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Beyond Mathematics

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Abstract

From antiquity to modern physics, mathematics has been regarded as the “language of Nature.” Yet is its success a discovery of the universe’s fundamental structure, or a product of human consciousness? This article examines forms of cognition and information processing that do not rely on abstract mathematical representation or decomposition into smaller parts. Its contribution lies in proposing a "Three Participants Test" designed to distinguish between a non-symbolic system that realizes a mathematical structure in another substrate, even if hidden from us, and an alternative descriptive language that cannot be fully translated into mathematics without loss of information.

Keywords: philosophy of science; mathematics and nature; mathematical realism; embodied cognition; morphological computation; neural networks; symbolic regression;¹ scientific representation.

¹ John R. Koza, Genetic Programming: On the Programming of Computers by Means of Natural Selection, Cambridge, MA: MIT Press, 1992.

1. The Limits of Mathematics as the Sole Language

The conventional starting point for discussions of the status of mathematics in the natural sciences is Galileo Galilei's claim that the universe cannot be understood without learning its language and recognizing the characters in which it is written. That language is mathematics, and its characters are triangles, circles, and other geometrical figures.² Often condensed into the statement that the book of nature is written in the language of mathematics, this formulation marked the transition from a qualitative conception of nature, grounded in Aristotelian tradition and verbal description, to an approach that sought to measure, quantify, and formulate general relations in geometric and algebraic form. From this emerged the assumption that the success of modern physics is not accidental. Natural world appears to respond in an exceptional way to mathematical language.

Eugene Wigner argued that the effectiveness of mathematics in natural sciences is profoundly unreasonable.³ Mathematical concepts that arise from internal considerations of beauty, consistency, or abstraction repeatedly reappear in physical contexts for which they were not originally intended. He offered several striking examples. Newton used the concepts of infinitesimal calculus, developed independently and in parallel by Leibniz, to formulate the laws of motion and gravity. Calculus enabled him to predict both the planetary orbits of the solar system and the ballistic trajectory of a stone with remarkable precision.

When Heisenberg sought mathematical formulation for quantum mechanics, he developed a computational mathematical method. Max Born soon recognized that Heisenberg's tools were an application of matrix algebra, which had been developed decades earlier by the mathematician Arthur Cayley as an abstract inquiry unrelated to physics.

While formulating general relativity, the theory of curved spacetime, Einstein discovered that the mathematical structure he required had already been developed decades earlier by Bernhard Riemann in the form of non-Euclidean differential geometry. Riemann had

² Galileo Galilei, "Excerpts from The Assayer", in *Discoveries and Opinions of Galileo*, trans. and ed. Stillman Drake, Garden City, NY: Doubleday, 1957.

³ Eugene P. Wigner, "The Unreasonable Effectiveness of Mathematics in the Natural Sciences", *Communications on Pure and Applied Mathematics* 13, no. 1, February 1960.

developed this geometry from aesthetic and mathematical interests, with no intention of describing Einsteinian spacetime.

Finally, Paul Dirac sought to reconcile quantum mechanics with special relativity. Through a mathematical manipulation of the wave equation, he obtained an equation containing negative-energy solutions. Rather than dismissing these solutions as physically meaningless, he proposed the existence of a new particle, the positron, an electron with positive charge, for which no evidence then existed. The particle was discovered experimentally several years later. Wigner did not regard such cases as straightforward proof that the world is mathematical. Instead, he identified a puzzle: why does an apparently human and abstract instrument of thought describe the structure of physical reality with such precision?

A stronger position appears in Max Tegmark's Mathematical Universe Hypothesis.⁴ According to Tegmark, it is not merely that the universe can be described mathematically. Physical reality itself is a mathematical structure. On this view, the distinction between description and the object described becomes tenuous. Mathematics is not a map of the universe but is embedded in it. By contrast, another philosophical tradition, associated with Willard Van Orman Quine and Hilary Putnam⁵, stressed the indispensability of mathematics to modern science.⁶ Even if this approach does not necessarily entail a fully developed mathematical idealism, it treats mathematics as a tool without which science cannot formulate its account of reality.

Alongside these approaches, a critical view emerged that treats mathematics not only as the discovery of an external order but also as a product of human culture. George Lakoff and Rafael Núñez argued that many mathematical ideas grow from cognitive structures and

⁴ Max Tegmark, "The Mathematical Universe," *Foundations of Physics* 38, no. 2, February 2008.

⁵ Hilary Putnam, "What Is Mathematical Truth?", in *Mathematics, Matter and Method: Philosophical Papers*, vol. 1, 2nd ed. (Cambridge: Cambridge University Press, 1979), 60–78.

⁶ W. V. O. Quine, "On What There Is," *Review of Metaphysics* 2, no. 1, September 1948): 21–38; Hilary Putnam, *Philosophy of Logic*, New York: Harper & Row, 1971.

embodied metaphors such as counting, movement, line, boundary, continuity, and infinity. These are not merely abstract entities, but concepts grounded in how human beings act.⁷

This yields a further critical line of thought. Even if mathematics is extraordinarily effective, its success may reflect the human mode of access to reality rather than the form of reality itself. Traditional mathematics relies heavily on decomposing systems into components, isolating variables, and establishing relations among them. It converts physical objects, actions, and experiences into symbols that can be substituted, differentiated, and calculated. Yet other ways of attuning to nature may proceed not through symbolization but through different mechanisms of action.

In addressing this issue, it is crucial to establish a fundamental methodological distinction between an external descriptive tool and an internal operational language. The fact that an external observer can formulate a mathematical model to describe, predict, or approximate the trajectory of a system does not inherently mean that the system itself operates via internal mathematical structures or symbolic algorithms. Confusing a mathematical description of a phenomenon with the internal mechanism that generates it risks conflating our epistemic access to reality with reality's intrinsic ontology.

2. The Footballer: Heading the Ball without Mathematics

The fact that a footballer does not solve differential equations to head a ball illustrates the limits of identifying physical success with explicit symbolic computation. From the standpoint of classical physics, the ball's trajectory, velocity, acceleration, air resistance, the player's posture, neck torque, and the timing of the jump can all be described by a complex system of equations. Yet the footballer does not translate the state of the world into a symbolic system, set initial conditions, or perform real-time integration. The action depends on a continuous perception-action loop in which the body, gaze, balance, prior experience, and environment jointly generate a predictive mechanism.

⁷ George Lakoff and Rafael E. Núñez, *Where Mathematics Comes From: How the Embodied Mind Brings Mathematics into Being* (New York: Basic Books, 2000).

In his studies of coordination and movement, Nikolai Bernstein⁸ argued that motor action cannot be understood as a central command that calculates in advance all the body's degrees of freedom. On the contrary, the body narrows the space of possibilities through its physical structure, constraints, muscular patterns, and continuous sensory feedback. In the terms of this article, the footballer does not calculate nature from the outside but participates in it. The body is part of the dynamic system it would supposedly have to calculate.

James Gibson's ecological psychology further sharpens this point. For Gibson, the environment is not first perceived as a neutral array of geometric data that the brain subsequently interprets, but as a field of affordances.⁹ An approaching ball is not merely an object with coordinates. It is an invitation to act, to wait, step backward, jump, stop, or head it. In this sense, the relevant knowledge need not appear as an equation but as a direct capacity to respond to the changing structure of the perceptual field.

This example does not undermine the validity of mathematics. On the contrary, mathematics may describe after the fact what occurred and construct a successful model of the header. It challenges only the assumption that every precise action requires an explicit symbolic mathematical representation within the performing system. There may be a principled distinction between an external description of a system and the way the system itself operates. The footballer is a relatively simple case of morphological computation¹⁰: the body, senses, and environment carry part of the functional burden, so the solution is not located in the brain alone but in the dynamic deployment of the body in the world. The same observations apply to a dog catching a flying disc in midair.

This provides limited support for the thought experiment proposed here. The fact that a person (or a dog) can perform a complex physical action without explicitly solving the

⁸ Nikolai A. Bernstein, *The Co-ordination and Regulation of Movements*, Oxford: Pergamon Press, 1967.

⁹ James J. Gibson, *The Ecological Approach to Visual Perception*, Boston: Houghton Mifflin, 1979.

¹⁰ Rolf Pfeifer and Gabriel Gómez, "Morphological Computation-Connecting Brain, Body, and Environment", in *Creating Brain-Like Intelligence: From Basic Principles to Complex Intelligent Systems*, ed. Bernhard Sendhoff et al., Berlin: Springer, 2009, 66–83.

equations that describe it shows that successful performance does not require conscious symbolic computation. It does not prove that the mechanism cannot be described mathematically or that its internal representation is not isomorphic to a mathematical structure. Nevertheless, it allows us to imagine forms of cognition in which matter, structure, and dynamics bear most of the burden of attunement to the world, thereby raising the question of whether mathematical description is the system's mode of operation or merely an external account of it.

The example shows that precise action can occur without conscious symbolic computation, but it does not determine whether the enabling structure is mathematical. This distinction leads to the following thought experiment, which asks whether a cognitive, material, or perceptual representation can yield accurate predictions without being fully translatable into mathematics.

3. Thought Experiment: The Three Participants Test

To examine whether mathematics is the sole language for describing nature, we must first specify the assumption under challenge. In its conceptual essence, mathematics is not merely a collection of numbers, but a formal system of logical relations, patterns, and order represented through symbols, variables, and rules of derivation. When modern physics claims that the book of nature is written in the language of mathematics, it assumes that deciphering, processing, and predicting the laws of reality must proceed through abstract symbolic mediation. This raises the question of whether general representation and accurate prediction of the universe must rest on quantitative symbolic structures, or whether a cognitive, material, or perceptual representation of physical laws could be non-mathematical in its essence.¹¹

The thought experiment places three intelligent forms of life, each with a different cognitive and physiological architecture, before the same task: to analyze and predict a novel and complex physical phenomenon, such as the dynamics of bodies in curved spacetime or

¹¹ John D. Norton, "Are Thought Experiments Just What You Thought?", *Canadian Journal of Philosophy* 26, no. 3, September 1996.

quantum fluctuations in an energy field. Participant A is a human who uses symbolic mathematics. Participant B is a being with a biological neural network that responds directly to the phenomenon. Participant C is a being with synesthesia and holistic perception that experiences physical dynamics as qualities of consciousness.

Participant A: A human who uses symbolic mathematics to examine the phenomenon. This participant understands nature by decomposing complex phenomena into discrete components, deriving quantitative variables, and converting dynamics into symbols such as differential equations and linear algebra. Prediction proceeds through the application of logical and mathematical rules of inference abstracted from immediate physical reality. The descriptive language is formal symbolic mathematics.

Participant B: A being with a biological network-mind. Its mode of perception neither uses symbols nor formulates equations such as $F = ma$, $E = mc^2$ or Einstein's gravity field equations. Its nervous system or biological-material structure responds and changes in direct physical synchrony with the laws governing the environment. This may be called morphological computation. Predicting motion or system behavior proceeds through direct and immediate simulation in an organ or neural network, producing an internal sense of the expected outcome.¹²

Participant C: A being endowed with synesthesia and a holistic form of consciousness. Rather than perceiving discrete objects in space and time, it experiences the universe's energy field as a unified spectrum of conscious states, sensations, and intrinsic qualities, or qualia.¹³ Its prediction of a planetary orbit is not represented as a sequence of points in space but as a melody or a complex affective experience, in which every change in physical dynamics corresponds to a change in the intensity and quality of conscious experience.

The criterion of evaluation is the test of language and isomorphism. To determine whether the non-symbolic languages of participants B and C are genuinely alternative languages or

¹² Andy Clark, *Being There: Putting Brain, Body, and World Together Again*, Cambridge, MA: MIT Press, 1997.

¹³ Frank Jackson, "Epiphenomenal Qualia", *Philosophical Quarterly* 32, no. 127, 1982.

merely “mathematics in disguise,” the thought experiment subjects them to the following decision criterion:

The isomorphism scenario, mathematics as the sole language: If non-symbolic systems must encode equivalence relations, conservation laws, and quantitative relations within their internal structures to achieve accurate prediction at quantum or astronomical scales, then a complete structural morphism exists between the physiological or experiential representation and mathematics. On this scenario, even if the external representation uses no symbols, its underlying cognitive or physical structure is mathematical in essence.

The alternative-language scenario: If the biological or experiential participant successfully predicts phenomena that symbolic mathematics cannot describe or compute to a comparable degree, and if translating its representation into mathematical structure causes a loss of information that impairs prediction, explanation, or discrimination among states, this would provide support for the existence of an alternative descriptive language. Even then, it would not constitute definitive proof, because the failure might arise from limitations in existing theory or measurement.

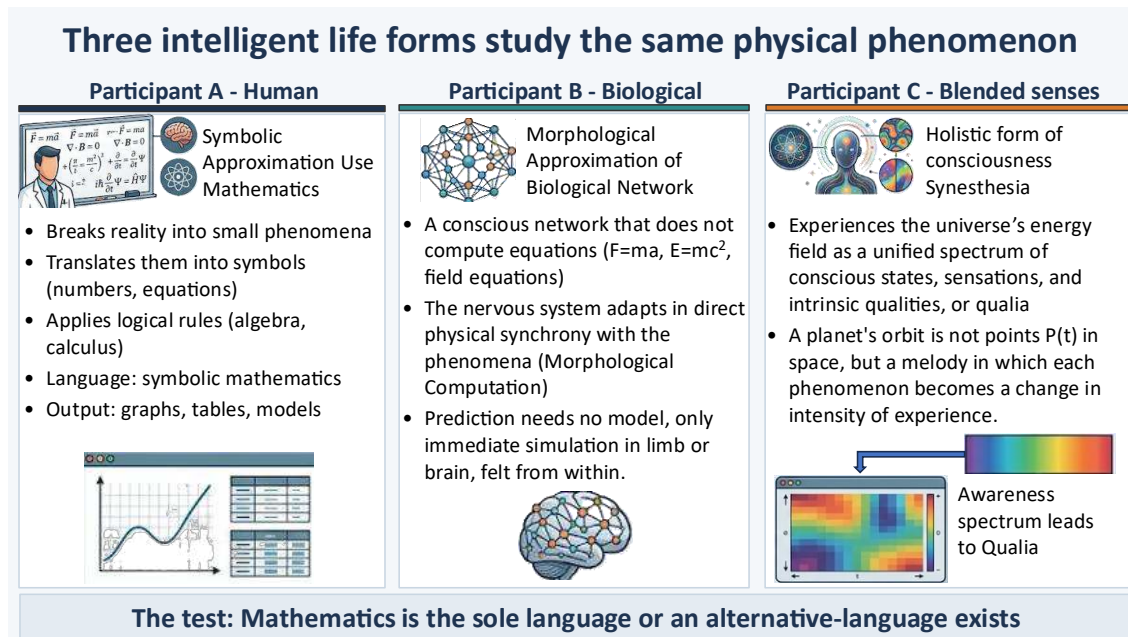


Image 1: Imaging the thought experiment.¹⁴

¹⁴ The image was prepared by the author using Microsoft PP

The thought experiment raises three fundamental questions. First is the question of isomorphism: when an alternative system, such as a large neural network or a direct physical model, arrives at the same predictions as differential equations, does it realize mathematics in another substrate or employ a genuinely different way of processing information? Second is the question of the limits of decomposition: are there holistic physical laws that cannot be broken into components or represented as mathematical continuity without losing their fundamental content? Third is the relation between quality and quantity: are the laws of nature based solely on quantitative relations and geometric structures, or can qualitative relations and meaning also play a fundamental role?

4. Analysis of the Thought Experiment

The strength of the thought experiment lies not in proving the existence of a non-mathematical language but in separating three questions that are often conflated. The first is whether a system explicitly uses mathematical symbols. The second is whether its internal structure admits complete mathematical mapping. The third is whether its predictive success depends on mathematical structure or can instead rest on a material, perceptual, or experiential organization that cannot be fully translated. This distinction is essential, because the absence of explicit equations does not by itself imply the absence of mathematical structure.

The three participants represent three degrees of distance from symbolic mathematics. Participant A separates the phenomenon from its representation and formulates relations through variables and rules of derivation. Participant B realizes correspondence through a biological structure that changes with the environment. Participant C presents a more radical possibility, in which the distinction among data, representation, and meaning becomes blurred within holistic experience. The important difference among them therefore lies not merely in the kinds of signs they employ but in where knowledge resides in an abstract model, a material body, or the totality of experience.

Methodologically, the experiment should be read as a conditional argument. If all the distinctions and predictions made by Participants B and C can be reconstructed through a

one-to-one mathematical mapping, then the difference lies primarily in substrate and implementation. If the outcomes can be reconstructed but not the process by which they arise, the result is a partial correspondence indicating an explanatory gap, though not necessarily an alternative language. Only if translation loss impairs the ability to predict, explain, or distinguish among states that the system itself distinguishes would there be grounds for the stronger claim that the system is not merely realizing mathematics in a different form.

The experiment nevertheless confronts a fundamental difficulty. Every Participant is a physical system and can therefore be given some external mathematical description. The mere possibility of describing the body, network, or experience by means of equations does not settle the issue. The question is whether the external description preserves the internal organization relevant to action and inference. In other words, we must distinguish mathematics as a tool used by a researcher to describe a system from mathematics as a language realized by the system itself.

A further difficulty concerns Participant C. An experience of melody, color, or intrinsic quality may be only another sensory encoding of quantitative relations. For the case to support a genuinely alternative language, the experiential quality must be shown to play an indispensable role in prediction rather than serving merely as a conscious envelope for relations that can be isolated mathematically. It is therefore not enough that the experience differs from the presentation of an equation. One must show that removing the qualitative dimension produces a real loss of capacity.

The experiment also reveals an asymmetry between success and failure. A successful mathematical mapping would strengthen the claim that mathematics is a deep structure shared by different modes of representation. A temporary failure to construct such a mapping would not immediately prove that another language exists, since it could arise from limitations in our theories, measurements, or computational power. A claim for an alternative language therefore requires a systematic and principled failure, not merely our present inability to translate the system.

To the "Three Participants Test" operational, one can construct an empirical test-bench using deep neural networks (representing Participant B). Consider a predictive model trained directly on raw, high-dimensional observational data of a complex physical system, such as turbulent fluid flow or double-pendulum dynamics, without any embedded physical equations. Once the model achieves superior predictive accuracy through its non-symbolic representations, a symbolic regression algorithm (such as PySR¹⁵ or SINDy¹⁶)¹⁷ can be applied to extract explicit mathematical equations from the data.

The core test of translation loss then measures two concrete metrics:

1. Predictive Performance Loss: The delta in prediction error (ΔE) between the original non-symbolic latent network and the derived explicit mathematical model when encountering out-of-distribution physical states.
2. State Discrimination Loss: The reduction in the system's ability to differentiate subtle phase-space transitions after its continuous representational space is discretized into symbolic closed-form equations.

A statistically significant, non-reducible loss in prediction accuracy following symbolic translation would provide operational evidence for a representation that cannot be mapped into standard mathematics without severe information degradation.

Despite these limitations, the experiment contributes by converting a general metaphysical question into a program of conceptual and empirical inquiry. Systems can be compared in terms of predictive accuracy, capacity to generalize to novel situations, degree of information compression, contextual dependence, and the possibility of reconstructing their inferential relations. The "Three Participants Test" thus becomes less a declaration

¹⁵ Miles Cranmer, "Interpretable Machine Learning for Science with PySR and Symbolic Regression" arXiv, May 2, 2023.

¹⁶ Steven L. Brunton, Joshua L. Proctor, and J. Nathan Kutz, "Discovering Governing Equations from Data by Sparse Identification of Nonlinear Dynamical Systems", *Proceedings of the National Academy of Sciences* 113, no. 15, 2016, 3932–37.

¹⁷ PySR (Symbolic Regression) uses evolutionary algorithms to build and mutate expression trees. It searches for an unlimited functional space to find any combination of mathematical operators that fit the data. SINDy (Sparse Regression) operates on a predefined library of candidate mathematics functions and uses sparse regression to select only the active terms that govern a dynamical system.

about the nature of reality and more a framework for comparative research on symbolic representation, neural networks, morphological computation, and other perceptual systems.

In this sense, the experiment does not oppose mathematics to its negation. Instead, it examines a continuum of possibilities: explicit symbolic mathematics, mathematical structure realized non-symbolically, partial correspondence that fails to preserve the process of formation, and finally a substantive failure of translation. This formulation reduces the risk of an artificial dichotomy and clarifies that the productive question is not whether the participant thinks mathematically, but which relations must be preserved for us to say that two modes of description constitute the same language.

The thought experiment finds broad echoes in contemporary science. Deep neural networks can learn the dynamics of complex physical systems, such as fluid mechanics or the motion of a double pendulum, directly from observational data. The network develops internal representations in a latent space that enables highly accurate prediction of system behavior without extracting a single differential equation.

Biophysics and soft robotics show how physical systems can “solve” complex kinematic and dynamic problems through their own mechanical and elastic structure, without translating them into a central processor that executes mathematical algorithms. As Stephen Wolfram has proposed, the fundamental language of nature may consist of discrete computational rules, such as cellular automata, rather than continuous analytical mathematics.¹⁸

5. Conclusion

We may possess no proof that mathematics is the only language of nature, but only evidence that it is the only language we can currently formulate explicitly. If other languages for describing physics exist, the limitation may lie in our ability to recognize as language only what appears as symbols, rules, and logical relations. The language of another material

¹⁸ Stephen Wolfram, *A New Kind of Science*, Wolfram Media, 2002.

system might instead appear as dynamic organization, patterns of attunement, or fields of response that do not decompose into separate units.

From this perspective, our position resembles that of an ancient person familiar with speech and gesture but not yet with writing. Such a person might believe that language is exhausted by sound and movement, not because no other forms of representation exist, but because the culture has not yet developed the means to recognize them. The same may be true of mathematics. It may not mark the limit of reality's possible expression but only humanity's present stage of discovery. Other languages, if they exist, may require different senses, different cognitive hardware, or technologies we do not yet possess.

The philosophical implication is that failure to discover something should not be confused with its nonexistence. The fact that every successful scientific description currently available to us can be expressed mathematically does not establish in advance that no other modes of description exist. It primarily records the history of our successes. The "Three Participants Test" is therefore not only a test of external systems but also one of epistemic humility: can we recognize that what appears to be a limit of nature may instead be a limit of the tools through which we inquire into it?

Symbolic mathematics is an extraordinarily powerful tool, yet its exclusive status in the description of nature may be connected to human cognitive architecture, which relies on discrete perception, decomposition, and the use of signs. The thought experiment does not determine whether non-mathematical languages exist. Its contribution is to propose criteria for distinguishing a non-symbolic representation of mathematical structure from a mode of description that cannot be fully translated into mathematics without loss of information.

The scholarly value of this article lies neither in empirically proving the existence of non-mathematical languages nor merely in claiming that cognition may be embodied, dynamic, or non-symbolic. Its proposed contribution is methodological and conceptual: the "Three Participants Test" seeks to transform a general philosophical question into a comparative framework for different representational systems by examining predictive accuracy, capacity for generalization, preservation of inferential relations, and information loss in

translation into mathematical structure. In its current form, the article offers a research program rather than a completed scientific finding. Its value will increase as a clear protocol is developed for distinguishing temporary difficulty in translation from a principled failure that indicates an alternative mode of description.

If other languages of physics exist, they may remain hidden not because nature conceals them, but because our perceptual structures, cognitive hardware, and technologies do not yet allow us to recognize them as languages. As artificial intelligence systems and non-symbolic computational technologies continue to develop, they may reveal entirely new ways of describing the universe, not necessarily as replacements for mathematics, but as members of a broader family of modes of correspondence among mind, matter, and the laws of nature.

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Gabi Siboni is the sole author of this article and is responsible for its conception, drafting, revision, and final approval.

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During the preparation of this manuscript, the author used Microsoft Copilot and Google Gemini for the following: Translation from Hebrew to English, language editing, stylistic refinement, structural organization, search for sources, and assistance in formatting the manuscript. The author reviewed and revised all AI-assisted output and takes full responsibility for the content of the publication.