In this paper, I provide an easy road to nominalism which does not rely on a Field-type nominalization strategy for mathematics (Field 1980). According to this proposal, applications of mathematics to science, and alleged mathematical explanations of physical phenomena, only emerge when suitable physical interpretations of the mathematical formalism are advanced. And since these interpretations are rarely distinguished from the mathematical formalism, the impression arises that mathematical explanations derive from the mathematical formalism alone. I correct this misimpression by pointing out, in the cases recently discussed by Mark Colyvan (2010), exactly where the interpretations of the formalism were invoked and the function they played in the resulting explanations. A viable form of easy-road nominalism, which is also sensitive to scientific practice, then arises.

1. Introduction

Mark Colyvan (2010) has recently challenged the possibility of developing easy roads to nominalism. These are nominalist approaches to mathematics that do not require the implementation of a Field-type nominalization strategy (Field 1980 and 1989), and thus they do not demand the hard work of identifying suitable nominalist replacements for scientific theories. Central to Colyvan’s argument is the claim that there are genuine mathematical explanations of physical phenomena, and that easy-road nominalists are unable to make room for them.

In this paper, I challenge this assessment. Properly understood, an easy-road approach to mathematics can be articulated. It makes perfectly good sense of mathematical practice and, as opposed to what Colyvan claims, it questions the possibility of genuine mathematical explanations. As will become clear, so-called mathematical explanations of physical phenomena emerge from suitable physical interpretations of the mathematical formalism. The actual work in such cases is ultimately done by identifying and defending the relevant physical interpretations. And because such interpretations are often not carefully distinguished from the mathematical formalism, the impression emerges that mathematical explanations result from the mathematical
formalism alone. I correct this misimpression by identifying, in the examples discussed by Colyvan, precisely where the interpretations of the formalism entered and the role they played in the resulting explanation. The result is a form of easy road nominalism that does not require a Field-type nominalization strategy. I submit that this is an easy road to nominalism that is not only viable, but also meshes well with scientific practice.

2. The case for mathematical explanations

Colyvan challenges easy-road nominalists by arguing that there are cases in scientific practice in which mathematics features in explanations. These cases put significant pressure on nominalists, who, as a result, face two options: (i) they need to ‘provide suitable and well-understood translations of the mathematical explanations’, or (ii) nominalists need to ‘show why the alleged explanations in question are not really explanations at all’ (Colyvan 2010, p. 302). If none of these alternatives are defensible, Colyvan insists, there are good reasons to take the explanations literally, including the ontological commitments to mathematical objects and relations they incur.

The existence of genuine mathematical explanations — that is, explanations in which mathematics alone plays a key explanatory role — is thus central to Colyvan’s case. Colyvan, however, formulates the requirement for mathematical explanations in a less demanding way. What is involved are ‘examples where mathematics seems to carry a significant portion of the explanatory burden’ (Colyvan 2010, p. 302). But, clearly, a stronger requirement is needed. Mathematics needs to bear more than just a ‘significant portion’ of the explanatory burden. The use of mathematics, perhaps in conjunction with some other factors, needs to be ultimately responsible for the explanation in question. After all, if something else other than the mathematics is providing the explanation, it is unclear why any ontological weight should be given to the relevant mathematics. A number of requirements need to be in place as a result:

(i) **Indispensability**: Mathematics needs to be indispensable to the explanation in question. That is, it is in virtue of the mathematics that the explanation is achieved, so that mathematics is far more than just a useful component of the explanation.
Colyvan, no doubt, embraces this requirement (see Colyvan 2001). However, is mathematics really indispensable to the relevant explanations? And even if it is, are we entitled to draw ontological conclusions from such explanatory role? (I will provide negative answers to both questions below.)

(ii) **Explanation versus description**: In order for mathematics to play the role Colyvan assigns to it, it is crucial that mathematics not only describes the phenomena in question, but that it also genuinely explains them.

The distinction between description and explanation is recognized by virtually all of the philosophical theories of explanation. The worry is that mathematical explanations of physical phenomena may turn out to be just descriptions of the phenomena in question. (This is, ultimately, the view that I will defend.)

(iii) **Understanding**: Given that genuine explanations provide understanding of the relevant phenomena, mathematics should offer such understanding.

But precisely what sort of understanding is offered in the case of mathematical explanations? And is it mathematics that is providing such understanding, or something else—such as a suitable physical interpretation of the mathematical formalism? (As will become clear below, I do not think that mathematics is offering such understanding—certainly not mathematics alone. And once we add other theoretical and empirical factors to the mathematics, the issue emerges as to whether the mathematics is indeed responsible for the understanding in question.)

(iv) **Epistemic significance**: If mathematics is indeed providing genuine explanations, it may receive epistemic significance for being invoked in an explanatory context. At least realists would defend such a claim.

However, it is unclear whether any such significance should be assigned in these cases. The explanatory gain may be a pragmatic feature rather than an epistemic one. (I think this is, indeed, the correct view of the matter.)

Presumably Colyvan would insist that mathematical explanations do satisfy all of the conditions above. If this were indeed the case, he could then corner the nominalist into the (supposedly troublesome)
predicament of assigning an explanatory role to mathematics but denying any ontological weight to mathematical objects. But do mathematical explanations in fact satisfy these conditions? And even if they do, how worried should the nominalist really be? Colyvan provides various examples. They are all challenging and well constructed. But I will argue that they ultimately fail to meet the relevant requirements. In the end, the nominalist should remain unmoved by them.

One of the cases offered by Colyvan (2010, pp. 302–3) is the explanation of the Kirkwood gaps. At issue is the need to account for why there are relatively so few asteroids in certain orbital bands in the main asteroid belt between Mars and Jupiter. The absence of asteroids in these bands constitutes the Kirkwood gaps. Colyvan notes that ‘the explanation for the existence and location of these gaps is mathematical and involves the eigenvalues of the local region of the solar system (including Jupiter)’ (2010, p. 302). More carefully, Colyvan continues, ‘the explanation involves the eigenvalues of the relevant operator associated with the system in question (under a suitable mathematical description)’ (2010, p. 302, n. 22). The central idea is that

the system has certain resonances and as a consequence some orbits are unstable. Any object initially heading into such an orbit, as a result of regular close encounters with other bodies (most notably Jupiter), will be dragged off to an orbit on either side of its initial orbit. An eigenanalysis delivers a mathematical explanation of both the existence and location of these unstable orbits (Murray and Dermott 1999). (Colyvan 2010, p. 302)

It may be argued that a better form of explanation in this case would be causal and non-mathematical. The explanation would provide an account of why particular asteroids do not occupy the Kirkwood gaps. The trouble with this form of explanation is that

each asteroid … will have its own complicated, contingent story about the gravitational forces and collisions that that particular asteroid in question has experienced. Such causal explanations are thus piecemeal and do not tell the whole story. Such explanations do not explain why no asteroid can maintain a stable orbit in the Kirkwood gaps. The explanation of this important astronomical fact is provided by the mathematics of eigenvalues (that is, basic functional analysis). We thus have scientific statements involving mathematical entities (the eigenvalues of the system) explaining physical phenomena (the relative absence of asteroids in the Kirkwood gaps). (Colyvan 2010, pp. 302–3)

Colyvan concludes that, faced with the indispensability of mathematical explanations, the nominalist has to provide an alternative, but still
nominalistically acceptable, type of explanation. After all, if the nominalist’s theory of the world

denied many of the usual scientific explanations without offering acceptable alternatives, mystery would be increased. Surely the nominalist is not willing to buy ontological parsimony at the price of increased mystery. (Colyvan 2002, p. 303)

To prevent this unwelcomed outcome, the nominalist needs, first, to block Colyvan’s challenge. But in order to account for the role mathematics plays in scientific explanations, it is not enough simply to resist the challenge. The nominalist also needs to offer a nominalization strategy that accommodates mathematical explanations without incurring unacceptable ontological costs or relying on a Field-type nominalism. How can this be accomplished? To answer this question is the goal of the next section.

3. Mathematical explanations contextualized and dissolved

In order to resist the challenge made by Colyvan, the nominalist needs to make two moves. The first is to deny that the alleged mathematical explanations satisfy the four conditions, (i)–(iv), outlined above. Thus, such alleged explanations are not genuine explanations. The second move is to argue that even if these conditions were met, we would not be justified in assigning any ontological significance to such mathematical explanations.

Let us return to the account of the Kirkwood gaps. As we saw, Colyvan points out that the explanation of these gaps is provided by the mathematics of eigenvalues: the eigenvalues of the relevant system explain the physical phenomena, namely, the relative absence of asteroids in the Kirkwood gaps. But is this really the case?

It seems surprising — in fact it is surprising — that the explanation of a physical phenomenon could be offered by a piece of mathematics.1 As an illustration, consider the case of a stone thrown into the air and the mathematical equation that describes the stone’s motion. At a certain point, the equation has value zero. Does the fact that the equation has such a value explain why the stone is at rest, or does it merely provide a mathematical description of the relevant phenomenon? Very likely, no one would take the fact that an equation has

1 As opposed to Colyvan’s suggestion, it is the platonist about mathematics, not the nominalist, who seems to increase mystery: how exactly can a piece of mathematics offer an explanation of a physical phenomenon?
value zero to be by itself an explanation of a physical phenomenon. An adequate physical interpretation, which identifies the relevant physical processes responsible for the production of the relevant phenomenon, is required to provide an acceptable explanation (for further discussion, see Bueno and French 2012).

When Daniel Kirkwood first studied the bands of asteroid orbits that would eventually be named after him, he clearly identified the non-random nature of the asteroids’ distribution and indicated that the distribution was likely the result of the perturbation produced by Jupiter. He noted:

As in the case of the perturbation of Saturn’s ring by the interior satellites, the tendency of Jupiter’s influence would be to form gaps or chasms in the primitive rings. (Kirkwood 1867)

We have here something more reasonable as an attempt to explain the gaps than the mere invocation of certain mathematical relations: the identification of a relevant physical event that is likely to be responsible for the production of the phenomenon in question. Rather than the mathematics doing the explanatory work, such work is achieved by determining a suitable physical event: the gravitational force exerted by Jupiter.

It turns out that the proper explanation of the Kirkwood gaps is more complex than Kirkwood himself could have anticipated, as it involves the perturbation not only of Jupiter, but also the Sun, other asteroids, and ultimately the chaotic behaviour of their motions. The resulting explanation is the so-called gravitational hypothesis:

According to this hypothesis the gaps can be understood in the context of the Sun-Jupiter-asteroid three-body problem. Research over the past two decades has shown that this is the most likely origin of the gaps and that chaotic motion is involved. However, the exact mechanism is not yet entirely understood. (Murray and Dermott 1999, p. 459)

In other words, the gravitational hypothesis emphasizes that the explanatory work is done by the gravitational force acting among the relevant objects (the Sun, Jupiter and the asteroids) as well as by the chaotic nature of the interaction. The mathematics, suitably interpreted, does not explain the gaps; rather it provides a mathematical description of the relevant interactions. This is as it should be.

Note also that Murray and Dermott are very honest in describing the status of the proposed explanation: the ‘exact mechanism’ underlying the production of the phenomena ‘is not yet entirely understood’. Even the mathematical description of the gaps fails to offer a
full account of the facts in question. Moreover, the ‘exact mechanism’
that Murray and Dermott talk about is not a suitable mathematical
state of affairs, but rather a physical state. In light of this situation,
should we assign any ontological weight to the mathematics used in
this case? The answer is clear: No.

What role does mathematics play in the explanation of the
Kirkwood gaps? The mathematics does play a descriptive role, helping
in the formulation of certain structures that, suitably interpreted, can
be used to describe various relations among the asteroids and planets
under study. But what ontological weight should be assigned to this
use of mathematics? As noted, the mathematics alone does not pro-
vide an explanation of the regularities involved in the Kirkwood gaps.
The explanation is offered by the identification of the gravitational
interaction between the asteroids, planets, and the Sun, subject to
chaos. The motion and, in particular, the orbits of the objects in
question are extremely sensitive to changes in the initial conditions:
small changes in the latter lead to significant changes in the pattern of
distribution of the asteroids. Gravitational forces are clearly the rele-
vant kind of physical interaction to explain the behaviour of the mo-
tions of these asteroids.

As opposed to Colyvan’s claim, the eigenvalues of the system are
not what explain that behaviour. Rather such values emerge from the
particular physical interactions among the objects that characterize the
system, as long as the mathematics used to describe the system is
interpreted in a suitable way. After all, without a suitable interpr-
etation, the mathematics does not state anything about the physical
world. Uninterpreted, the equations describe relations among various
functions and, in certain cases, numbers. They do not specify relations
among physical objects. For mathematical expressions, taken by them-
selves, are not about physical events in the world: they need, first, to be
(properly) interpreted before they can become relevant to the descrip-
tion of the physical phenomena. A differential equation has multiple
interpretations, and depending on the interpretation one adopts, the
equation may provide no implications at all to the physical world, or
implications that turn out to be empirically inadequate, or implica-
tions that, suitably reconstructed, may capture some aspect of the
physical world.

This situation is clearly illustrated by Dirac’s equation (another
example also discussed by Colyvan (2001); see Bueno 2005 for a re-
response). In 1926, when Dirac first formulated the equation that now
bears his name, he realized that it had negative energy solutions.
He proposed that these solutions be disregarded, as is routinely done with similar cases in classical mechanics. Two years later, however, Dirac devised a physical interpretation of his equation that allowed him to make sense of the negative energy solutions. On this interpretation, these negative solutions would stand for ‘holes’ in space-time. Heisenberg, Weyl, and others, however, immediately pointed out that it followed from this interpretation that protons and electrons had the same mass, but this was, clearly, empirically inadequate. In 1930, Dirac formulated yet another interpretation of the equation. According to this interpretation, no ‘holes’ are involved, but the negative energy solutions indicate the existence of a particle that has the same mass as the electron but the opposite charge. Two years later, Anderson was able to produce experimental data that, on a suitable interpretation, constitute evidence for the existence of Dirac’s particles. The positron, as such particles were eventually called, had been discovered. When Anderson was asked about whether he knew about Dirac’s equation, he responded that he had heard of Dirac’s work, but he was so busy dealing with his instruments that, as far as he was concerned, the discovery of the positron was an ‘accident’ (for further discussion, see Bueno 2005, and Schweber 1994).

This case clearly illustrates the fundamental role played by physical interpretations in the application of mathematics. The same mathematical equation (namely, Dirac’s equation) is compatible with three dramatically different empirical situations: one in which the equation fails to describe anything about the world (Dirac’s first interpretation of his equation); one in which the equation yields an empirically inadequate result (Dirac’s second interpretation), and one in which the equation receives empirical support (the third interpretation). Thus, the same equation is compatible with drastically distinct physical set ups. We can then conclude that taken by itself the equation does not state anything substantive about the world.

Where do such statements come from then? Clearly, that role is played by suitable physical interpretations of the relevant equation. It is only based on such interpretations that the equations will imply anything at all about the world (with the exception perhaps of the cardinality of the domain of interpretation, given that certain mathematical statements can only be satisfied in domains of certain cardinalities).

The picture that emerges here is one in which the key work of the applied mathematician (whether a physicist, a chemist, or a biologist) consists in (a) selecting appropriate mathematical structures, that
prima facie have suitable relations that may be relevant to the description of a certain empirical set up, and (b) devising suitable interpretations of the mathematical structures so that these structures can be used, in conjunction with the selected interpretation, to describe relevant features of the world. As a result, it is not the mathematics, certainly not the mathematics alone, which is responsible for the explanation of the phenomena in question.

The explanation of the Kirkwood gaps is not different. The mathematics involved helps to identify suitable structures that can be used, under proper interpretation, to describe the behaviour of the relevant planetary and asteroidal motions. The explanation is ultimately achieved by the identification of suitable causal structures: the gravitational forces among the planets and asteroids. Even the role of chaos is not an emergent feature of the mathematical formalism, but rather it results from the particular physical interactions among the celestial bodies under consideration.

Does the use of mathematics in the explanation of the Kirkwood gaps exemplify the four requirements on mathematical explanation discussed above? The requirements need to be examined in turn.

(i) **Indispensability**: Despite the insistence of platonists on this point, it is no easy task to establish that a certain piece of mathematics is indispensable for the explanation of a given physical phenomenon. The mathematics may be useful, it may simplify the description of the events under consideration, it may help to express various relations among the relevant objects; but none of that in fact establishes that the mathematics is indispensable. To establish the indispensability one needs to show that no explanation could be obtained without the use of the particular sort of mathematics that was in fact invoked (or some related piece of mathematics). To establish such indispensability may be harder than to show that the mathematics can be dispensed with, since for the latter all that is required is to provide an explanation without recourse to the relevant mathematics (or some related conceptual framework). While showing the general dispensability of mathematics is no easy task (and may not even be possible), to establish the dispensability of mathematics in particular cases is often not too difficult.
Having said that, I do not think the nominalist need to worry too much about the indispensability requirement. Even if mathematics turns out to be indispensable to the construction of certain explanations, that does not justify the ontological commitment that the platonist thinks that follows from such explanations. There are several reasons for this conclusion:

Firstly, the quantifiers used in the relevant explanations need not be ontologically committing (McGinn 2000, Azzouni 2004). The existential quantifier, traditionally interpreted, carries two very distinctive roles: on the one hand, that quantifier indicates that some part of the domain of quantification, rather than the whole domain, is quantified over; on the other hand, the existential quantifier indicates the existence of some objects in the domain. These two roles, however, are importantly different, as can be seen by the fact that sentences such as ‘There are fictional detectives who do not exist’ are not contradictory. Once this point is recognized, the possibility emerges of quantifying over mathematical objects — including those that are indispensable in explanatory contexts — without thereby being ontologically committed to their existence. In order to indicate the existence of certain objects, the best resource is to add an existence predicate in the language, ‘E’, whose conditions could be provided in such a way that one does not beg the question against the platonist. This can be achieved, for instance, by specifying only sufficient, but not necessary, conditions for this predicate, such as having a spatiotemporal location, being causally active, etc.² In this way, the sentence about fictitious detectives just mentioned above could be formulated consistently as: \( \exists x (Fx \& \neg Ex) \), where ‘F’ stands for the predicate is a fictitious detective and ‘E’ stands for the existence predicate. Since quantification and existence come apart, the nominalist is free to quantify over mathematical objects and to refer to them in explanatory contexts while denying that such quantification is ontologically committing.

Secondly, physical interpretations of the mathematical formalism are typically available, and they are ultimately responsible for the explanatory work. What does that mean? It means that it is the identification of suitable physical processes involving the relevant objects that explains why they behave in the way they do. The mathematics — despite being indispensable to the description of the relevant objects — provides no such support. The cases examined above of

² This is just an example. The particular details need not be settled here. For further discussion, see Azzouni 2004, Bueno 2005, and Bueno 2009.
Kirkwood gaps and Dirac’s equation clearly illustrate this situation. The relevant differential equations may turn out to be indispensable to the description of the phenomena under study. But the explanation of such phenomena emerges from the identification of the processes that produce the relevant phenomena. The mathematics is simply unable to do that. The examples suggest a strategy for nominalizing particular applied mathematical theories by identifying suitable physical interpretations of these theories and indicating that the actual explanatory work is ultimately done by such interpretations rather than by the mathematical formalism. The formalism is descriptively useful, even indispensable, but it is the identification of the relevant physical processes that explains why the phenomena under consideration obtain.\footnote{Incidentally, by clearly distinguishing the indispensability of the mathematical formalism (to the description of certain phenomena) from the explanatory power such formalism may provide, it is possible to resist a move made by Azzouni (2011) in his charge that the concept of nominalist content is ultimately incoherent. Such content is supposed to capture only the non-mathematical features of a mathematically described empirical situation. Azzouni considers a set up in which two particles are moving so that the distances between them change in a cyclical way. Clearly, one needs mathematics to describe the motions of the particles. But the explanation of the particles’ behaviour emerges from the particular forces that are being acted on them, not from the mathematics. The relation among these forces is what the nominalist content is about. And that content is independent of the mathematical framework that may be needed to describe such a relation. In the end, the concept of nominalist content involves no incoherence.}

Finally, explanations can be taken as pragmatic rather than epistemic features (van Fraassen 1980). We value explanations because they provide useful understanding, even if they turn out to rely on false theories (as Newtonian mechanics clearly illustrates). On this view, explanations need not be factive. Newtonian mechanics offers us an understanding of how the world could be even if the theory itself does not correctly describe such a world. Similarly, the mathematics used in physical explanations need not be true (the mathematical objects referred to in the relevant explanations may not exist). Although it is useful to invoke such mathematical formalisms, they need no be taken to be true.

It is important to highlight that one need not adopt all of the three moves just outlined — call them (a), (b), and (c) — in order to implement a nominalist view. One could favour an ontologically non-committal interpretation of the quantifiers (thus following (a)), while denying, at least in certain cases, the possibility of providing physical interpretations of certain explanatorily relevant pieces of mathematics (thus rejecting (b)), and still insist that the resulting
explanations are factive (as opposed to (c)). This is, in fact, the view favoured by Jody Azzouni. He explicitly defends (a) in Azzouni 2004. Despite its focus not being on explanation, Azzouni 2011 provides the example of those two particles that move in such a way that the distances between them change cyclically, and this example indicates that Azzouni would deny (b). Finally, (c) is explicitly rejected in Azzouni 2000, given his insistence that explanation is factive.

It is also possible to defend (a) and (c) without however advancing the claim that a physical interpretation of the mathematical formalism is available. But in this case an account is lacking of the way in which applied mathematics is in fact implemented.

To address this concern, one could then adopt all three moves. The result is a distinctively nominalist view, since an account is offered of the way in which mathematics is interpreted, and thus applied, without ontological commitment, while still allowing for some explanatory role, even though such role is pragmatic rather than epistemic. This is the view I ultimately favour.

(ii) Explanation versus description: It is unclear that in the case of the Kirkwood gaps the mathematics provides an explanation of the physical phenomenon rather than a description of them. Given that the phenomenon in question is of a physical nature, it is reasonable to expect that the relevant considerations that explain its emergence be of a physical nature as well. Clearly the mathematics lacks the appropriate ontological import to bear such a burden. Under a suitable interpretation, the mathematics may be able to provide a description of the phenomenon, but it alone cannot identify the relevant physical processes responsible for its production. The identification of these processes is the key feature of the explanation. The mathematics alone cannot deliver that.

(iii) Understanding: An important feature of explanations, particularly scientific ones, is the fact that they provide understanding. An explanation allows us to understand why the phenomenon in question emerges as it does. In the case of the Kirkwood gaps, the resonances among the planets and asteroids and the instability of certain orbits explain why the gaps emerge. But this is not a mathematical fact: it is a fact about planets, asteroids, and the gravitational forces
among them. Similarly, the instability of the orbits is not a mathematical feature; it is a physical feature of the objects involved that emerges from the relevant gravitational forces. Rather than providing understanding, the mathematics—properly interpreted—allows the expression of certain relations among the objects in question. The understanding emerges from elsewhere.

(iv) Epistemic significance: According to certain conceptions of explanation, explanations should receive epistemic significance, as long as they identify the relevant components that are responsible for the production of the phenomena. On such a realist construal, explanations are a mark of the real: only existing features of the world can produce the phenomena in question. What else could have such power? As a result, those features that are involved in genuine explanations should be assigned a special epistemic significance: they are no idle traits, but key components of the furniture of the world.

Of course, not every account of scientific explanation is realist in this way. One could insist that explanatory power is just a pragmatic feature that good scientific theories exhibit (van Fraassen 1980). Thus, one is not forced to grant such realist commitment to every aspect of a successful explanation.

But even if we grant the epistemic significance to explanatory power, why should such significance be extended to the mathematics used in the formulation of the relevant explanations? Why should mathematics be taken as doing the explanatory work? As discussed above, in the case of the Kirkwood gaps, it is not the mathematics, but suitable physical descriptions of the relevant phenomena that can be said to explain the existing gaps. So, what should receive epistemic significance is not the mathematics, but the proper specification of the relevant physical processes. The construction of the proper interpretation yields the crucial work. This should be the locus of epistemic significance.4

4 Note that even if the four conditions for mathematical explanations discussed above were all met by particular explanations, the nominalist need not be concerned. Explanations in general, and mathematical explanations in particular, need not be taken as a guide to truth. As noted, there are perfectly good explanations (including scientific ones) that are not true, nor are they based on true scientific theories. Newtonian physics offers a perfectly good explanation of the motion of planets and objects near the surface of the earth, even though
4. Conclusion: the road ahead

The considerations above suggest a clear form of nominalism. It acknowledges the indispensability of mathematics: the need to use mathematics in theory construction and in the explanation of physical phenomena. But from such indispensable role of mathematics, it does not follow that we ought to be ontologically committed to mathematical objects, structures, and relations. After all, as noted above, (a) quantifiers need not be taken as ontologically committing, (b) the same piece of mathematics is compatible with distinct physical situations (corresponding to different interpretations of the mathematical formalism), and (c) mathematical explanations need not be factive.

The crucial feature of the form of nominalism advanced here is that mathematics cannot be said to carry on the explanatory work. After all, as also noted, the mathematics is compatible with significantly different physical situations, and since what one is trying to make sense of in science are precisely these situations, the actual work is not being done by the mathematics. As far as the mathematics is concerned, it is the interpretation of it that ultimately matters. The mathematics is just a useful guide that suggests possible structures that can be explored to make sense of the physical world.

Does this mean that mathematics should have no ontological weight? Those who are inclined to accept the indispensability argument will insist that since we are using various (indispensable) mathematical theories and structures in the explanation of physical phenomena, we ought to be ontologically committed to the relevant mathematical objects and relations. To deny that would be to get involved in some double talk.

But is this really the case? I do not think so. Mathematics alone fails to specify what is going on at the physical level. Since the same piece of mathematics is compatible with dramatically different physical scenarios, the mathematics does not determine, it does not even constrain, the physical world. This is not surprising given that mathematics, that is, pure mathematics, does not state anything about the physical world. It is concerned with mathematical objects, relations, and structures. But these entities, as usually understood, are abstract: they are neither located in space-time nor are they causally active. However, the world, at least the part of it that science aims to describe and explain, is embedded in space-time. In order to hook the

the theory is, strictly speaking, false: the world simply does not include gravity as the theory characterizes it.
mathematical vocabulary to empirical events, a careful interpretation of mathematics is required. But at this point we realize that the physical world may exemplify a variety of situations that are still mathematically possible. Thus, we have here a form of underdetermination of the physical world by the mathematics.\(^5\)

The result is an easy-road to nominalism that, without invoking a Field-style nominalization strategy, provides a viable account of the use of mathematics in science without the commitment to mathematical objects. In the end, the road is still open for nominalism.\(^6\)

References


\(^5\) As noted above, the only possible constraint has to do with cardinality considerations: the size of the domains of the structures that satisfy the relevant mathematics.

\(^6\) My thanks go to Jody Azzouni, Mark Colyvan, Peter Godfrey-Smith, and Rohit Parikh for helpful discussions of the issues examined here. Thanks are also due to Thomas Baldwin, editor of *Mind*, for helpful comments on an earlier version of this paper.


