M*, which is constituted by the model description, *D*, and the model content, *C*. In other words, it is *M*, and not the model system or the model description, that stands in the denotation relation with the target.[11] The model thus defined

[11] In this respect, the new fiction view differs from Currie's ([2017]) identification of models with their descriptions (which he also calls their 'vehicles'). On the new fiction view, a model is constituted by its model description and its propositional content. It is this complex object that is the vehicle of the representation relation between models and reality.

exists and therefore can stand in the denotation relation with real world systems. This novel version of anti-realism about model systems identifies models with objects that are akin to fictional stories. The model description exists: it is the set of sentences and mathematical symbols that are akin to the texts of fictional stories. They are the props that prescribe imagining certain propositions, the primary *f*-truths of the game of make-believe. These primary *f*-truths are then further integrated with the implied *f*-truths derived from the primary *f*-truths through the principles of generation. Together, they constitute the propositional content *C* of the model. On the assumption that propositions also exist, the whole model *M* exists. And *M* is the object that enters into the denotation relation with targets.

The new fiction view can also respond to the problem of truth conditions by building on Walton's analysis of fictional discourse. Standard accounts posit that learning with models involves two steps. First, scientists manipulate and develop a model to learn about its features and generate claims about it. Second, they transfer what they have learned about the model into knowledge of reality via a set of comparative claims based on a relation of similarity between the model system and the target. However, model systems cannot share any properties with physical systems. So, how can model–world comparisons be true? To better understand this further step, I will appeal to one important distinction that Walton makes between two kinds of games of make-believe, authorized and unofficial. Authorized games are constrained by the prescriptions to imagine of the game, including those prescribed by the model descriptions and those generated through the principles of generation. Unofficial games are constrained by *ad hoc* rules of generation. I will illustrate this distinction in what follows.

Scientists make claims that seem to be about model systems and when they do this, they engage in what I call 'model reports'. For example, when studying the simple pendulum model, we can say 'the point mass is attached to a massless string'. Such an utterance is a move within an authorized game of make-believe for the simple pendulum model because it conforms to the model's prescriptions to imagine. The utterance can be construed as an instance of one of two different types of discourse about fiction: intra-fictional discourse or meta-fictional discourse. Intra-fictional discourse involves a perspective that is internal to the authorized game of make-believe of the model. Utterances produced in intra-fictional discourse are pseudo-assertions, that is, speech acts that look like assertions (they have a declarative form and seem to describe certain facts), but they have fictional truth conditions (rather than genuine truth conditions) and the attitude the speaker has towards their content is imagination (rather than belief).

Meta-fictional discourse involves a perspective that is external to the game of make-believe, and therefore to the model. In this case, the claim is really about the model (*M*). Its content is based on the model content, but it is broader than that. The content includes genuine reference to the model and it is better rephrased as, 'according to *M*, the point mass is attached to a massless string'. This proposition can be assessed for genuine truth, because it is stating a fact about the model (it is reporting features of the model by identifying one of its constitutive propositions). Utterances produced in meta-fictional discourse are genuine assertions, they have genuine truth conditions (rather than fictional truth conditions), and the attitude the speaker has towards their content is belief (rather than imagination). Notice, however, that meta-fictional discourse ultimately depends on intra-fictional discourse and therefore intra-fictional discourse is more fundamental than meta-fictional discourse. We could not report features of the model without knowing what propositions are among the prescriptions to imagine and the implied *f*-truths that are constitutive of its content.

These considerations extend to model–world comparisons but for a few crucial elements. The first difference between model reports and model–world comparisons is that the former are moves within authorized games while the latter are moves within unofficial games, namely, games that are constrained by *ad hoc* rules of generation. Consider the comparative claim: 'the dynamic oscillation of a real pendulum is approximately similar to the dynamic oscillation of the simple pendulum'. The claim is literally false because it involves apparent reference to an imaginary system, the simple pendulum, that does not exist. On the internal reading, such a claim is assessed within an unofficial game that includes information about the dynamic oscillation of a real pendulum and the dynamic oscillation of the imaginary pendulum. On the external reading, the same claim is really about the unofficial game implied by comparing the dynamic oscillation of the real pendulum and the dynamic oscillation of the imaginary pendulum. On the external reading, the claim is therefore construed as embedded within operator *U* (standing for the unofficial game): 'according to *U*, the dynamic oscillation of a real pendulum is approximately similar to the dynamic oscillation of the simple pendulum'. The original claim, without operator *U*, was only true in the unofficial game of make-believe. The paraphrased claim embedded in operator *U* is genuinely true because it is a description of the unofficial game of make-believe *U*.[12]

The second important difference between model reports and model–world comparisons concerns the sort of epistemic justification involved in the two cases. The sort of epistemic justification that a scientist has when uttering a model report in intra-fictional discourse derives from the model content. A particular claim (and a particular imagining) in model reports is justified if and only if the objective *f*-truths of the model provide good evidence for that particular claim. That is, one's imaginings are justified if and only if they conform to the prescriptions established by the model description and the principles of generation in

[12] Similar considerations apply to comparative claims involving quantification over degrees of properties and mathematical entities on a measurement scale.

force in the particular context of use. The sort of epistemic justification one has when assessing the truth conditions of model reports in meta-fictional discourse involves evidence that is provided by the model itself. The truth conditions of model–world comparisons, however, are constrained by prescriptions to imagine concerning features of the model system and features of the real systems they are about. The claim ‘the dynamic oscillation of a real pendulum is approximately similar to the dynamic oscillation of the simple pendulum’ must be assessed with respect to the model’s prescriptions to imagine and with respect to reality. If real systems do not show the same sort of dynamic oscillation that is (fictionally) instantiated by the simple pendulum, then the comparative claim will be false.

But is there a way to step out of the make-believe and formulate theoretical hypotheses that do not involve any reference to the imaginary entities of models? The answer is positive, and it involves the recognition of a second type of theoretical hypotheses that is also generated within the modelling practice. This type of theoretical hypotheses is gained through make-believe but are exported outside of the make-believe in the form of a direct attribution to real world systems of the properties involved in the model content. Thus, a scientist can say things like, ‘for small angular displacements θ, the restoring force on the bob of a real pendulum is approximately simple harmonic’. This claim is a theoretical hypothesis that is exclusively about reality and that can be tested.

The generation of direct attributions can be explained with the amended version of Frigg’s notion of an interpretation key. According to the new fiction view, a key is a rule for converting claims about model systems into claims about targets. When the key is identity or approximate similarity the imagined properties of model systems and the real properties of targets can only be fictionally identical or approximately similar. That is, they can only be identical or approximately similar within a game of make-believe, and hence we can only have imagined identity or imagined similarity. A scientist can export properties $P_1...P_n$ from

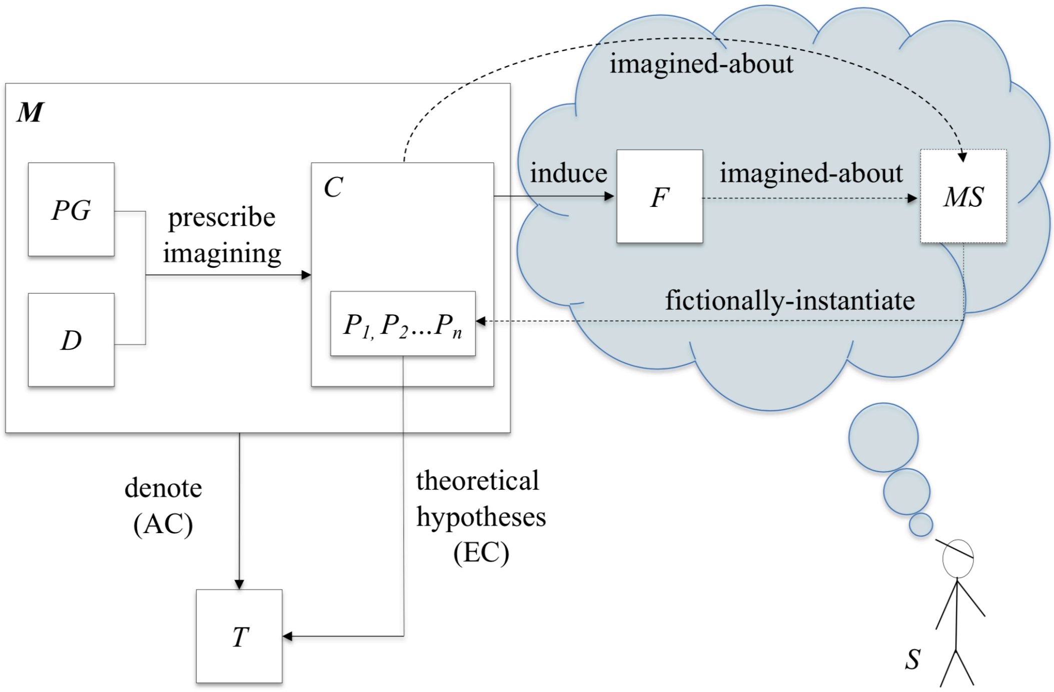

Figure 3.

model content *C* as claims about reality by stepping out of the game and attributing the same properties to a real target. To do this, she will have to predicate these very properties of the target. An interpretation key is therefore nothing other than a principle of exportation of *f*-truths as claims about reality that can be tested for genuine truth. The key enables to export an *f*-truth outside of the game of make-believe for the simple pendulum model into a claim about a real corresponding fact about real pendulums (see Figure 3).

6 Conclusion

In this article, I developed the new fiction view as a novel account of how models represent in ways that enable learning about reality. To this aim, I drew on Walton's theory of fiction as a game of make-believe, which naturally combines with fictional anti-realism, the view that there are no fictional entities and therefore that there are no model systems. I argued that neither the indirect fiction view nor the direct fiction view successfully addresses the problem of identification and the problem of truth conditions. I reconceptualized the notion of a model by building on the analogy between models and fictional stories and explored the ways this view can be developed to explain some important aspects of the face-value practice of modelling. After this, I advanced a response to the identification problem that starts from the recognition that models as complex entities composed by model descriptions and model content are the only possible vehicles of denotation. And I answered the problem of truth conditions by recognizing that model–world comparisons can be analysed as moves in unofficial games of make-believe. This motivated the recognition of a second type of theoretical hypotheses, namely, direct attributions of model properties to their targets. Direct attributions are one step away from the make-believe, yet they can only be formulated through a necessary detour in make-believe. The upshot is that the representation function of scientific models involves a denotation relation between models (construed in the above way) and the world, and the formulation, in make-believe, of two main types of theoretical hypotheses, model–world comparisons and direct attributions.

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