Fiction and Reality: An Uncanny Relationship

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Abstract

In this paper, I will deal with the use of fictional models in the context of the realism *vs* antirealism debate. Specifically, I will argue that the explanatory role of fictional models can be accommodated by scientific realism. I will refer to the work of Alisa Bokulich, who has proposed a modification of realism in order to account for explanations employing fictional models. My own approach will be to offer an alternative: instead of a modification of realism, I will propose a modified notion of representation. Based on the work of James Clerk Maxwell and Bokulich's own account of it, I will introduce the notion of a 'ladder of abstractions', meaning an hierarchical organisation of mathematical structures constituting both models and theories. In this way, fictional model explanations can be construed realistically if understood as offering partial representations of a physical situation corresponding to an appropriate level of abstraction.

Keywords: Models, Fiction, Representation, Explanation.

1. Introduction

The term 'fictional models' will signify in the following "theoretical structures describing physical systems that are not, in fact, instantiated" (Zorzato 2023).[1] Fictional models are often considered to be problematic in terms of the debate between scientific realism and anti-realism. It would appear that their role is confined to being merely tools for calculations and predictions. However, fictional models can contribute positively to scientific explanation. Alisa Bokulich, in a book and a series of papers, has offered plenty of cases demonstrating that fiction can be 'a vehicle for truth' (Bokulich 2016). My main concern in this paper is to see how the use of fictional models can be accounted for from a realist viewpoint. In general, I agree with Bokulich when she says that her "account of explanatory fictions lies within a broadly realist approach to science" (Bokulich, 2016: 261).

[1] It is important to stress that the interest here is not in the ontology of scientific models; the question whether models are fictions or abstract entities will not concern me (for such questions see, e.g., Hendry and Psillos 2007, and Fiora Salis 2019).

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However, I shall argue that the question of how to relate scientific realism to fictional models is still on the table. In particular, Bokulich does not endorse mainstream realism;[2] rather, she opts for a 'moderate' kind of realism, i.e., one that is able to accommodate fictional model explanations alongside non-fictional ones. In my view, this modification is not required: instead, I propose to keep the mainstream notion of realism and modify the notion of representation. Then, my argument will be that fictional models may 'represent' in a partial sense aspects of a physical situation. I will base my argument on an understanding of the structural makeup of theories and models as an hierarchy of mathematical structures at different levels of abstraction. To justify this 'ladder of abstractions', as I call it, I will turn to James Clerk Maxwell's notions of 'physical analogies' and 'embodied mathematics', and Bokulich's own account of them in her (2014).

This paper is divided into five sections. In Section 2, I will offer a case study illustrating the role of a fictional model in the explanation of a quantum phenomenon. In Section 3, I present the view of Bokulich and the most relevant objections to it. Section 4 deals with the possible reassessment of her view. Conclusions are drawn in Section 5.

2. An Example: The Rydberg Atom

I begin by presenting a case where the explanatory role of a fictional model is manifest. It is the case of so-called Rydberg atoms, which is dealt with in detail by Alisa Bokulich (2008a). Rydberg atoms (named after Johannes Rydberg) are very simple quantum systems, consisting in light atoms that have been highly excited, so that their outermost electrons are at the threshold of ionisation. Their size becomes enormous, approaching the dimensions of minute macroscopic particles. Due to this fact, they are amenable to the methods of 'semiclassical physics'. In general terms, this means the employment of classical notions to study highly complex quantum systems, at the interface between the so-called microcosm and macrocosm. Faced with a lack of straightforward quantum mechanical solutions for such systems, scientists resort to hybrid models, seeking classical 'analogues' of the systems at hand and then mixing fictional features of a classical nature, mainly orbits traversed by imaginary particles, with genuinely quantum concepts such as wavefunctions and probability densities. Notable cases are those of 'quantum chaos', so named because the classical 'analogues' used in their study exhibit chaotic behaviour.

Rydberg atoms moreover offer fertile ground for philosophical considerations concerning the relations between classical and quantum. Bokulich compares such an atom with a grain of sand, remarking that

> These atoms call to mind Tom Stoppard's play Hapgood, in which he writes 'there is a straight ladder from the atom to the grain of sand, and the only real mystery in physics is the missing rung. Below it, [quantum] particle physics; above it, classical physics; but in between, metaphysics' […] As an atom that is the size of a grain of sand, Rydberg atoms are ideal tools for studying the 'metaphysics' of the relation between classical and quantum mechanics (Bokulich 2008a: 115).

[2] By 'mainstream realism' I mean the philosophical stance advocated by, e.g., Psillos 1999.

The historical precursor of the phenomena I am going to describe here is the so-called Zeeman effect, which concerns the changes in atomic spectra in the presence of a magnetic field. The effect consisted in the splitting of spectral lines into multiplets separated by spacings of variable size, with increasing complexity depending on the structural intricacies of the atoms and the strength of the magnetic field. In very simple cases, solutions were available, even based on the 'old' quantum mechanics. However, when the magnetic field used becomes sufficiently strong, complicated patterns appear that still defy a complete treatment by modern quantum mechanics. Notably, the dynamics of even the simplest atom, hydrogen, becomes classically chaotic when subjected to a very strong magnetic field (Bokulich 2008a: 115).

Rydberg atoms came into the picture with a number of experiments performed relatively recently, beginning in the late 1960s. Henceforth, my exposition follows Bokulich (2008a), to which I refer for details. In a series of experiments, researchers studied the spectra of barium atoms, reaching Rydberg states when excited through illumination with light. Increasing the intensity of the light, the spectra, as expected, showed peaks at the photon energies which could be absorbed by the atoms. When the photon energy exceeded the ionisation energy of the atoms, the peaks disappeared. A striking phenomenon occurred, however, when the experiments were repeated in the presence of very strong magnetic fields: the peaks persisted even after the ionisation energy was reached and passed.

A further complication was discovered, in similar experiments with hydrogen atoms at Bielefeld in the mid-80s that revealed irregular patterns of lines. Bokulich mentions the conclusion of the researchers involved, stressing the need to probe the connections of quantum mechanics with classical chaos utilising classical concepts (Bokulich 2008a: 117). Subsequently, the Bielefeld researchers achieved a breakthrough: they performed a Fourier transformation turning the energy dependence of the spectral patterns into a time dependence, with a striking result. A definite correspondence was revealed between the irregular spectral lines ('resonances') and hypothetical *classical* orbits of electrons in a *fictional classical model* of the same Rydberg atoms under the same conditions. Bokulich (2008a: 118) quotes the verdict of the scientists:

> In this work we have discovered the resonances to form a series of strikingly simple and regular organization, not previously anticipated or predicted […] The regular type resonances can be physically rationalized and explained by *classical* periodic orbits of the electron on closed trajectories starting at and returning to the proton as origin (Main et al. 1986: 2789–90; emphasis in original).

I want to stress two points in this discussion. So far, there seems to be an *explanation* of the Rydberg spectra in the above conditions based on the employment of a *fictional model*: the classical electron trajectories used do not exist. To repeat what I wrote in the Introduction, fictional models—in the sense in which I am using the term—are "theoretical structures describing physical systems that are not, in fact, instantiated" (Zorzato 2023). The classical model employed in the Rydberg atom case was discovered through analysis of experimental results, independently of quantum mechanics as the appropriate theory. However, justification was needed. This came with theoretical developments, resulting in the so-called 'closed orbit theory'. It established a kind of correspondence between "the average quantum density of states and the periods and stabilities of the classical periodic orbits, which allows a calculation of the quantum quantities on the basis of these classical quantities" (Bokulich 2008a: 120). In essence, it blended classical orbits with propagating waves that interfere and produce the observed patterns. There is definitely no question of quantum mechanics being reduced to, or replaced by classical mechanics. At the same time, the quantum mechanical wave interference considerations do not stand by themselves: the classical orbits are indispensable.

The second point I want to make is based on a surprising fact established in the late 1990s, when a group of researchers studied Rydberg atoms, of lithium in this case, in a strong electric field (Stark effect). Their result was that, starting from the experimentally observed spectrum, they managed to reconstruct the corresponding fictitious classical orbits. This sent the scientists wondering about the ontological status of the associated classical orbits, which undoubtedly were not real. It is this fact that underlies Bokulich's suggestion, that "What seems to be called for – given these experiments and the fertility of using classical trajectories in semiclassical mechanics more generally – is something less than a full-blown realism, yet more than a mere instrumentalism that dismisses them as nothing more than a calculational device" (Bokulich 2008a: 125).

3. The Tension: Fiction and Truth

We saw above how a fictional model involving classical electron trajectories plays an indispensable role in explaining a complex quantum phenomenon. This creates tensions for mainstream realism. Bokulich presents the problem in these terms:

> Science, it is commonly thought, must deal only in the truth, the whole truth (if possible), and nothing but the truth. After all, isn't fiction ultimately antithetical to truth? Won't scientists be misled into a labyrinth of confusion and be lulled by the mere illusion of understanding if they trade in fictions? Even those who have granted a limited function for fictions in science have denied that they can play a role in scientific explanation or in generating genuine knowledge. […] The difficulty, however, is that an examination of scientific practice reveals that models routinely play a central role in scientific explanation and that all models are non-veridical to some degree (Bokulich 2016: 2-3).

The issue that Bokulich addresses is a more general problem that arises in philosophy of science in dealing with models. Traditionally, there are two ways to interpret the extensive and fundamental role of models in science: the realist view and the instrumentalist view. According to the latter, scientific models are instruments, useful tools for predictions. Obviously, here the issue about the model's fictional nature does not arise. According to the former view, there is (some) correspondence of models with the world and with the entities they postulate, i.e. models genuinely represent their target system. This notion is essential for an explanatory role. One of the most influential notions of explanation is the one developed by C. Wesley Salomon (Salomon 1984a; 1984b; 1989), according to which an explanation is genuine if it describes the causal processes in the existing target system. This notion of causal explanation requires that the target system exists in the world. In the case of fictional models, the realist's position is presented with the difficulty of how to account for the role of these models and their correlation with the real world.

Since fictional models are used in almost all fields of science, the tension with realism is spread over different contexts. Therefore, the importance of acknowledging the presence of this tension and of offering a solution is a requirement for philosophers and scientists alike. Let me now present Bokulich's argument in answering the challenge of fictional models. To reconcile the accepted fictionality of certain models with their recognised explanatory role in science, Bokulich offers an argument that accommodates the fictional nature of such models with a 'moderate' realism. Let us follow her argument step by step.

3.1. The 'Eikonic' Conception

In order to defend the explanatory feature of fictional models, Bokulich distinguishes the 'ontic' from the 'eikonic' conception of explanation. The ontic conception requires that "explanations are the concrete entities in the world" (Bokulich 2016: 1; 2018a). Even if not explicitly, the ontic conception shares its requirement with the causal notion of explanation developed by Salmon (Bokulich 2016: 5). Bokulich contrasts the ontic conception with what she calls the 'eikonic' conception. The eikonic approach is meant to allow non-causal explanations—i.e., fictional model explanations- alongside causal ones. It is based on three main points (Bokulich 2008a; 2008b; 2012; 2018a): first, the explanations must involve a scientific model. Second, the model doing the explanation has a counterfactual structure, in the sense that it is answering to 'what-if-things-had-been-different' questions. Third, not all fictional models explain: a 'justificatory step' is necessary to differentiate explanatory fictional models from non-explanatory ones. This step is understood as "specifying what the domain of applicability of the model is, and showing that the phenomenon in the real world to be explained falls within that domain".[3] It is a process which can either proceed from "an overarching theory, specifying the domain of applicability of the model", or instead "through various empirical investigations" (Bokulich 2011: 39). Therefore, the 'justificatory step' is an empirical question to be answered by scientists on a case-by-case basis. Since mainstream realism would not be in agreement with the eikonic approach, which allows for fictional model explanations, Bokulich proposes a slight modification of realism, to "moderate" it in some sense.

The main point is how to establish a structural correspondence between the model and the target system. According to Bokulich, "we require that the counterfactual structure of [the model] be isomorphic in the relevant respects to the counterfactual structure of [the phenomenon to be explained]" (Bokulich 2011: 39-43). As an example, Bokulich (2016) cites the explanation of the tides based on Newton's theory of gravity. Newtonian gravitation is considered a fiction in light of General Relativity. However, the Newtonian model—in virtue of the "similarity"[4] of the predictions of the Newtonian and the General Relativistic theories of gravity—is able to represent the tides, as well as the positions of the Sun,

[3] For more details, the reader is referred to the original papers of Bokulich (2011: 39).
[4] Alongside assertions that "General Relativity *exactly* reduces to Newtonian theory", it is stressed that "the Newtonian approach [...] is only valid (with justification from General Relativity)" under definite conditions (Mukhanov and Viatcheslav 2005: 10; 24; emphasis in original).

the Moon and the Earth along their orbits and along their possible variations (if, for instance, the Moon had a different mass, the model would explain the possible variation of the tides). The high precision of the model is, according to Bokulich, justified by the fact that it can describe the *explanandum* (the tides).

The structures of the model and the target are then isomorphic in the sense that they share in some way the same features. According to Bokulich, the real target has a structure and so does the explanation. The structure appears at different levels, both for the target and for the explanation of it. Appealing to Woodward and Hitchcock' account (2003: 198), Bokulich (2008a: 152) talks about the 'explanatory depth' of the model, i.e. "a measure of how much information the explanans provides about the system of interest" (Bokulich 2008a: 152). Bokulich, in detailed discussions of specific cases (e.g., Bokulich 2015), argues that a model can be associated with a relevant theory, in which case it stands in as a proxy for the theory when it captures generic features of the target system; it truly describes *aspects* of the target despite being fictional.

Two points should be stressed here. First, a fictional model may stand in as a proxy for a theory, but its role can be autonomous: the model does not ride piggyback on the theory. I'll return to this in the following. Secondly, the model "does aim to give genuine insight into the way the world is" (Bokulich 2011: 44); so it illuminates some genuine aspects of the target system which the relevant theory cannot. It can be that a theory may in principle explain the phenomena in a different way, even if in a more complicated way than the model itself. However, the model is necessary in cases where explanations based on the relevant theory are lacking. These points bring me to the criticisms that have been levelled at Bokulich. I shall argue that my own argument can counter both objections raised against Bokulich.

3.2. Criticisms

Samuel Schindler (2014) claims that Bokulich's aim at maintaining both the fictionality and the autonomy of the fictional models fails, unless she provides an extra argument for establishing the autonomy of fictional models. Commenting on quantum mechanical cases cited by Bokulich (2008a; 2008b; 2011; 2012), where the justification of fictional model explanations involves a 'link' with a relevant theory, Schindler writes:

> The tension is this: either model fictions are justified or they are not. If they are not, they provide no genuine explanation. […] But if the model fictions are justified, i.e., they are linked (in a very precise manner) to quantum mechanics through semi-classical theory […] how can model fictions be claimed to be explanatorily autonomous? (Schindler 2014).

The main point of Schindler's criticism is that the explanatory role is played by the theory and not by the fictional model. Thus, there is no reason to claim that the fictional model is explanatory because all the job is done by the theory and the model is merely a calculation tool.

James Nguyen (2021) too offers a criticism of Bokulich starting from one distinction: on the one hand, there are questions such as 'why does certain behaviour occur?'; on the other, questions like 'why does the counterfactual dependence invoked to answer that question actually holds?'. According to the author, fictional models can answer the former but are in trouble with the latter (Nguyen 2021: 3229). But, if so, fictional models lose their fictionality, since the actual representation is the only one that remains. In Nguyen's words:

> [E]ither these models cannot answer these sorts of explanatory questions, precisely because they are fictional; or they can, but in a way that requires reinterpreting them such that they end up accurately representing the ontological basis of the counterfactual dependency, i.e., reinterpreting them so as to rob them of their fictional status. Thus, the existence of explanatory fictions does not put pressure on the idea that accurate representation of some aspect of a target system is a necessary condition on explaining that aspect (Nguyen 2021: 3229).

I will return to both criticisms in the following.

4. Reassessing Bokulich

Fictional models have a representational role with respect to a specific aspect of the associated theory's proper target. My argument for this claim hinges on what I dub 'the ladder of abstractions'. It can be captured by the slogan: the more you go up the ladder, the deeper you go into the object. What does it mean? The expression 'ladder of abstraction' is meant to highlight the hierarchical arrangement of mathematical structures making up a theory, or a model for that matter. To illustrate my point, I now turn to relevant aspects of J.C. Maxwell's work in developing his electromagnetic theory. At a certain stage in his endeavours, Maxwell made use of a mechanical model, which was fictional in my sense of the term:

> Maxwell constructed an imaginary physical system, contrived solely for the purpose of developing a mathematical scheme applicable to a specific physical domain. He could then draw consequences from this imaginary system to the physical domain of electromagnetism that was rich in experimental results (Hon et al. 2021: 253).

Bokulich's reading of J.C. Maxwell's method of using a mechanical fictional model points to his methodology of 'physical analogy' (Bokulich 2015): It is based on the use of an analogy to develop a new domain starting from a familiar one. The crucial point is that the analogy referred to is between the relations of things, not between the things themselves (Maxwell 1881: 52). On this basis, Maxwell developed his 'idle wheels' model (Maxwell [1861/62] 1890: 486). The core of the model was the use of a fluid, which was "not even a hypothetical fluid" but "merely a collection of imaginary properties" (Maxwell, 1890/1965: 160). Eventually, Maxwell reinterpreted the connexion between his mechanical contraption and his nascent electromagnetic theory, to demonstrate that the latter possessed generic features expressible in terms of the Lagrangian formalism of classical mechanics. Therefore, it could be embedded in that formalism in its abstract form (Maxwell [1876] 1890: 308).

Bokulich (2015) interprets Maxwell's methodology in terms of an hierarchical organisation of mathematically formulated theories addressing specific physical situations: at the highest level, there is the purely mathematical form (the

Lagrangian formalism). Below, there is a level of what Maxwell calls the 'embodiment' of that abstract mathematical form (Maxwell 1890/1965: 187). It is at this level that, according to Bokulich (2015: 31), a model can stand in as a proxy for a theory, in representing the target system. Generally, structures at various levels may be shared by different theories as well as models, even if those models are fictional. The hierarchy of mathematical structures is correlated to the abovementioned notion of 'explanatory depth' (Bokulich 201: 35).

I propose that the hierarchical structure indicates at which level *explanandum* and *explanans* are connected, and, depending on the level at which this happens, the explanation provided is more or less deep. Moreover, I suggest that fictional models can explain without even being directly related to a theory (such is the case of Bohr's atomic model, discussed in Bokulich 2008a). Indeed, it is possible for a fictional model not only to stand in as a proxy as claimed by Bokulich, but also to 'mediate' horizontally (Bokulich 2003) between different domains, establishing connections at higher levels of abstraction. Here, the role of physical analogies is evident. At the higher level of structural correspondences, mathematical structures are shared, allowing exploration and development of new domains. A model, even a fictional one, can capture essential features of a phenomenon targeted by an associated theory at a level below pure mathematics, that is, at the embodied mathematics level, where the model 'stands in as a proxy' for the theory.

In the process of probing the structure of the model, the depth of the explanation is also assessed. Indeed, the capacity of the abstraction is to be broader and to include more fundamental features, hence to reach deeper into the object, teasing out properties and relations of the target system. The less abstract the explanation, the more focused on the details of the phenomena it is. The success of fictional models is then explained by the range of abstraction achieved by the explanation: an adequate representation can succeed in providing physical insight into the target system, as the structure of the model is capturing *something* of the more abstract structural aspects of that system. To sum up, the 'ladder of abstractions' alludes to an hierarchy of mathematical structures as a fundamental feature of theory articulation. It is then possible to vary the degree of abstraction of the level of explanation, meaning that along the backbone of the ladder, the path of gaining knowledge depends on the level at which the explanation focuses on. Going upwards means going deeper into the object, zooming out to get the broader picture of its properties.

The 'ladder of abstraction' argument supports scientific realism because it allows capturing directly something of the object in the world. In this way, no modification of realism is required. Indeed, there is a correspondence between the *explanandum* and the *explanans* that satisfies the requirements of realism. In those cases when a fictional model is acting as a proxy for a theory, as in quantum mechanical situations, the representational role is inherited by the model because the structures shared with the theories represent an essential part of the theories' target. The crucial point here is precisely the possibility of high-level structures to be representational. In defence of this point, I claim that what fills the 'representational gap' for them is the physical interpretation that turns abstract mathematical relations into 'embodied' mathematics, which are in turn embedded into the full representation afforded by the theory.

As a result, through scrutinising in each case the concrete experimental and mathematical constraints that define the level at which structural correspondences between a fictional model and a theory obtain, scientists can tease out knowledge of physical connections inherent in the object of investigation but invisible to the proper theories concerned.

I turn next to the challenges posed by the criticisms of Bokulich's account. Schindler's criticism concerns a fictional model's autonomy in relation to a theory relevant to a concrete phenomenon. Autonomy is established in specific cases studied by Bokulich, where: (a) a fictional model can explain in the absence of any theory (Bohr' atomic model—Bokulich 2008a); (b) a fictional model is indispensably explaining features of quantum phenomena unaccounted for by quantum mechanics ('wavefunction scarring', quantum dots); and (c), in semi-classical physics, 'horizontal' models mediate between different sectors, constructed in manifestly autonomous ways (Bokulich 2003).

Concerning Nguyen's criticism, let me stress that, as I have already noted in relation to the Maxwell case, the 'target' of a *fictional* model is itself fictional, i.e., non-existent. However, the model acts as a proxy for a theory in virtue of encoding such properties of *that theory*'s actual *target system* as those entering in structural correspondences between the model and the theory. It is in this, and this sense only, that the model can be said to represent the theory's target, albeit in a restricted, partial way, although it is a *false* model of—i.e., *misrepresents*—that target in its totality (see Zorzato 2023).

5. Conclusion

Bokulich's contribution is a remarkable step towards the analysis and comprehension of the role of fictional models in science and in philosophy. Her philosophical approach shows that the instrumentalist position concerning the status of those models fails, since it has been proven that the explanations provided by fictional models are genuine. Her claim is justified on the ground of an isomorphism between the structure of the target and the structure of the model. The solution offered by Bokulich is a 'moderate' version of realism, that can accommodate both fictionality and the explanatory role of those models. However, according to the criticisms levelled at her approach, her argument does not show how the model can capture reality without being dependent on the theory, and it does not make clear how can a model be both explanatory and fictional. In my account, the approach of Bokulich can be reassessed in the spirit of mainstream realism. The main concepts I have considered are the notions of 'embedded mathematics' and of 'physical analogy' borrowed from Maxwell's works. Those two notions helped me articulate an analysis of the relation between the target system, the model and an associated theory that follows a process of moving along what I have labelled a 'ladder of abstraction'. Moreover, my approach helps dissipate the doubts arising from criticisms about the autonomy and the representational role of fictional models.

My proposal is well illustrated by the case of Rydberg atoms. Here, classical orbits are involved in the explanation of a quantum phenomenon. Following the 'ladder of abstraction' process, I claim that the structure of the classical orbits, even fictional, plays an explanatory role partially explaining the behaviour of the electrons. This is because a relation between the classical orbits and the density of quantum states is established in the context of 'closed orbit theory', amounting to a structural correspondence at a definite level of abstraction, and equivalent to a certain depth in probing the phenomena. This argument answers the criticisms about the autonomy and the representational role of the model.

The main conclusion of my argument is that no modification of realism is needed. What I suggest is the need for a broader concept of representation, including representation of a system without representing that system in its totality. When the analysis is focused on the structure of the model at a higher level of abstraction, the ability of capturing some part of the structure of the target system is enhanced. The fictionality can be accommodated by the old, good scientific realism. The problem of the explanatory role of fictional models is a practical scientific issue and it is far from being covered yet. I hope that philosophers, on the basis of future scientific developments, will provide increasingly richer knowledge about the conditions for their use.[5]

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