Changing the Epistemology of Spacetime: Toward a Second-Order Science

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Abstract

Scientific revolutions are commonly understood to emerge from new observations, improved measurements, or more comprehensive theories. This paper explores a different possibility: that scientific inquiry may also advance through the recursive examination of the ontological premises from which successful theories arise. Rather than introducing philosophy into science, the present inquiry expands the horizons of scientific investigation by treating ontology as a legitimate source of empirically testable hypotheses.

Using Einstein's relativistic formalism as an exemplar, the paper demonstrates that mathematical structure may remain invariant while the ontology through which that structure is interpreted changes. Replacing **time** with **duration** as the ontological constituent preserves the mathematical formalism while generating scientific questions that could not be formulated within the previous explanatory terrain. The consequence is methodological rather than metaphysical. Second-order inquiry expands the space of possible hypotheses without requiring the abandonment of established mathematics or empirical findings.

The practical implications are illustrated through biological organization and exceptional longevity, where identical chronological intervals may coexist with markedly different biological outcomes. From this perspective, duration becomes an investigable scientific construct capable of generating new hypotheses and potentially revealing biological markers unavailable to first-order inquiry because they originate from a different ontological premise.

The paper proposes that scientific progress need not depend exclusively upon new data or increasingly sophisticated instrumentation. It may also emerge from recursively examining the ontologies that determine which scientific questions become possible to ask. In this sense, second-order inquiry extends rather than replaces the foundations of scientific investigation.

Keywords

Second-order science, spacetime, biocognitive epistemology, recursive epistemology, spaceduration

Introduction

Scientific theories are commonly evaluated by their logical consistency, mathematical formalism, predictive accuracy, and empirical agreement with observation. These criteria have produced extraordinary advances across the physical and biological sciences and remain indispensable to scientific progress. Yet they primarily evaluate theories after their conceptual architecture has already been established. Far less attention is devoted to the epistemological and ontological conditions from which scientific theories emerge, despite the historical observation that many conceptual revolutions begin not with new measurements, but with a reorganization of the assumptions that determine what is being measured.

Recent work in the philosophy of physics has begun to revive the epistemology of spacetime as a distinct field of inquiry, asking how the structures of space and time become accessible through physical theory and empirical investigation rather than focusing exclusively on their metaphysical status (Dewar et al., 2022). The present inquiry begins from that renewed emphasis but asks a recursive question. Rather than examining how spacetime becomes epistemically accessible, it examines the epistemological and ontological conditions that make any account of spacetime scientifically conceivable in the first place.

The history of physics illustrates this distinction with particular clarity. Newton's mechanics and Einstein's theory of relativity did not differ simply because one employed more sophisticated mathematics than the other. Each emerged from a different ontological interpretation of physical reality. Newton's conception of absolute space and absolute time provided the framework within which forces, motion, and gravitation became intelligible. Einstein's reconceptualization of space, time, simultaneity, and gravitation produced a new theoretical architecture whose mathematical formalization yielded predictions of unprecedented precision. In both cases, the mathematical formalism followed an epistemological and ontological reorganization of the physical world rather than preceding it (Einstein, 1905, 1916; Friedman, 2001; Norton, 2019).

Scientific revolutions are often recognized by the theories they produce. This inquiry asks whether they begin earlier, in the ontological premises from which those theories emerge.

The present paper argues that this recursive level of scientific inquiry deserves explicit recognition as a legitimate domain of science rather than being regarded solely as a philosophical enterprise. The proposal is not to introduce philosophy into science, but to expand the horizons of scientific inquiry by recognizing ontology as a legitimate source of empirically testable hypotheses. It proposes a second-order framework in which ontology and epistemology are understood as the generative conditions from which the logical, mathematical, and empirical tools of science emerge.

This distinction also clarifies the relationship between the present framework and contemporary work on the epistemology of spacetime. Whereas recent scholarship systematically surveys the epistemic routes through which physical theories justify claims about spacetime, the present proposal shifts the recursive level of analysis by examining the ontological architecture from which those epistemic routes themselves emerge. The inquiry therefore complements rather than competes with existing work in the epistemology of spacetime.

To illustrate this methodology, the paper develops a thought experiment that leaves the mathematical structure of relativity unchanged while asking whether the temporal coordinate is more coherently interpreted as **duration** rather than **time**. The purpose is not to replace relativity, but to examine whether a change in ontology can expand explanatory coherence while preserving the predictive success of the existing theory. More specifically, the inquiry asks whether a change in ontology can expand the horizon of scientifically testable hypotheses while preserving the mathematical and empirical achievements of the existing theory.

Scientific Theories Are Generated Before They Are Tested

Scientific inquiry is commonly characterized by the formulation of hypotheses followed by logical analysis, mathematical formalization, empirical testing, and predictive evaluation. This sequence accurately describes how mature theories are examined, but it does not fully explain how they originate. Before a hypothesis can be tested, the scientist must first determine what constitutes a legitimate object of inquiry, what kinds of entities are assumed to exist, and by what means those entities may be known. These prior commitments are neither mathematical nor empirical. They constitute the epistemological and ontological architecture from which scientific theories emerge (Friedman, 2001).

Scientific discovery therefore depends not only on the testing of hypotheses, but also on the conditions through which hypotheses become scientifically conceivable.

The history of science suggests that major theoretical advances occur when this underlying architecture undergoes conceptual reorganization. Newton's mechanics, Einstein's theory of relativity, and subsequent scientific revolutions did not arise merely from new observations or more sophisticated mathematics. They emerged because previously accepted assumptions about physical reality were reconsidered, allowing existing observations to be interpreted within a different conceptual framework. Mathematical formalism subsequently provided precision to that new framework, while empirical investigation determined its explanatory and predictive adequacy (Einstein, 2019; Friedman, 2001; Kuhn, 2012).

The distinction is methodological rather than philosophical. It concerns the scientific conditions through which new explanatory terrains become available for empirical investigation.

Recognizing this generative sequence does not diminish the central role of empirical science. On the contrary, it clarifies why scientific revolutions are uncommon. Scientific theories are ordinarily subjected to rigorous first-order evaluation, whereas the epistemological and ontological conditions from which those theories arise frequently remain implicit. When these conditions themselves become the explicit object of inquiry, scientific investigation enters a second-order domain in which the architecture of theory becomes available for recursive examination. While Kuhn described the historical dynamics through which paradigms undergo transformation, the present framework asks what epistemological and ontological architecture makes such transformations possible (Kuhn, 2012; Friedman, 2001).

Logic Is a Scientific Tool, Not a Scientific Tool Maker

Recognizing ontology and epistemology as the generative conditions of scientific inquiry necessarily redefines the role of logic. Logic is indispensable to science because it evaluates the internal coherence of propositions, the consistency of theoretical structures, and the validity of inferential relationships. Yet logic does not determine what entities constitute legitimate objects of scientific investigation, nor does it establish the epistemological conditions under which those entities become knowable. Logic therefore functions within a conceptual architecture that it did not create.

This distinction has important consequences for scientific theory construction. A logical argument may be internally valid while remaining constrained by the ontological assumptions from which it proceeds. Likewise, mathematical precision may increase indefinitely without questioning the conceptual architecture that determines what mathematics is formalizing. Scientific progress therefore depends not only upon increasingly rigorous logical analysis, but also upon the recursive examination of the epistemological and ontological conditions within which logical analysis operates. Logic evaluates theories; it does not generate the conceptual horizon from which theories emerge (Haack, 1978; Priest, 2008).

The distinction is methodological as well as scientific. If ontology determines what becomes available for scientific investigation, logic determines whether the resulting inquiry proceeds coherently. The two functions are complementary rather than interchangeable.

Viewing logic as a scientific tool rather than a scientific tool maker does not diminish its authority. On the contrary, it clarifies its proper function within scientific inquiry. Logic achieves its greatest explanatory power when it operates upon well-constructed epistemological and ontological foundations. Conversely, when those foundations themselves become the object of investigation, logic remains indispensable, but its role changes. Rather than constructing the conceptual architecture of science, it becomes the principal instrument through which that architecture is recursively examined. This transition marks the point at which first-order scientific reasoning naturally extends into second-order inquiry.

Second-Order Inquiry Expands the Horizon of Scientific Questions

If ontology and epistemology are the makers of scientific tools, and logic is one of those tools, then scientific progress depends not only upon the refinement of theories but also upon the recursive examination of the architecture from which those theories emerge. The significance of second-order inquiry therefore lies not in introducing a different form of scientific reasoning, but in enlarging the horizon of questions that science is capable of asking. Questions that appear philosophically speculative within an accepted conceptual framework may become scientifically legitimate once that framework itself becomes the object of investigation (Martinez, 2001).

From this perspective, first-order and second-order inquiry differ not in logical rigor but in the horizon toward which the same logical instrument is directed. First-order inquiry asks whether a theory is internally coherent, mathematically consistent, and empirically adequate. Second-order inquiry asks whether the epistemological and ontological assumptions that generated the theory remain the most coherent basis for scientific explanation. The distinction therefore reflects an expansion of inquiry rather than a departure from scientific methodology.

Scientific revolutions may be understood as moments in which this expanded horizon permits questions that previously could not be formulated within the prevailing conceptual architecture. Newton could not ask whether gravitation was a manifestation of spacetime geometry because such a question lay beyond the epistemological and ontological horizon of classical mechanics. Einstein's achievement was not merely to answer a new question, but to enlarge the horizon within which that question became scientifically conceivable (Hacking, 1983). Second-order inquiry seeks to understand the recursive conditions under which such expansions become possible.

The duration-space proposal developed in the following sections begins from this methodological position. It does not initially ask whether relativity should be replaced or whether its mathematical formalism should be revised. It asks a prior question: Does second-order inquiry permit the ontology of the temporal coordinate to be reconsidered while preserving the mathematical structure of the theory? If so, the resulting investigation concerns not the correction of relativity, but the expansion of the horizon from which relativity itself may be interpreted.

What If Einstein Had Applied Second-Order Inquiry?

Einstein questioned Newton's ontology without abandoning Newton's commitment to mathematical rigor. The equations changed because the ontology changed. Space and time were no longer independent realities but a unified explanatory terrain from which gravitation, simultaneity, and motion acquired a different meaning (Einstein, 2019).

The recursive question is whether Einstein's own ontology can be approached in the same manner. The success of relativity does not eliminate this question; it makes it possible. Once a theory has demonstrated extraordinary explanatory power, second-order inquiry shifts from evaluating its predictions to examining the ontology from which those predictions are interpreted.

The temporal coordinate has traditionally been understood to represent **time**. But is time demanded by the mathematics, or has time become the accepted ontology through which the mathematics has been understood? This distinction is not mathematical. It is ontological. As proposed in *From Neuromaps to Meaning*, representation does not exhaust meaning. Mathematical formalism and explanatory ontology occupy different terrains of inquiry (Martinez, 2026).

Suppose the temporal coordinate is interpreted as **duration** rather than **time**. Nothing in the mathematical formalism is initially disturbed. The equations remain. The predictions remain. The measurements remain. What changes is the ontology.

The consequences begin immediately. Velocity no longer slows time. Velocity alters duration. Gravitation no longer curves time. Gravitation alters duration. Clocks no longer measure time itself. They measure duration under different physical conditions. Time remains indispensable, but its function changes. It becomes the measure of duration rather than the ontology of what is being measured.

The question therefore is not whether relativity should be replaced. The question is whether Einstein's own method leads beyond the ontology that has traditionally accompanied his equations.

Formulations: Mathematics Remains—Ontology Changes

The preceding discussion proposed that second-order inquiry leaves Einstein's mathematics intact while questioning the ontology through which that mathematics is interpreted. The distinction therefore concerns neither geometry nor prediction, but the ontological premise from which the mathematics derives its explanatory terrain (Einstein, 2019; Martinez, 2026).

Einstein's implicit ontological formulation

ds2=c2dt2−dx2−dy2−dz2

Second-order ontological formulation

ds2=c2dD2−dx2−dy2−dz2

The mathematical formalism remains unchanged. The inquiry now turns to the consequences of replacing time with duration while preserving the same mathematical structure.

The difference between these formulations is confined to a single ontological constituent. Their mathematical invariance shifts the inquiry from formalism to consequence. The question is no longer whether the equations remain valid, but whether the explanatory terrain changes when duration, rather than time, becomes the ontological constituent.

Second-order inquiry therefore does not revise Einstein's mathematics. It recursively examines the ontology from which that mathematics derives its explanatory orientation. The remaining sections derive the consequences of that ontological substitution while the mathematics remains invariant.

The Measurement of Duration

The first scientific consequence of replacing **time** with **duration** emerges when chronological equivalence is compared with biological organization. Two individuals may accumulate the same chronological years while exhibiting profoundly different biological ages. The clock records equivalent temporal intervals. Biology does not.

This distinction has become increasingly evident in studies of exceptional longevity. Centenarians frequently exhibit biological profiles that diverge substantially from what chronological age alone would predict. Within the conventional formulation, these findings are interpreted as variability within the aging process. From the present formulation, they invite a different question: Do identical chronological intervals necessarily represent identical durations?

The distinction is not semantic. If **time** measures **duration**, then biological organization need not correspond directly to chronological measurement. The same temporal interval may embody different durations because duration reflects the contextual organization through which biological processes unfold rather than the numerical passage of time alone.

This reformulation does not alter the measurement of chronological age. Nor does it modify the mathematics through which temporal intervals are calculated. It changes the explanatory terrain from which biological differences are interpreted. Chronological time remains invariant. Duration becomes the ontological constituent through which biological organization acquires explanatory coherence.

The centenarian therefore becomes more than an exceptional survivor. Within a second-order inquiry, the centenarian represents a natural experiment in which identical chronological measurement coexists with markedly different biological organization. The scientific question shifts accordingly. Rather than asking why some individuals age more slowly in time, the inquiry asks how different durations become biologically organized while chronological time remains equivalent.

The consequence extends beyond reinterpretation. Once duration becomes the ontological constituent, second-order inquiry generates hypotheses that were not available under first-order inquiry because they originate from a different explanatory terrain. Rather than treating chronological age as the primary explanatory variable, the inquiry asks whether distinct organizations of duration correspond to distinct biological organizations despite equivalent chronological measurement.

This shift expands scientific discovery. Second-order inquiry does not create new biological markers; it generates new hypotheses through which previously unrecognized markers may become scientifically identifiable. Biological organization is no longer examined solely as a function of chronological time, but as a function of duration. The ontology changes before the hypothesis is formulated, allowing science to investigate biological relationships that remained inaccessible within the explanatory terrain of first-order inquiry.

Conclusion

The purpose of this inquiry has not been to replace Einstein's mathematics, nor to diminish the explanatory power of relativity. On the contrary, it has been to ask whether scientific inquiry itself can advance by recursively examining the ontological premises from which successful theories emerge.

The distinction developed throughout this paper is therefore methodological before it is physical. First-order inquiry evaluates hypotheses within an established ontology. Second-order inquiry examines the ontology from which those hypotheses arise. The consequence is not the rejection of existing science, but the expansion of its explanatory terrain.

The reformulation proposed here illustrates that a change in ontology may preserve mathematical structure while generating new scientific questions. When **duration** becomes the ontological constituent and **time** its measure, the mathematics remains invariant, yet the inquiry acquires access to hypotheses that could not be formulated within the previous explanatory terrain. Scientific progress therefore need not depend exclusively upon new observations or increasingly sophisticated instruments. It may also emerge from the recursive refinement of the ontologies through which observations become scientifically meaningful.

The implications extend beyond relativity. Whenever science assumes that its measurements exhaust the phenomena they represent, the underlying ontology becomes transparent through familiarity. Second-order inquiry restores that transparency to examination. In doing so, it does not ask science to abandon its achievements, but to reconsider the explanatory horizons from which those achievements derive their meaning.

The present proposal therefore occupies a different methodological terrain from current discussions within the epistemology of spacetime. Existing work has substantially clarified how physical theories provide epistemic access to spacetime and has called for renewed attention to this neglected domain. The contribution of second-order inquiry is to ask a prior scientific question: What epistemological and ontological architecture determines which conceptions of spacetime become available for scientific investigation? By treating that architecture itself as an object of inquiry, second-order science seeks to enlarge the horizon from which future physical theories may emerge.

The history of science has often been written as a succession of discoveries. This inquiry suggests an additional possibility. Scientific revolutions may begin before new discoveries are made, when the ontologies that generate scientific questions, themselves become available for recursive examination. If so, the future of science may depend not only on what remains to be discovered, but also on the willingness to reconsider the explanatory terrains from which discovery itself emerges.

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