# What does mathematics tell us about the physical world?

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## Abstracts

Arianna Borrelli: **The materiality of physical-mathematical concepts: Angular momentum and its conservation laws**

Scientific concepts are accessible to historical and philosophical analysis only insofar as they are expressed and communicated in specific ways in situated contexts, and as such possess a material and performative component which can only be neglected at the risk of analyzing not scientific practices as they are, but only their idealized, a posteriori reconstructions. To address the issue of what mathematics tells us about the physical world it is therefore of paramount importance to keep into account the variety - and often the mutual incoherence - of physical-mathematical representation strategies, which include symbols, words, images, formulas, measurement units, instruments, standard procedures and more. In particular, from this perspective no clear-cut distinction obtains between a physical notion and the mathematical structures expressing it, suggesting that a nominalistic approach to mathematics, such as the one proposed by Hartry Field, might also have implications as far as physical concepts are concerned.

In contemporary scientific practices, mathematical forms have taken up a central position, since a growing number of physical notions can only be expressed with recourse to mathematical symbols and structures. Indeed, many scientists and philosophers have come to regard mathematical formulas as epistemically privileged tools for conceptualizing phenomena, and perhaps even as a perfectly transparent medium to grasp the hidden reality of nature, as structural realists or string theorists implicitly or explicitly suggest. Yet mathematical notations and structures are far from being historically immutable constructs and, when taken on their own, they are often in no position to seamlessly connect different observations and measurements into a coherent whole. An example is the case of angular momentum. Today angular momentum is on the one hand conceived by physicists as a physical quantity which is conserved in classical, quantum and relativistic systems. Yet, on the other hand, in each of those physical domains angular momentum is expressed by completely different mathematical forms. In my presentation, I will endeavor to offer an example of this complexity by discussing how bodily experiences, experimental set-ups, verbal statements and different kinds of mathematical notations combined in the late 19th century to give rise to the classical concept of angular momentum. I will then briefly sketch how that unity was soon shattered by the extension of the concept of angular momentum to the quantum-mechanical context.

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Radin Dardashti: **Mathematics and the Limits of Physical Possibility**

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Neil Dewar: **Representation and Invariance**

Much work on the representation of the physical by the mathematical appeals, explicitly or implicitly, to the "mirroring" account of representation: to put forward a given mathematical structure as representing the world is to argue that the world has the same structure as this piece of mathematics. In this talk, I want to first raise some problems for this account of representation, drawing on ideas from recent debates over theoretical equivalence; and second, to think a little about what an alternative account might look like. In order to give this alternative account, I'll make use of some of Ernst Cassirer's arguments for a "functional" rather than a "copy" theory of knowledge.

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Ladislav Kvasz: **Galileo, Descartes, Newton—Founders of the Language of Physic**

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Casey McCoy: **Ambient Randomness in the Foundations of Probability Theory**

Axiomatic probability theory, for example in the classic presentation of Kolmogorov, is a branch of measure theory, focused on measure spaces with a finite (or unit) total measure. Characterizing probability theory in this way, however, would be, as Terence Tao quips, like "calling number theory the study of strings of digits which terminate." This is because the conceptual content of probability theory outstrips its "deterministic" formal presentation. In this talk I will discuss the modern mathematical point of view on probability theory, the "probabilistic way of thinking" as Tao calls it, which prioritizes the implicit role of randomness (whether ontic or otherwise) in the theory and essentially effaces the role of the sample space.

I will conclude by suggesting extensions of this way of thinking to non-commutative probability theory and ramifications for statistical physics applications.

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Vit Punčochář: **Are mathematical objects just useful fictions?**

A theory postulating mathematical entities can be useful in a weak sense or in a strong sense. We say that it is weakly useful if it simplifies our reasoning about physical world; and it is strongly useful if it is in fact indispensable for expressing our best theories of the physical world. According to Hartry Field, only the strong usefulness of a mathematical theory would commit us to regarding its claims as literary true and, consequently, to believing in the existence of the mathematical entities that the theory postulates. The weak usefulness does not require truth of the mathematical theory but rather something quite different: its conservativeness. Moreover, Field's project of nominalization of physical theories casted doubt on the general conviction that abstract mathematical entities are really indispensable and thus support ed the claim that mathematical theories are useful only in the weak sense. This led Field to the conception of mathematical entities as useful fictions. In my talk, I will discuss Field's reasons for such a conclusion and consider some arguments against Field's fictionalism. I will attempt to support the view that it might be reasonable to take a more realist stand on mathematical entities even if they are useful only in the weak sense.

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Davide Romano: **Does decoherence theory support the Many Worlds Interpretation of quantum mechanics?**

It is usually claimed that the theory of decoherence supports the intuitive picture of the Many Worlds Interpretation (MWI) of quantum mechanics, i.e. a universe continuously branching in different physical worlds. However, on careful analysis, this claim turns to be not physically and philosophically well-justified, unless we adopt a specific stance on the ontology of operators. My argument will be based on the analysis of the two major frameworks of decoherence theory: environmental decoherence and decoherent histories. Concerning the former approach, it does not actually indicate a branching process: while it describes loss of coherence between different relative states of the (sub)system *via* the reduced density matrix, this phenomenon is non-trivially connected with a physical separation of the wave function in different branches. Concerning the latter approach, it does indicate a real branching process – the emergence of separate histories from the initial decomposition of Hilbert space. However, such histories are basically mathematical objects defined as sequences of POVM operators and, therefore, the connection between emergent decoherent histories and a branching process in physical space in non-trivial. Nevertheless, I will argue that, in this case, the problem can be (at least, partially) solved by taking a specific stance on the ontology of operators in quantum mechanics. To sum up: while decoherence theory is certainly not incompatible with MWI, this relation is not plain and intuitive as usually suggested, and comes at a cost.

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Antonio Vassallo: **On the nomic status of Einstein field equations.**

The dynamics of general relativity is encoded in a set of sixteen differential equations, the so-called *Einstein field equations*. It is usually believed that Einstein's equations represent a physical law describing the (contingent) coupling of spacetime and material fields. However, just six of these equations actually describe the coupling mechanism: the remaining ten represent some mathematical redundancies plus a set of four differential relations known as *Bianchi identities*. In virtue of this fact, it becomes unclear to what extent Einstein's equations can be taken to represent a full-fledged law of nature. In my talk, I will present this issue in detail and discuss whether it might have a bearing on the broader debate about the metaphysics of laws of nature.

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Jo E. Wolff: **Quantitative and qualitative structures**

The representational theory of measurement describes measurement as a mapping of qualitative relational structures to numerical relational structures. This conception of measurement suggests that the difference between qualitative and quantitative structures is the presence of numbers. I argue in this paper that this way of delineating quantitative and qualitative structures is unsatisfying and show that representationalism has the resources to draw a better distinction between quantities and qualities.