The Empirical-Axiomatic Framework: Knowledge, Epistemic Capacity, and Representation

Akash Shivaji Pawar*

Department of Physics, Indian Institute of Technology Madras,
Chennai, Tamil Nadu, India, 600036

Abstract

This paper introduces the Empirical-Axiomatic Framework, a conceptual framework designed to clarify the relationships between empirical reality, abstract space, knowledge, epistemic capacity, and representation. The framework begins from a strict separation: empirical reality is physical, causal, and mind-independent, while knowledge consists of abstract structures that exist in abstract space independently of their use, discovery, or interpretation. Knowledge is not representation, not epistemic activity, and not reducible to models or theories. Representation arises only when an empirical system with epistemic capacity selects and applies abstract structures under interpretive rules to model aspects of empirical reality. Epistemic capacity itself is treated as an empirical property of physical systems, constrained, finite, and causally instantiated, which enables selection and use of abstract structures without creating or defining them.

Using physics as a primary case study, the paper demonstrates that scientific progress is driven by the need for increasingly expressive abstract structures as empirical reality reveals features that cannot be represented within existing mathematical frameworks. The progression from classical mechanics to quantum mechanics, quantum field theory, and modern theoretical approaches is analyzed as a sequence of epistemic responses to representational failure, each requiring axiomatic enrichment of mathematics. Mathematical advancement is shown to consist in the introduction of new axioms and structures, expanding representational capacity while remaining inherently open-ended, as guaranteed by Gödel's incompleteness for sufficiently strong formal systems. Consequently, physical models can achieve increasing accuracy without ever attaining completeness.

The framework further clarifies the role of empirical limits, showing how epistemic saturation produces the illusion of finality and motivates the mistaken notion of a theory of everything. This illusion reflects practical constraints on empirical access, not exhaustion of abstract space or closure of reality. Finally, the framework is applied to the concept of self, distinguishing the empirical self as a physical system from multiple axiomatic selves as abstract models, including experiential and enlightenable selves, without introducing new ontological categories. By enforcing strict conceptual discipline between empirical reality and abstract representation, the Empirical-Axiomatic Framework dissolves persistent confusions in epistemology, philosophy of science, and philosophy of mind while preserving the reality of experience, the success of science, and the open-ended nature of epistemic progress.

Keywords: Knowledge, Epistemic Capacity, Scientific Models, Mathematical Axioms, Limits of Physics, Gödel Incompleteness, Self, Philosophy of Science.

*ph24d066@smail.iitm.ac.in

1 Introduction

The central aim of this paper is to establish a clear and disciplined framework for understanding the relationship between empirical reality, knowledge, epistemic capacity, and representation. Much confusion in philosophy of science, epistemology, and the study of self arises from the failure to separate these domains cleanly. Concepts such as "knowledge," "model," "theory," "reality," and "self" are often treated as if they belong to the same ontological category, leading to category errors, false metaphysical problems, and the persistent illusion that scientific progress must converge toward a final description of reality. This paper proposes the Empirical–Axiomatic Framework as a way to dissolve these confusions by strictly separating what exists empirically from what exists abstractly, and by carefully locating epistemic activity within physical systems rather than in abstract space itself.

The framework begins from a non-negotiable starting point: empirical reality exists independently of description, theory, language, mathematics, or any epistemic agent. Empirical reality is physical, causal, and mind-independent, and it does not consist of models, axioms, or abstract structures. At the same time, this paper recognizes the existence of abstract space, the domain in which mathematical structures, logical systems, and formal relations exist as abstract entities. Knowledge, within this framework, is identified strictly with abstract structures themselves. Knowledge is not an activity, not a mental state, and not something that comes into existence only when it is used or represented. Abstract structures exist independently of whether any epistemic system accesses them, applies them, or even discovers them.

A crucial consequence of this separation is that representation is not part of the definition of knowledge. Abstract structures do not intrinsically represent empirical reality. Representation arises only when an epistemic system uses an abstract structure under interpretive rules to track some aspect of empirical reality. This use is an epistemic act performed by physical systems with epistemic capacity, a capacity that is itself entirely empirical, finite, and constrained. Epistemic capacity does not create knowledge, does not populate abstract space, and does not define which abstract structures exist. It merely selects, instantiates, and deploys abstract structures that already exist, under the constraints imposed by empirical reality.

Physics is treated in this paper not as the discovery of what knowledge is, nor as the creation of abstract space, but as a paradigmatic case study of epistemic capacity operating under empirical constraint. The historical progression from classical mechanics to quantum mechanics, quantum field theory, and modern theoretical frameworks illustrates a single structural pattern: as empirical reality reveals features that existing mathematical frameworks cannot represent, epistemic capacity must select richer abstract structures with greater expressive power. This requires mathematical advancement through axiomatic enrichment. However, because abstract space is inexhaustible and empirical access is finite, this process never terminates in a final theory. Apparent completeness arises only through epistemic saturation, giving rise to the illusion of finality, not to genuine ontological closure.

Finally, the framework is applied to the concept of the self. The self is treated neither as a metaphysical primitive nor as a purely subjective construct, but as a system analyzed at two strictly separated levels: the empirical self, which is a physical system in empirical reality, and the axiomatic self or selves, which are abstract models of that system. This allows the same conceptual structure used in physics to be applied to traditionally problematic domains such as experience, consciousness, and selfhood, without reductionism and without introducing new ontological entities.

By maintaining strict discipline between empirical reality, abstract space, epistemic capacity, and representation, the Empirical–Axiomatic Framework provides a unified and internally consistent way to understand knowledge, scientific modeling, and the limits of theory. The goal of this paper is not to offer a final description of reality, but to clarify why such finality is structurally impossible, and how meaningful epistemic progress nevertheless remains possible. [Pawar, 2026b, Pawar, 2026c, Pawar, 2026a, Pawar, 2026d, Pawar, 2026e, Kuhn, 1962, Popper, 1959, van Fraassen, 1980, Cartwright, 1983]

2 Empirical Reality

In the Empirical-Axiomatic Framework, the starting point is empirical reality, and this starting point is non-negotiable. Empirical reality is what exists independently of any description, theory, language, mathematics, or epistemic agent. It does not depend on humans, minds, models, symbols, or formal systems for its existence. It simply is. This independence is not an assumption made for convenience; it is the minimal condition required to make sense of error, correction, discovery, and constraint. If empirical reality depended on our descriptions, then the distinction between correct and incorrect descriptions would collapse, and epistemic activity itself would lose meaning.

Empirical reality is physical. By physical, we mean that it is composed of physical constituents and governed by causal relations. These constituents may be described by current physics in terms of particles, fields, spacetime, or other structures, but crucially, those descriptions are not what empirical reality is. They are attempts to describe it. Empirical reality does not consist of equations, models, axioms, or mathematical objects. Even if all mathematical descriptions were erased, empirical reality would remain exactly as it is. Thus, empirical reality is not abstract, not symbolic, and not formal. It is the domain in which causal interactions occur.

Empirical reality is also mind-independent. This does not mean that minds are unreal; it means that the existence and behavior of empirical reality do not depend on being perceived, conceptualized, or known. A planet existed before humans observed it. Light propagated long before any theory of optics existed. Biological organisms evolved before any concept of life was formulated. Empirical reality does not wait for interpretation. It does not become real when it is modeled. It precedes all epistemic activity and all abstract structure.

At the same time, empirical reality is not intrinsically partitioned into well-defined systems. Nature does not come pre-labeled with boundaries such as “object,” “system,” or “self.” These partitions are introduced by epistemic agents for the purpose of study and modeling. For example, when we speak of a human body, a river, a photon, or a beam of light, we are selecting a region of empirical reality and treating it as a system because doing so allows successful modeling. The success of these selections is judged empirically, not ontologically. The system is not defined by nature; it is selected because it works epistemically.

Empirical reality is causally structured. Events in empirical reality influence other events through causal relations, regardless of whether those relations are understood or modeled. Causality here does not mean any specific metaphysical doctrine; it simply means that changes in one part of empirical reality can bring about changes in another part. This causal structure is what allows empirical reality to constrain knowledge. If empirical reality were not causally structured, experiments would not yield reproducible outcomes, and epistemic refinement would be impossible.

One of the most important roles of empirical reality in the Empirical-Axiomatic Framework is that it constrains what can succeed epistemically. This does not mean that empirical reality dictates our theories or determines which abstract structures must exist. Rather, it acts as a filter. Abstract structures that, when used epistemically, consistently fail to align with empirical observations are rejected or revised. Abstract structures that succeed in tracking empirical regularities are retained. The constraint is negative and selective, not constructive. Empirical reality does not tell us what model to build; it tells us which models fail.

It is crucial to emphasize that empirical reality is not knowledge. Knowledge exists in abstract space as abstract structure. Empirical reality exists independently of abstract space. The two must never be conflated. When we say “we know reality,” we are not saying that reality itself has become knowledge. We are saying that some abstract structures successfully correspond, within a domain, to aspects of empirical reality. Confusing empirical reality with knowledge leads to the error of treating theories as if they were constituents of the world itself.

Empirical reality is also not axiomatic. Axioms belong to abstract systems. They are assumptions, starting points, or formal commitments that enable the construction of models and theories. Empirical reality does not operate according to axioms, nor does it require axioms to exist. Axioms are tools of epistemic capacity, not features of reality. When we say that a theory "assumes" something, that assumption is in the abstract model, not in the world. The world does not assume anything.

Another important clarification concerns identity and persistence in empirical reality. Empirical systems persist not because they retain the same material constituents, but because they maintain organizational and causal continuity. A human body replaces most of its atoms over time, yet remains the same empirical system. A river constantly exchanges water molecules, yet remains the same river. A flame consumes fuel and emits exhaust, yet remains the same flame. These examples show that empirical reality is organized dynamically, not statically. Identity is grounded in causal coherence, not in fixed substance.

Empirical reality also includes systems that can later be described as epistemic systems, such as human organisms or machines. However, their epistemic capacities do not alter the ontological status of empirical reality itself. A brain that produces knowledge is still a physical system within empirical reality. Its capacity to engage with abstract space does not elevate it into a different ontological category. This point is essential for avoiding anthropocentrism and for treating humans, animals, and machines within a unified framework.

Finally, empirical reality places limits on empirical access, but these limits are not limits on reality itself. There may be scales, energies, or conditions that are inaccessible to current instruments or even to any finite epistemic system. These limits do not imply that reality ends there. They only imply that epistemic capacity has boundaries. Empirical reality continues beyond what is observed, measured, or modeled. Confusing epistemic limits with ontological limits is another source of deep confusion that this framework explicitly avoids.

In summary, within the Empirical-Axiomatic Framework, empirical reality is independent, physical, causal, mind-independent, and non-abstract. It is not knowledge, not axiomatic, and not constituted by models or descriptions. Its role is not to provide axioms or structures, but to constrain epistemic success through causal interaction. Maintaining this strict separation between empirical reality and abstract space is the foundation upon which all subsequent discussions of knowledge, epistemic capacity, representation, and self must rest. [Pawar, 2026b, Pawar, 2026c, Pawar, 2026a, Pawar, 2026d, Hacking, 1983, Cartwright, 1983]

3 Abstract Space and Knowledge

After fixing empirical reality as independent, physical, causal, and non-abstract, the Empirical-Axiomatic Framework introduces a second, equally fundamental domain: abstract space. Abstract space is the domain in which abstract structures exist. It is not a region of physical space, not a hidden layer of the universe, and not something that causally interacts with empirical reality. Abstract space is defined purely by the existence of abstract structures—such as mathematical systems, logical relations, formal languages, and internally consistent symbolic constructions. These structures do not occupy spacetime, do not have mass or energy, and do not participate in causal chains. Their mode of existence is abstract, not physical.

Within the Empirical-Axiomatic Framework, knowledge is identified with the contents of abstract space. That is, knowledge consists of abstract structures themselves. This identification is strict and foundational. Knowledge is not something that happens only when an agent knows, uses, believes, or applies it. Knowledge exists whether or not it is accessed, interpreted, or instantiated by any epistemic system. A mathematical structure, once defined and internally consistent, exists as knowledge in abstract space even if no one ever uses it, applies it to the real world, or even discovers it.

It is essential to state this explicitly: knowledge exists independently of use. Use is an epistemic activity performed by physical systems with epistemic capacity. Knowledge, by contrast, is not an activity and not a process. It is a static abstract structure. For example, group theory existed as an abstract structure before it was applied to physics, chemistry, or crystallography. Many branches of mathematics were developed without any empirical motivation and only later found applications. Their existence as knowledge does not depend on those applications. Even abstract structures that never find any empirical application are still knowledge within this framework.

Equally important is the clarification that knowledge does not require epistemic capacity in order to exist. Epistemic capacity is a property of empirical systems, such as humans, animals, machines, or collectives, that allows them to access, construct, manipulate, and deploy abstract structures. But epistemic capacity is not what brings abstract space into existence. Abstract space is not generated by minds, brains, or machines. Epistemic capacity only determines which parts of abstract space are accessed, explored, or used. If no epistemic agents existed at all, abstract space and thus knowledge would still exist.

This point is crucial for consistency. If knowledge required epistemic capacity in order to exist, then knowledge would collapse into psychology, neuroscience, or sociology. The Empirical-Axiomatic Framework explicitly rejects this collapse. Knowledge is not mental content, not neural activity, and not social convention. Those are physical or social processes that may interact with knowledge, but they are not what knowledge is.

Another foundational clarification is that representation is not part of the definition of knowledge. Knowledge does not inherently represent anything. Representation occurs only when an abstract structure is used epistemically to correspond to some aspect of empirical reality. Many abstract structures represent nothing at all. They are internally consistent formal systems with no referent. For example, large areas of pure mathematics do not represent physical systems, and they are not defective or incomplete because of that. Their existence as knowledge does not depend on representational success.

This distinction is vital because much confusion arises when people assume that knowledge must be "about" something in the world. In the Empirical-Axiomatic Framework, being "about" something is an epistemic role that abstract structures can take on, not an intrinsic feature of knowledge. Knowledge, as abstract structure, is neutral with respect to application. It does not point to reality by itself. It becomes representational only when an epistemic system maps it onto empirical phenomena.

Abstract space, therefore, should not be imagined as a mirror of reality or as a shadow world encoding physical facts. It is a space of possibilities—possible structures, possible relations, possible formalisms. Empirical reality constrains which of these possibilities can successfully function as models, but it does not determine which abstract structures exist. The space of abstract structures is vastly larger than the space of empirically successful models. This asymmetry is fundamental and must never be inverted.

Within abstract space, structures are defined by internal consistency, not by truth in the empirical sense. An abstract structure can be perfectly consistent and well-defined even if it has no empirical counterpart. Conversely, an abstract structure that is inconsistent fails as knowledge, regardless of whether someone attempts to apply it to reality. Consistency is therefore the minimal requirement for something to count as knowledge in this framework. Empirical adequacy is a separate criterion that applies only when knowledge is used epistemically.

It is also important to emphasize that abstract space is not hierarchical in an ontological sense. More "advanced" mathematics is not more real than elementary mathematics. Functional analysis is not ontologically superior to arithmetic. These distinctions are epistemic and pragmatic, not metaphysical. Abstract structures differ in complexity, expressive power, and applicability, but they all exist equally as knowledge once defined consistently.

This understanding of knowledge also explains why abstract space is, in principle, unbounded. New abstract structures can always be defined by introducing new axioms, new relations, or new formal rules, as long as consistency is maintained. This does not mean that knowledge grows because reality demands it. It means that abstract space admits indefinitely many structures, and epistemic capacity can, over time, explore more of this space. Gödel's incompleteness results reinforce this point by showing that no sufficiently strong formal system can exhaust all truths expressible within it, but the key idea here is broader: abstract space is not closed or final.

Finally, the strict separation between empirical reality and abstract space must be maintained at all times. Empirical reality constrains epistemic success, but it does not populate abstract space. Abstract space contains knowledge, but it does not act on empirical reality. The connection between the two is mediated entirely by epistemic capacity, which will be discussed in later sections. Any attempt to collapse abstract space into empirical reality, or to treat empirical reality as itself axiomatic or abstract, destroys the coherence of the framework.

In summary, within the Empirical-Axiomatic Framework, abstract space is the domain of abstract structures, and knowledge is identified with those structures themselves. Knowledge exists independently of use, independently of epistemic capacity, and independently of representation. It is not physical, not causal, and not empirical. Representation and modeling are epistemic activities that involve using abstract knowledge to track empirical reality, but they are not part of the definition of knowledge. Maintaining this separation is essential for all subsequent discussions of epistemic capacity, models, physics, and the self. [Pawar, 2026b, Pawar, 2026c, Pawar, 2026a, Pawar, 2026d, Gödel, 1931, Enderton, 1977]

4 Epistemic Capacity

Having clearly separated empirical reality from abstract space and knowledge, we now introduce epistemic capacity. Epistemic capacity is the bridge that connects these two domains, but it is crucial to state at the outset that epistemic capacity belongs entirely to empirical reality. Epistemic capacity is not abstract, not axiomatic, and not part of knowledge itself. It is a physical capacity of empirical systems such as humans, animals, machines, or collectives to interact with abstract space. This interaction includes accessing abstract structures, selecting among them, instantiating them in physical processes, and using them in epistemic activities such as reasoning, modeling, prediction, and revision.

The most important constraint to keep in mind is this: epistemic capacity operates on abstract space, but does not define it. Abstract space exists independently, and knowledge exists independently within abstract space. Epistemic capacity does not bring abstract space into existence, does not populate it, and does not determine which abstract structures exist. Epistemic capacity merely determines which abstract structures are accessed, explored, instantiated, or used by a particular empirical system. This distinction must never be blurred, because once epistemic capacity is treated as defining knowledge, the framework collapses into a form of psychologism or constructivism, which the Empirical-Axiomatic Framework explicitly rejects.

Epistemic capacity therefore does not produce knowledge. This must be stated explicitly and repeatedly. Knowledge already exists as abstract structure. What epistemic capacity does is produce new instantiations, selections, combinations, interpretations, or uses of abstract structures within empirical systems. For example, when a mathematician proves a theorem, epistemic capacity does not create the abstract structure itself; rather, it accesses and articulates relations that already exist within abstract space. Similarly, when a physicist formulates a new theory, epistemic capacity selects certain abstract structures, combines them, and deploys them in a representational role. At no point is abstract space itself generated by this activity.

Epistemic capacity is grounded in physical organization and causal processes. In humans, it is instantiated in neural architecture, sensory systems, memory, symbolic manipulation, language, and social communication. In machines, it is instantiated in hardware, algorithms, data structures, and physical computation. In scientific communities, it is distributed across individuals, instruments, mathematical frameworks, and institutional practices. The specific implementation varies, but in all cases epistemic capacity remains a property of empirical systems, not of abstract space.

It is also essential to clarify what epistemic capacity is not. Epistemic capacity is not consciousness, not subjective experience, and not the experiential self. A system can possess epistemic capacity without having any inner experience at all. For example, an automated system that detects patterns, updates parameters, and refines predictions based on data is exercising epistemic capacity, even if it lacks awareness or feeling. Conversely, subjective experience alone does not guarantee epistemic capacity; a system may experience sensations without being able to construct or revise abstract structures. This separation prevents confusion between epistemology and phenomenology.

Another critical point is that epistemic capacity is finite and constrained. Because epistemic capacity is a physical capacity, it is limited by physical resources such as time, energy, memory, computational power, and access to empirical data. Humans have finite lifespans and finite cognitive resources. Machines have finite architectures and operational limits. These constraints do not limit abstract space itself, but they limit which parts of abstract space can be accessed or used by a given system. This finitude explains why epistemic systems never exhaust abstract space and why refinement and exploration continue indefinitely.

Epistemic capacity also explains error, correction, and progress. Because epistemic capacity operates by selecting and using abstract structures under empirical constraint, it can fail. A system may select an abstract structure that, when used representationally, does not align with empirical reality. The ability to detect such failure and revise the selection is a central feature of epistemic capacity. Importantly, this process does not involve changing abstract space; it involves changing which abstract structures are used and how they are used. Abstract space remains unchanged throughout.

The role of mathematics within epistemic capacity is particularly instructive. Mathematics extends epistemic capacity by providing richer abstract structures that can be accessed and deployed. When existing mathematical tools are insufficient to represent observed empirical regularities, epistemic capacity motivates the exploration of new areas of abstract space. This is not because reality demands new abstract structures, but because richer structures allow epistemic systems to construct more effective representational uses. The growth of mathematics is therefore an expansion of epistemic access, not a creation of abstract space.

Epistemic capacity is also non-anthropocentric. There is nothing in its definition that restricts it to humans. Any empirical system with the appropriate physical organization can, in principle, possess epistemic capacity. This includes animals, machines, and hybrid systems. What differs between systems is not the existence of epistemic capacity, but its degree, scope, and form of implementation. This point is essential for treating humans, machines, and other systems within a unified framework.

Finally, epistemic capacity is the mechanism through which abstract knowledge becomes epistemically relevant, but not ontologically altered. When abstract structures are instantiated in reasoning, computation, or modeling, they do not change their ontological status. They remain abstract structures in abstract space. The epistemic system changes its internal states, representations, and behaviors but abstract space remains untouched. This asymmetry must be preserved to maintain coherence.

Within the Empirical-Axiomatic Framework, epistemic capacity is a physical capacity of empirical systems to access, select, instantiate, and use abstract structures that already exist in abstract space. It does not define abstract space, does not create knowledge, and does not determine what abstract structures exist. It operates under empirical and physical constraints and is finite in scope. Understanding epistemic capacity in this precise way allows us to explain how knowledge is accessed and applied without collapsing knowledge into psychology, neuroscience, or social practice, and without violating the strict separation between empirical reality and abstract space. [Pawar, 2026b, Pawar, 2026c, Pawar, 2026a, Pawar, 2026d, Hacking, 1983, Frigg and Hartmann, 2006, Morgan and Morrison, 1999, Dennett, 1991]

5 Representation and Modeling

With empirical reality, abstract space, knowledge, and epistemic capacity clearly separated, we can now carefully introduce representation and modeling. In the Empirical-Axiomatic Framework, representation and modeling are not new ontological domains. They do not introduce new kinds of entities, and they do not modify the nature of knowledge or abstract space. Instead, representation and modeling are epistemic activities specific ways in which epistemic capacity uses abstract structures to relate to empirical reality.

A model is not a special kind of abstract object. It is not a subset of knowledge, and it is not a different category of abstract structure. A model is an epistemic role played by an abstract structure when an epistemic system deploys that structure in relation to an empirical system. The same abstract structure can exist entirely without being a model, and later become a model when it is used representationally. Nothing ontological changes in the abstract structure itself when this happens. Only the epistemic use changes.

This point is critical and must be stated explicitly: models are not ontological entities distinct from abstract structures. There is no separate category called "model-objects" living inside abstract space. There are only abstract structures, and there are epistemic systems that sometimes use those structures to represent empirical reality. The word "model" refers to this use, not to a different kind of thing.

Representation, in this framework, is therefore a relation, not a substance. It is a relation established by epistemic capacity between an abstract structure and an empirical system. This relation is not intrinsic to the abstract structure and not intrinsic to the empirical system. It exists only insofar as an epistemic system actively maps elements of the abstract structure onto aspects of empirical reality. When that mapping is abandoned, representation ceases, but the abstract structure and the empirical system both remain exactly as they were.

Representation also does not require that an abstract structure be "about" reality in its definition. Most abstract structures are not about anything. When an abstract structure is used as a model, it is interpreted under certain rules. These interpretive rules are laid down by the epistemic system, not by abstract space and not by empirical reality itself. For example, when differential equations are used to model motion, the equations themselves do not intrinsically refer to position or time. Those references arise only through an interpretive mapping introduced by epistemic capacity.

The rules that govern representation come from the internal structure of the abstract system combined with epistemic choices. Abstract structures impose constraints on what can be done with them: certain operations are allowed, others are not, because of the internal rules of the structure. Epistemic capacity works within these rules when using an abstract structure as a model. However, the decision to interpret a variable as position, or a function as a field, or an operator as an observable is not dictated by abstract space alone. It is an epistemic act guided by empirical constraints.

Because representation is epistemic and rule-governed, domain validity becomes central. A model is valid only within the domain where the interpretive mapping between abstract structure and empirical reality holds. Outside that domain, the abstract structure does not suddenly become false or incorrect as knowledge. It simply ceases to function successfully as a model. This distinction is essential: failure of representation does not imply failure of the abstract structure itself.

This leads to the important distinction between silence and inconsistency. When an abstract structure, used as a model, makes predictions that contradict empirical observations within its intended domain, it is inconsistent in that representational role. When it simply does not address a phenomenon because the mapping does not apply, it is silent. Silence is not error. It only indicates that the abstract structure is not being used in that representational context. Confusing silence with inconsistency leads to unnecessary rejection of useful models.

The Empirical-Axiomatic Framework also explains why multiple models can coexist for the same empirical system without contradiction. This coexistence does not arise because there are multiple kinds of knowledge or multiple realities. It arises because epistemic capacity can establish different representational relations between different abstract structures and the same empirical system. Each representational use is governed by its own interpretive rules and domain of validity. The abstract structures themselves do not compete; they simply exist. It is the epistemic uses that differ.

Equally important is the fact that the same abstract structure can be used to model multiple empirical systems. This again does not imply anything special about the abstract structure itself. It reflects the generality of abstract rules. For example, the same mathematical structure can be used to represent different physical systems if the epistemic mapping is appropriate. This does not turn the abstract structure into something empirical; it remains abstract throughout.

At no point in this framework does representation alter abstract space or empirical reality. Abstract space remains unchanged regardless of how abstract structures are used. Empirical reality remains unchanged regardless of which models are applied to it. Representation is entirely a feature of epistemic activity occurring within empirical systems that have epistemic capacity.

Finally, it must be emphasized again that representation and modeling are not required for knowledge to exist. Knowledge exists independently in abstract space. Representation is only relevant when an epistemic system aims to understand, predict, or organize empirical reality. This asymmetry must never be reversed. Knowledge does not depend on representation; representation depends on epistemic capacity accessing knowledge.

Within the Empirical-Axiomatic Framework, representation and modeling are epistemic uses of abstract structures, not ontological categories and not subsets of knowledge. Models are abstract structures playing a representational role under interpretive rules established by epistemic capacity. Abstract structures remain unchanged by use, empirical reality remains unchanged by representation, and only epistemic systems undergo change. Maintaining this discipline is essential to preserve the coherence of the framework and to prevent collapse into representationalism or constructivism. [Pawar, 2026b,Pawar, 2026c,Pawar, 2026a,Pawar, 2026d, van Fraassen, 1980,Frigg and Hartmann, 2006,Cartwright, 1983]

6 Physics as a Case Study of Epistemic Capacity

Physics, within the Empirical-Axiomatic Framework, is not treated as the discovery of what knowledge is, nor as the creation of abstract space. Physics is treated as a paradigmatic case study of epistemic capacity in action. What physics shows most clearly is how an epistemic system interacts with empirical reality under constraint, selects abstract structures from abstract space, and uses them as models to represent aspects of the world. Physics is therefore not ontologically foundational in this framework; it is epistemologically instructive.

The empirical world existed before physics. Abstract space existed before physics. Mathematics existed before physics. What physics does is select, apply, and refine abstract structures in response to empirical constraints. This distinction must be maintained throughout this section. Physics does not populate abstract space, does not generate mathematical truth, and does not determine what abstract structures exist. It only determines which abstract structures can successfully function as models within certain empirical domains.

6.1 Why Advanced Mathematics Is Necessary

Before discussing specific physical theories, it is necessary to clarify why the advancement of mathematics is crucial for the advancement of physical models. This point is not optional; it is structurally central to your framework.

Empirical reality exhibits patterns, regularities, and constraints. However, being constrained by reality is not enough to represent it. Representation requires abstract structures with sufficient expressive power. When epistemic capacity encounters empirical phenomena that cannot be captured using existing abstract tools, it does not "discover new reality"; instead, it seeks richer abstract structures within abstract space that can be used representationally.

Advanced mathematics is therefore not an aesthetic choice or a technical luxury. It is a representational necessity. As empirical phenomena become more subtle, more precise, or more structurally complex, simpler abstract structures cease to be adequate. Epistemic capacity then extends its reach into abstract space, accessing more complex mathematical frameworks that already exist abstractly but were not previously used.

Crucially, this does not mean that more advanced mathematics is "closer to reality" in an ontological sense. It means that advanced mathematics provides rules and structures that allow epistemic systems to build models with finer resolution, broader domain validity, or deeper unification. The mathematics itself remains abstract and unchanged; only its epistemic use changes.

6.2 Gödel's Incompleteness and Infinite Axiomatic Extension

At this point, Gödel's incompleteness theorem becomes conceptually essential.Gödel showed that any sufficiently strong formal system specifically, any system capable of expressing arithmetic cannot be both complete and consistent. There will always exist true statements (true within the intended interpretation) that cannot be proven within the system. Importantly, this does not mean the system is flawed. It means that no finite axiomatic system can exhaust all truths expressible within its language.

Within the Empirical-Axiomatic Framework, this has a profound epistemic implication. It means that abstract space admits unending axiomatic extension. One can always add new axioms to a formal system, thereby creating a new formal system with greater expressive power. That new system, in turn, will again be incomplete, allowing further extension. This process has no final endpoint.

When you speak of an "infinite number of axioms," you are not claiming that any single formal system explicitly contains infinitely many axioms. Rather, you are pointing to the fact that there is no principled stopping point to axiomatic refinement. Abstract space allows indefinite extension, and epistemic capacity can, in principle, continue selecting richer and richer structures.

This point is crucial:the openness of mathematics mirrors the openness of epistemic refinement, without implying that abstract space is created by epistemic activity.

6.3 Terminological Clarifications Used in This Section

Before proceeding further, it is necessary to explicitly define certain terms that are introduced or used for the first time in this section. These terms are framework-dependent, meaning their meaning is fixed by the Empirical-Axiomatic Framework and should not be assumed to coincide with how they are used in other philosophical or scientific contexts. Using them without definition would introduce ambiguity and risk collapsing the distinctions carefully established earlier.

The first such term is **advanced mathematics**. In this framework, "advanced mathematics" does not mean mathematics that is closer to reality, more fundamental, or more true in an ontological sense. Advanced mathematics refers strictly to abstract structures with greater expressive capacity, meaning they allow the construction of more complex relations, higher-dimensional structures, infinite degrees of freedom, or more refined internal rules. The term is epistemic and pragmatic, not ontological. Arithmetic, group theory, functional analysis, and category theory all exist equally in abstract space as knowledge. They differ only in how richly they can be used by epistemic capacity for representation. Advanced mathematics is therefore not superior knowledge; it is more flexible abstract structure for epistemic use.

The second term is **refined representation**. Refined representation does not mean that a model becomes identical to reality or that it captures reality completely. Refinement refers to an epistemic process in which an abstract structure, when used representationally, allows finer discrimination of empirical patterns, broader domain validity, or reduced mismatch with empirical constraints. Refinement always occurs at the level of epistemic use, not at the level of abstract space itself. The abstract structure remains unchanged; only the mapping rules and interpretive deployment are refined.

The third term is **empirical limit**. Within the Empirical-Axiomatic Framework, an empirical limit is not a boundary of reality itself. It is a boundary of empirical access available to epistemic systems. An empirical limit arises due to constraints such as finite measurement resolution, finite energy, finite time, instrumental limits, or physical barriers to observation. Crossing an empirical limit does not reveal that "nothing exists beyond it"; it only marks where empirical testing and observation currently cease. Empirical limits are therefore epistemic and practical, not ontological.

Closely related but distinct is the term epistemic saturation. Epistemic saturation refers to a condition in which, given existing empirical limits and available abstract tools, further refinement of models no longer produces empirically distinguishable consequences. This can create the appearance that a theory is final or complete. However, epistemic saturation does not imply that abstract space is exhausted, that representation is complete, or that refinement is impossible in principle. It indicates only that epistemic capacity has reached a plateau relative to current empirical access.

Another important term introduced in this section is **axiomatic extension**. Axiomatic extension refers to the process of adding new axioms to an existing formal system, thereby generating a new formal system with greater expressive power. In this framework, axiomatic extension is understood as movement within abstract space, not as modification of reality. Each axiomatic extension produces a different abstract structure, not a correction of the previous one. This concept is essential for understanding why refinement can continue indefinitely without contradiction.

This leads to the framework-specific meaning of **infinite axiomatic openness**. This term does not mean that any single theory contains infinitely many axioms. It means that there is no principled endpoint to axiomatic extension in abstract space. Gödel's incompleteness theorem guarantees that any sufficiently strong formal system can be extended. Infinite axiomatic openness is therefore a structural feature of abstract space itself, not a claim about human knowledge being infinite or complete.

Finally, the term illusion of finality is used. This refers to the epistemic situation in which a model appears complete because it successfully accounts for all empirically accessible phenomena within current limits. The illusion of finality arises when epistemic saturation is mistaken for ontological completeness. In the Empirical-Axiomatic Framework, this illusion is explicitly rejected. Finality is never established ontologically; it is only experienced epistemically under constraint.

Very important closing clarification

None of the above terms introduce new ontological commitments. They only describe epistemic conditions, limits, and processes as understood within the Empirical-Axiomatic Framework.

They do not alter the definitions of empirical reality, abstract space, knowledge, or epistemic capacity already established.

6.4 Case Study 1:Why Quantum Mechanics Requires More Advanced Mathematics than Classical Mechanics

6.4.1 What Empirical Reality Forced Us to Explain

Empirical observations revealed phenomena that classical mechanics could not represent:

1. Discrete energy levels
2. Interference patterns
3. Measurement disturbance
4. Intrinsic probabilistic outcomes
5. Superposition of states
6. Order-dependence of measurements

These are features of empirical reality, not mathematical artifacts.

6.4.2 Why Classical Mathematics Failed

Classical mechanics relies on mathematical structures that assume:

1. States are points in phase space
2. Physical quantities are real-valued functions
3. All observables commute
4. Evolution is deterministic
5. Measurement does not alter the system

These assumptions are built into the mathematics itself.
Classical mathematics cannot express:

1. Superposition of states
2. Non-commuting observables
3. Probabilities as structural features

This is a structural expressive failure, not a numerical one.

6.4.3 New Mathematics Required

To represent the new empirical structure, epistemic capacity had to select abstract structures that allow:

1. States to be non-point-like
2. Observables to act on states
3. Probabilities to be fundamental

This required:

1. Complex vector spaces
2. Linear algebra (advanced)
3. Inner product spaces
4. Hilbert spaces
5. Operator theory
6. Spectral theory
7. Probability theory (non-classical role)

Key shift:

1. $State \neq pointinspace$
2. State = vector in an abstract space

6.4.4 Core Axioms / Postulates (Conceptual)

Quantum mechanics assumes:

1. State postulate:A system's state is a vector in a Hilbert space.
2. Observable postulate:Physical quantities correspond to operators.
3. Measurement postulate Outcomes follow probabilistic rules tied to operator spectra.
4. Time evolution postulate:States evolve linearly via a differential equation.
5. Non-commutativity:Measurement order matters fundamentally.

6.4.5 Empirical-Axiomatic Framework Insight

1. Empirical reality violated classical representational limits.
2. Epistemic capacity selected new abstract structures.
3. Mathematics enabled the model; it did not decorate it.
4. Quantum mechanics became expressible only after mathematical advancement.

6.5 Case Study 2:Why Quantum Field Theory Requires More Advanced Mathematics than Quantum Mechanics

6.5.1 Limits of Quantum Mechanics

Quantum mechanics assumes:

1. Finite degrees of freedom
2. Fixed particle number
3. External spacetime background

Empirical reality shows:

1. Particle creation and annihilation
2. Fields as fundamental
3. Infinite degrees of freedom
4. Relativistic constraints
5. Quantum mechanics cannot represent these structurally.

6.5.2 What QFT Models Instead

Quantum Field Theory models:

1. Fields rather than particles
2. Interactions as field couplings
3. Vacuum structure
4. Spacetime symmetries
5. Dynamical creation/annihilation processes

6.5.3 Why QM Mathematics Fails

Hilbert spaces in QM:

1. Work for finite systems
2. Break down for fields
3. Cannot control infinities rigorously

This is again a representational failure, not a physical one.

6.5.4 Mathematics Required by QFT

To represent empirical field behavior, epistemic capacity had to select:

1. Infinite-dimensional Hilbert spaces
2. Functional analysis
3. Distribution theory
4. Operator-valued fields
5. Renormalization theory
6. Lie group theory
7. Gauge theory
8. Tensor calculus

Each of these adds new axioms and constraints.

6.5.5 Core Axioms (Conceptual)

QFT assumes:

1. Field primacy:Fields are fundamental; particles are excitations.
2. Relativistic invariance:Physics respects spacetime symmetries.
3. Approximate locality:Interactions are local in spacetime.
4. Infinite degrees of freedom:Fields exist at every spacetime point.
5. Renormalizability:Infinities can be consistently absorbed.

6.5.6 Empirical-Axiomatic Framework Insight

1. Reality demanded infinite-dimensional abstraction.
2. New mathematics was required before coherent modeling.
3. QFT exists only because abstract space offered richer structures.

6.6 Case Study 3:Why Modern Theories (e.g., String Theory) Require Even More Advanced Mathematics

6.6.1 Why QFT Is Still Incomplete

QFT fails to:

1. Include gravity consistently
2. Explain spacetime itself
3. Remain finite at Planck scale

Empirical and theoretical constraints suggest:

1. Spacetime may not be fundamental
2. Geometry may be dynamic
3. Additional dimensions may exist

6.6.2 What Modern Theories Attempt

Modern theories attempt to:

1. Unify forces
2. Quantize gravity
3. Explain spacetime structure
4. Resolve infinities fundamentally

6.6.3 Why QFT Mathematics Fails

QFT assumes:

1. Fixed background spacetime
2. Point-like particles
3. These assumptions break at Planck scale.

6.6.4 Mathematics Required by Modern Theories

Epistemic capacity must now select:

1. Differential geometry
2. Topology
3. Algebraic geometry
4. Category theory
5. Higher-dimensional manifolds
6. Supersymmetry algebras
7. Duality structures
8. Non-perturbative methods

This mathematics goes far beyond QFT.

6.6.5 Core Axioms (Conceptual, Simplified)

Modern theories assume:

1. **Extended fundamental objects**
   Not point particles.
2. **Extra dimensions**
   Hidden spatial dimensions may exist.
3. **Attempted background independence**
   Geometry is dynamical.
4. **Duality**
   Different theories can describe the same physics.

6.6.6 Empirical-Axiomatic Framework Insight

1. Mathematics expands representational space.
2. More axioms $\rightarrow$ more expressive power.
3. Abstract space is never exhausted.
4. No final mathematical structure exists.

Empirical reality repeatedly exhibits structures that existing abstract frameworks cannot represent. Each time this occurs, epistemic capacity must select richer abstract structures requiring new axioms and mathematics before a coherent model can even be stated. Classical mechanics required calculus; quantum mechanics required Hilbert spaces; quantum field theory required infinite-dimensional analysis; modern theories require advanced geometry and topology. This progression is forced by reality, not aesthetic preference. Because abstract space is inexhaustible and empirical access is finite, theoretical refinement has no final endpoint, and a complete theory of everything is impossible in principle.

6.7 What This Case Study Shows

This entire progression from classical mechanics to modern theories illustrates a single, consistent pattern:

1. Abstract space is stable and independent.
2. Knowledge exists independently of physics.
3. Epistemic capacity selects increasingly complex abstract structures.
4. Advanced mathematics enables refined representation.
5. Gödel incompleteness guarantees no final axiomatic closure.
6. Empirical limits create the illusion of finality, not actual completeness.

Physics, therefore, is not a discovery of ultimate knowledge, but a continuous epistemic process operating under constraint, refinement, and finite access. [Pawar, 2026b, Pawar, 2026c, Pawar, 2026a, Goldstein, 2002, Pawar, 2026d, Dirac, 1930, Bell, 1964, Conway, 1990, Peskin and Schroeder, 1995, Rudin, 1976, von Neumann, 1955, Weinberg, 1995, Haag, 1996]

7 Mathematical Advancement as Axiomatic Enrichment and Its Role in Physical Modeling

Within the Empirical-Axiomatic Framework, the advancement of physical theory is inseparable from the advancement of mathematics, not because mathematics is reality, but because mathematics provides the abstract structures through which empirical reality can be represented epistemically. A physical theory is a model, and a model is an epistemic use of an abstract structure. This immediately imposes a structural constraint: no physical theory can represent more structure than its underlying mathematical framework allows. If the mathematics used by a theory cannot express certain relations, constraints, or distinctions that empirical reality exhibits, then the theory is not merely inaccurate it is structurally incapable of representing those aspects of reality at all.

Mathematics itself exists in abstract space and is defined axiomatically. Every mathematical structure is fixed by a set of axioms that specify what objects exist and how they relate. When mathematics "advances," this does not mean that it moves closer to reality in an ontological sense; it means that additional axioms are introduced, new constraints are imposed, and richer abstract structures are defined. In other words, mathematical advancement is axiomatic enrichment. Each enrichment restricts the class of allowed structures while simultaneously increasing expressive power. This process is internal to abstract space and is independent of physics, but physics depends on it epistemically.

Classical mechanics provides the clearest starting point. In its Newtonian formulation, classical mechanics relies primarily on two mathematical frameworks: real analysis and geometrical (physical) vector theory. Real analysis assumes the existence and completeness of the real numbers, the notions of limits, continuity, differentiability, and integrability. These are axiomatic assumptions, not empirical facts. They allow physical quantities to be represented as smooth real-valued functions of space and time, leading naturally to differential equations. Geometrical vector theory adds further axioms: Euclidean space, linearity, vector addition, scalar multiplication, and commutativity. Together, these frameworks encode assumptions such as smooth trajectories, determinism, continuity, finite degrees of freedom, and the commutativity of physical observables. Classical mechanics works where empirical reality approximately satisfies these assumptions, but the assumptions are already built into the mathematics itself.

As empirical access improved, reality began to reveal features that could not be represented within this mathematical structure. Discrete energy levels, interference phenomena, measurement disturbance, intrinsic probabilistic outcomes, and non-commuting observables appeared. Importantly, this was not a matter of classical mathematics giving the wrong numerical answers; it was a matter of classical mathematics lacking the expressive capacity to even state these phenomena coherently. Concepts such as superposition or non-commutativity cannot be represented within a framework where states are points in phase space and observables are commuting real-valued functions. At this stage, further progress in physics was impossible without mathematical enrichment.

Quantum mechanics became possible only because epistemic capacity selected a richer abstract structure: functional analysis. Functional analysis is not merely "harder" mathematics; it is an axiomatic extension of earlier frameworks. It combines real analysis with advanced linear algebra, but crucially adds new axioms and structures: inner products, norms, completeness, infinite-dimensional vector spaces, and linear operators acting on those spaces. Not every vector space has an inner product, not every normed space is complete, and not every operator has a well-defined spectrum. Quantum mechanics requires precisely these additional axioms. States are no longer points in physical space but vectors in an abstract Hilbert space; observables are operators; probabilities arise from inner products; and non-commutativity is structurally encoded. Without these axiomatic enrichments, quantum mechanics is not merely unmotivated it is literally inexpressible.

This pattern continues. Quantum mechanics still assumes finite degrees of freedom, fixed particle number, and an external spacetime background. Empirical and theoretical considerations then reveal phenomena such as particle creation and annihilation, fields as fundamental entities, relativistic invariance, and infinite degrees of freedom. Representing these features requires further axiomatic enrichment, leading to quantum field theory. The mathematics required now includes infinite-dimensional Hilbert spaces, functional analysis in full generality, distribution theory, operator-valued fields, renormalization theory, gauge theory, Lie groups, and tensor calculus. Each of these frameworks introduces new axioms and constraints. Again, physics does not invent these structures; epistemic capacity selects them from abstract space because simpler structures cannot represent the observed constraints.

The same logic applies to modern theories beyond quantum field theory. Attempts to unify interactions, include gravity consistently, or describe physics at the Planck scale encounter structural features that QFT mathematics cannot represent, such as dynamical spacetime geometry, background independence, or extended fundamental objects. Representing these ideas requires even richer axiomatic frameworks, drawing on differential geometry, topology, algebraic geometry, category theory, and related structures. Whether these theories are empirically correct is a separate question. What matters here is the structural point: without further axiomatic enrichment of mathematics, such theories cannot even be coherently formulated.

At this point, the role of Gödel's incompleteness theorem becomes crucial for conceptual clarity. Set theory, which underlies most modern mathematics, is strong enough to encode arithmetic, and therefore Gödel's theorem applies. This guarantees that no axiomatic system of sufficient strength can be complete and that axioms can always be extended. Each extension resolves some previously undecidable truths while introducing new undecidable ones. This establishes what can be called infinite axiomatic openness: the process of mathematical enrichment has no final endpoint in principle. Consequently, the space of possible abstract structures is inexhaustible.

Within the Empirical-Axiomatic Framework, this has a direct implication for physics. Physics is an exercise of epistemic capacity operating under empirical constraints. When empirical reality reveals features that existing models cannot represent, epistemic capacity is forced to select richer abstract structures. As mathematics advances, physics gains access to greater representational power and can construct more accurate models. However, empirical access is finite:

measurement resolution, energy scales, time, and instrumental limits impose hard constraints. Eventually, further mathematical enrichment produces models whose differences cannot be empirically distinguished. This condition is epistemic saturation. From within such a situation, it appears as though a final theory has been reached.

This appearance is an illusion of finality. It arises not because abstract space has been exhausted or because reality has been fully captured, but because epistemic and empirical limits prevent further discrimination. More advanced mathematics always exists in abstract space, and more refined models are always possible in principle, but they may lie beyond empirical reach. Therefore, while increasing axiomatic complexity in mathematics allows physical theories to approach greater accuracy and completeness, there is no point at which a perfect theory of everything is attained.

In summary, the advancement of mathematics enables the advancement of physical theory because mathematical enrichment increases expressive power by adding axioms and constraints. Each enrichment allows epistemic capacity to represent deeper structural features of empirical reality. Because axiomatic extension is unending and empirical access is finite, physical theories can improve indefinitely but can never be complete. This structural relationship not historical accident, aesthetic preference, or metaphysical commitment explains both the success of increasingly advanced physical theories and the impossibility of a final theory of everything. [Pawar, 2026b, Pawar, 2026c, Pawar, 2026a, Pawar, 2026d, Gödel, 1931, von Neumann, 1955, Shapiro, 1997, Enderton, 1977]

7.1 The Asymptotic Knowledge Curve

Important Preliminary Note: This Is an Analogy

1. **Nature of the Graph**
   (a) This graph is a **conceptual analogy**, not a literal empirical measurement.
   (b) It functions as a **visual and mathematical tool** to aid understanding of the relationship between:
   - mathematical development, and
   - our ability to construct accurate physical theories.

   (c) The axes do **not** represent quantities that can be directly measured in standard physical units.
2. **Abstract Character of the Axes**
   (a) Both axes represent **abstract dimensions**, not observable variables.
   (b) These dimensions correspond to:
   - intellectual progress, and
   - epistemic adequacy in theory construction.

X-Axis: Mathematical Advancement / Axiomatic Complexity

1. **What the X-Axis Represents**
   (a) The horizontal axis represents the **richness and sophistication of mathematical structures** available for constructing physical theories.
   (b) This includes:
   - the number of axioms,
   - the depth of abstract structures,
   - the expressive power of mathematical languages,

- the complexity of formalism.

2. **Meaning of Advancement Along the X-Axis**
   (a) Moving rightward corresponds to adopting **more sophisticated mathematical frameworks**.

3. **Representative Positions Along the X-Axis**
   (a) **Early positions (near $x = 0$):**
   - basic arithmetic,
   - Euclidean geometry,
   - simple calculus.

   (b) **Middle positions:**
   - differential geometry,
   - group theory,
   - functional analysis.

   (c) **Far positions (large x):**
   - advanced algebraic topology,
   - category theory,
   - non-commutative geometry,
   - higher-order mathematical structures.

4. **Role of the X-Axis in the Analogy**
   (a) The x-axis captures the idea that **mathematics is an open-ended enterprise**.
   (b) There is no "final" or "complete" mathematical framework.
   (c) Moving rightward provides increasingly powerful tools for describing nature, while the axis itself extends indefinitely.

5. **Key Insight About the X-Axis**
   (a) Mathematics is **unbounded**.
   (b) We can always:
   - construct more axioms,
   - explore new structures,
   - develop richer mathematical languages.

Y-Axis: Accuracy / Completeness of Physical Theory

1. **What the Y-Axis Represents**
   (a) The vertical axis represents how well a physical theory represents **empirical reality**.
   (b) This representation is restricted to domains accessible to **observation and experiment**.
   (c) It measures **epistemic adequacy**: how completely a theory captures observable phenomena.

2. **Meaning of Accuracy / Completeness**
   (a) $y = 0$: no theoretical understanding (a pre-scientific state).

(b) $0 < y < 1$: progressively better theories with increasing explanatory scope and precision.

(c) $y \to 1$: approaching a theory that perfectly accounts for all empirically accessible phenomena.

(d) $y = 1$: a hypothetical **Theory of Everything (TOE)** that is perfect and complete.

3. **Role of the Y-Axis in the Analogy**

(a) The y-axis measures **epistemic success relative to empirical constraints**.

(b) It does **not** represent:

- absolute ontological truth about reality,
- understanding of entities beyond empirical access,
- metaphysical completeness.

4. **Critical Constraint on the Y-Axis**

(a) The y-axis is **bounded above** by $y = 1$.

(b) This bound represents a theoretical maximum of empirical adequacy.

(c) Unlike the x-axis, which extends infinitely, the y-axis has a ceiling.

(d) This ceiling can never actually be reached, even in principle, as indicated by the analogy.

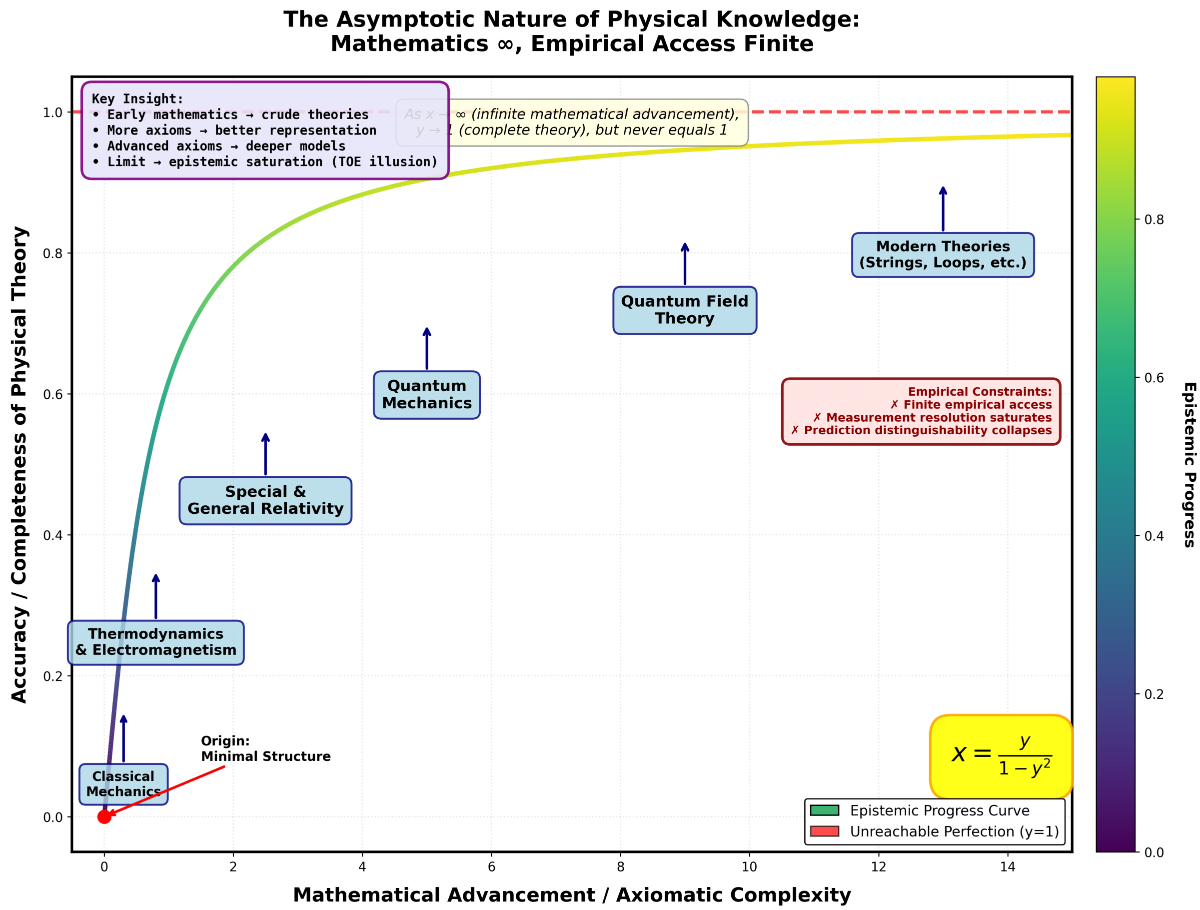

Figure 1: The asymptotic relationship between mathematical advancement and theory completeness.

8 Epistemic Capacity and the Self

This section clarifies the concept of self within the Empirical-Axiomatic Framework. The central aim here is not to introduce a special metaphysical entity, but to remove confusion by applying the same conceptual discipline used in physics to systems traditionally treated as philosophically exceptional. The self is not introduced as a primitive or foundational category. It is an application of the framework to a particular class of empirical systems.

8.1 What the Self Is

In this framework, a self is not a mysterious inner entity. A self is simply a system, treated at two strictly separated levels:

1. Empirical self
2. Axiomatic self

The empirical self is the actual physical system that exists in empirical reality. For a human, this is the living organism: body, brain, nervous system, cells, biochemical processes, and causal organization. This empirical self exists independently of how it is described. It eats, moves, ages, reacts, and interacts whether or not any theory of self exists.

The empirical self is mind-independent, causal, physical, and non-abstract. It is not defined by introspection, language, or narrative. Like all empirical systems, it is selected as a system because it exhibits sufficient causal coherence and organizational continuity to be studied successfully.

8.2 What the Self Is Not

The self, in this framework, is not:

1. a soul
2. a metaphysical substance
3. an inner observer
4. a fundamental ontological primitive
5. something over and above the physical system

There is no additional "self-thing" hidden behind the body. Introducing such an entity would violate the framework's discipline and repeat the same category mistake already resolved in the case of light. [Pawar, 2026d]

8.3 Axiomatic Selves

An axiomatic self is a model-level representation of an empirical self, constructed in abstract space using concepts, assumptions, and mathematics. Axiomatic selves are not entities in reality; they are abstract representations used epistemically.

For a single human empirical self, there exist many axiomatic selves, for example:

1. the biological self
2. the neurological self
3. the cognitive self

4. the experiential self
5. the social self
6. the enlightenable self

Each axiomatic self highlights certain aspects of the same empirical system and ignores others. None of them is identified with the empirical self itself. None of them is complete. None of them has ontological priority.

This vertical multiplicity one empirical self, many axiomatic selves is essential. Without it, explanation collapses into reductionism, where one model is falsely elevated as the "real" self.

8.4 Empirical Multiplicity

Equally important is the reverse relation: one axiomatic self can apply to many empirical selves.

For example:

1. The "biological organism" axiomatic self applies to many animals.
2. The "experiential self" applies to many humans.
3. The "enlightenable self" applies to many humans and potentially to future artificial systems.
4. The "wave model" applies to many light systems.

This Empirical multiplicity is not a bug; it is the entire point of modeling. Axiomatic selves are general templates, not individual fingerprints. Individuality is preserved at the level of the empirical self, not at the level of the model.

8.5 The Experiential Self

The experiential self is a specific axiomatic self that models first-person experience the feeling of being, the "what it is like" aspect of a physical system. It is real as a phenomenon because it is instantiated in physical organization (primarily neural structure), but it is not ontologically fundamental.

Treating the experiential self as a model dissolves traditional confusions about consciousness. The experience is real; the model is abstract; the system is physical. No extra metaphysical layer is required.

The so called "hard problem" arises only when the experiential model is mistakenly treated as a separate substance rather than as a representational framework.

8.6 The Enlightenable Self

The enlightenable self is another axiomatic self. It captures the capacity of a physical system to examine, revise, and improve its own models. This includes abstraction, self-reflection, learning, and meta-cognition.

This capacity is instantiated in physical organization, not in a metaphysical essence. Because it is model-level, it can apply to many empirical systems. This explains how different humans and potentially non-human systems can share this axiomatic self without losing individuality.

8.7 Why This Structure Is Necessary

This framework for the self is not optional. Without it:

1. models are confused with reality
2. experiential descriptions are mistaken for substances
3. individuality and generality are falsely opposed
4. humans are granted unjustified ontological privilege

By applying the same structure used in physics to the self, the framework achieves conceptual unification without reduction. The self becomes clear, not diminished.

A self is a system: one empirical self exists in reality, many axiomatic selves exist as abstract models of it, and the same axiomatic self can apply to many empirical selves; confusing these levels creates philosophical problems, while separating them dissolves them. [Pawar, 2026b, Pawar, 2026c, Pawar, 2026a, Pawar, 2026e, Metzinger, 2003, Dennett, 1991]

9 Limits, Saturation, and the Illusion of Final Knowledge

This section addresses a central consequence of the Empirical-Axiomatic Framework: why theoretical refinement does not terminate, why the idea of a final "theory of everything" arises repeatedly, and why that idea is ultimately an illusion generated by epistemic and empirical limits rather than a reflection of reality or abstract space itself. To understand this clearly, we must distinguish three different kinds of limits that are often conflated: limits of empirical access, limits of epistemic capacity, and the openness of abstract space. Only the first two are real limits; the third is not a limit at all.

Within this framework, all genuine limits are epistemic and empirical, not ontological. Empirical reality does not end where our experiments end. Abstract space does not end where our mathematics ends. What ends, repeatedly, is our capacity to access, test, and distinguish further structure. This distinction is the key to dissolving the illusion of finality.

9.1 What a Limit Is

An **empirical limit** is a boundary on what can be observed, measured, or experimentally tested by an epistemic system. Such limits arise from finite energy, finite resolution, finite time, instrumental constraints, and physical barriers. For example, there are limits to spatial resolution, limits to achievable energies, and limits to isolating systems without disturbing them. These limits constrain what can be empirically distinguished, not what exists.

An **epistemic limit** is a boundary on what an epistemic system can represent, compute, or conceptually manage, given its physical organization. Human cognition, machines, and institutions all have finite memory, finite processing power, and finite lifespans. These limits constrain what abstract structures can be accessed and used, not what abstract structures exist.

It is crucial to state explicitly what limits are not. Limits are not limits of abstract space itself. Abstract space, as the domain of abstract structures, is not constrained by empirical access or cognitive capacity. The existence of mathematical structures does not depend on our ability to reach or use them. Abstract space remains open-ended regardless of epistemic failure or success.

9.2 What Saturation Means

Epistemic saturation occurs when, given current empirical limits and available abstract tools, further refinement of models no longer produces empirically distinguishable consequences. At this point, different theoretical extensions may exist, but they cannot be discriminated by experiment. From within the epistemic situation, it feels as though refinement has reached an endpoint.

However, saturation is not completion. It is not finality. It is a local plateau reached by an epistemic system under constraint. Saturation reflects the alignment between representational power and empirical access, not the exhaustion of reality or abstract space.

This distinction is critical. When saturation is mistaken for completion, the illusion of a final theory arises.

9.3 Why Models Depend on Mathematics (First Principle)

To understand why saturation and illusion of finality arise, we must recall what a model actually is within this framework.

A model is an abstract structure, equipped with an interpretation, used epistemically to represent selected aspects of empirical reality. A model cannot say more than its underlying abstract structure allows. This point is not rhetorical; it is structural.

If the mathematics underlying a model cannot:

1. express a relation,
2. encode a constraint,
3. represent a dependency,
4. or distinguish two empirically different cases,

then no amount of physical intuition, experimental ingenuity, or interpretive cleverness can compensate. The model simply lacks the expressive capacity to track reality at that level. Reality does not simplify itself to fit our mathematics. Our mathematics must expand to track reality.

9.4 Why Reality Forces Mathematical Advancement

Empirical reality exhibits structure: quantities, relations, symmetries, constraints, regularities, discontinuities, probabilistic behavior, and in many cases infinite degrees of freedom. These structures exist independently of our descriptions. Early mathematics captures only coarse structure. Counting leads to integers; ratios lead to rationals; basic geometry leads to simple motion.

This is why classical mechanics could exist at all. Its mathematics silently assumes smooth trajectories, determinism, separability, and absolute time. These assumptions were not metaphysical discoveries; they were consequences of limited expressive tools that happened to work within a restricted empirical domain.

As empirical access improved, reality violated those assumptions. Discrete spectra, probabilistic outcomes, non-commutativity, superposition, and measurement disturbance appeared. Classical mathematics cannot even express these phenomena, let alone represent them coherently. At that point, mathematical advancement becomes mandatory, not optional.

9.5 The Mechanism: How Mathematics Enables Better Models

The advancement of mathematics enables better models through a precise mechanism, not by historical accident.

First, expressive power increases. New mathematics allows new kinds of relations and constraints to be represented. Hilbert spaces allow states that are not points in space. Operator algebra allows non-commuting observables. Functional analysis allows infinite-dimensional structures. Without these, quantum mechanics and quantum field theory are literally inexpressible.

Second, representational resolution increases. Advanced mathematics allows finer distinctions: discrete versus continuous, local versus global, deterministic versus probabilistic, finite versus infinite degrees of freedom. Probability theory, for example, does not merely add uncertainty; it allows uncertainty to be represented structurally rather than as ignorance.

Third, new interpretive spaces open. Mathematics creates new abstract environments in which reality can be interpreted. Before functional analysis, fields were intuitive notions. After it, fields become rigorously defined entities with infinite degrees of freedom, making quantum field theory possible.

In all three cases, mathematics does not force reality to behave differently. It allows epistemic systems to see what reality was already doing.

9.6 Why Advanced Physical Theories Require Advanced Mathematics

This mechanism explains, logically and not merely historically, why physical theories require increasingly advanced mathematics.

Classical mechanics requires calculus and differential equations because it represents smooth, deterministic motion. Quantum mechanics requires linear algebra, Hilbert spaces, operator theory, and probability because reality exhibits superposition, non-commutativity, and probabilistic outcomes. Quantum field theory requires functional analysis, distributions, gauge theory, and renormalization because reality exhibits fields with infinite degrees of freedom and particle creation and annihilation.

In each case, the mathematics is not decoration. Without it, the theory cannot even be stated.

9.7 Mathematical Advancement and Infinite Axiomatic Openness

Advancement in mathematics means introducing new axioms, extending formal systems, and defining new abstract structures. Gödel's incompleteness theorem guarantees that this process has no final endpoint. Any sufficiently strong formal system can be extended; each extension resolves some truths and generates new undecidable ones.

This is exactly what you mean by infinite axiomatic openness. It does not mean that any single theory contains infinitely many axioms. It means there is no principled stopping point to axiomatic extension in abstract space. Mathematical advancement is therefore unending in principle, even though epistemic access to it is finite.

9.8 Why This Does Not Collapse into "Mathematics = Reality"

It is crucial to restate what this framework does not claim. It does not claim that reality is mathematics, that mathematics causes reality, or that all abstract structures are physical. It claims that reality has structure, mathematics provides abstract representations of structure, and better mathematics enables better representation.

Representation is not identity. Abstract space remains abstract. Empirical reality remains empirical. Epistemic capacity mediates between them.

9.9 The Illusion of Finality

The illusion of finality arises when epistemic saturation is mistaken for ontological completion. When a theory explains all phenomena accessible within current empirical limits, it feels complete. But this feeling reflects the alignment of representational power with empirical access, not the exhaustion of reality or abstract space.

Because empirical access is finite and abstract space is open-ended, refinement has no final endpoint. Theories improve, domains expand, assumptions shift, and mathematics advances. Finality is never achieved; it is only experienced locally.

9.10 Final Synthesis

Reality exhibits structural complexity that cannot be exhausted by any finite representational framework. Mathematics provides the abstract structures through which models are constructed. As empirical reality reveals constraints that existing mathematics cannot express, new mathematical structures become necessary. Each mathematical advancement expands the representational capacity of models, enabling more accurate but never complete approximations of reality. Because mathematical extension is unending and empirical access is finite, theoretical refinement has no final endpoint, and the theory of everything remains an epistemic illusion rather than an attainable goal. [Pawar, 2026b, Pawar, 2026c, Pawar, 2026a, Pawar, 2026d, Gödel, 1931, Wilson, 1971, Anderson, 1972]

10 Conclusion

This paper has developed the Empirical-Axiomatic Framework to clarify the relationship between empirical reality, abstract space, knowledge, epistemic capacity, and representation. The central distinction is strict and non-negotiable: empirical reality is physical, causal, and mind-independent, while knowledge consists of abstract structures that exist in abstract space independently of their use, interpretation, or discovery. Knowledge is not representation, not activity, and not epistemic success; it is the totality of abstract structures themselves. Representation arises only when a physical system with epistemic capacity selects and applies an abstract structure under interpretive rules to model some aspect of empirical reality.

Epistemic capacity is treated as an empirical property of physical systems, instantiated in finite, causally constrained organizations such as biological brains or artificial machines. It does not create knowledge, define abstract space, or determine which structures exist. Its role is limited to selection, instantiation, and use. Physics is therefore not the discovery of knowledge itself nor the construction of abstract space, but a paradigmatic exercise of epistemic capacity operating under empirical constraint. The historical progression from classical mechanics to quantum mechanics, quantum field theory, and modern theoretical frameworks exemplifies how epistemic capacity must continually select richer abstract structures as empirical reality reveals features that existing mathematics cannot represent.

Mathematical advancement is shown to be axiomatic enrichment: the introduction of new axioms and structures that expand expressive power. This process is unending in principle, as guaranteed by Gödel's incompleteness for sufficiently strong formal systems. Consequently, physical models can become increasingly accurate without ever becoming complete. Empirical limits impose saturation points beyond which further theoretical refinement cannot be experimentally discriminated, producing the illusion of finality and motivating the false idea of a theory of everything. This illusion reflects epistemic and empirical constraints, not exhaustion of abstract space or closure of reality.

The same structural framework applies to the concept of self. A single empirical self a physical system admits multiple axiomatic selves as models, while a single axiomatic self may apply to multiple empirical systems. Experiential and enlightenable selves are treated as model-level descriptions instantiated in physical organization, not as metaphysically fundamental entities. By enforcing a strict separation between empirical reality and abstract representation, long-standing confusions in philosophy of science, epistemology, and philosophy of mind are dissolved without denying the reality of experience, the success of science, or the meaningfulness of normative commitments.

In summary, the Empirical-Axiomatic Framework shows that epistemic progress is real, open-ended, and constrained; knowledge is inexhaustible; models are necessarily incomplete; and final theories are structurally impossible. What science achieves is not ontological closure, but ever improving representational alignment between abstract structure and empirical constraint an achievement that remains profound precisely because it is never final. [Pawar, 2026b, Pawar, 2026c, Pawar, 2026a, Pawar, 2026d, Pawar, 2026e, van Fraassen, 1980, Gödel, 1931, Cartwright, 1983, Morgan and Morrison, 1999]

Appendix

Appendix A:Terminologies used in the Empirical-Axiomatic Framework

1. **Empirical Reality**

   Empirical reality refers to everything that exists independently of description, theory, language, mathematics, or any epistemic agent. It is physical, causal, mind-independent, and it constrains what can succeed epistemically, regardless of whether it is understood or modeled. Empirical reality is not knowledge, not abstract, not axiomatic, and not representational. It does not consist of equations, theories, or descriptions, and it does not depend on human cognition for its existence. This distinction is necessary because failed models do not erase reality; reality persists even when theories are wrong. Examples include electrons, photons, bodies, brains, light propagation, ecosystems, stars, and all physical phenomena.

2. **System**

   A system is a portion of empirical reality that is selected for study because it exhibits causal coherence and organizational stability. Systems are not naturally labeled or pre-partitioned by reality itself; rather, epistemic agents select systems because modeling them works. A system is not defined by a model, nor is it identical to any particular description. This concept is necessary because scientific practice always involves carving reality into tractable units without assuming that nature itself comes pre-divided. Examples include a human organism, a beam of light, a river, a flame, or a single photon when isolated for study.

3. **Empirical Self**

   An empirical self is a system in empirical reality treated as a unified object of study, possessing causal and organizational continuity. The term “self” here is system-relative and does not imply consciousness, subjectivity, or agency. An empirical self is not a soul, not an axiomatic structure, and not a model. This definition is required to remove anthropocentrism and to allow the same conceptual framework to apply to humans, light, particles, and other systems. Examples include a human body, light as a physical phenomenon, or a photon treated as an isolated system.

4. **Organizational Continuity**

   Organizational continuity refers to the persistence of a system over time based on maintained organization and causal pattern rather than on the sameness of material constituents. It is not identity through fixed atoms or components. This concept is necessary because many real systems persist despite continuous material turnover. Human bodies replace atoms, rivers exchange water molecules, and flames consume fuel, yet each remains the same empirical system due to preserved organization and causal coherence.

5. **Abstract Space**

   Abstract space is the domain in which abstract structures exist, including mathematics, logic, formal systems, theories, and conceptual frameworks. It is not physical space, not spacetime, not causal, not energetic, and not empirical. Abstract entities do not interact causally with the world, yet they are real as abstractions. This distinction is necessary to prevent confusion between representation and reality. Examples of abstract space include set theory, group theory, Hilbert spaces, differential geometry, and logical systems.

6. **Knowledge**

   Knowledge, within this framework, is the totality of abstract structures that exist in abstract space, independently of use, discovery, or representation. Knowledge does not require an epistemic agent to exist, and it is not created by epistemic activity. It is not identical to models, representations, or theories-in-use. This definition is required to explain why mathematical structures exist regardless of whether anyone has discovered or applied them. Examples include group theory, number theory, functional analysis, and abstract mathematical structures that have never been used to model the physical world.

7. **Abstract Structure**

   An abstract structure is a formally defined set of relations, rules, and constraints that exists in abstract space. It is not empirical, not causal, and not physical. Abstract structures are necessary because models require rule-governed frameworks to function coherently. Examples include vector spaces, operators, manifolds, probability spaces, and algebraic systems.

8. **Axiom**

   An axiom is a foundational assumption that defines an abstract structure and fixes its internal rules. An axiom is not an empirical fact and not a physical law. It is required to ensure internal consistency and coherence of abstract systems. Examples include the axioms of group theory, the axioms defining Hilbert spaces, and the foundational assumptions of set theory.

9. **Infinite Axiomatic Openness**

   Infinite axiomatic openness is the property that no formal system strong enough to describe arithmetic can be complete, and that axioms can always be extended. It does not mean that any single theory contains infinitely many axioms. This concept is necessary to explain why mathematical advancement never terminates in principle. Examples include the continual extension of set theory and the development of new mathematical frameworks beyond existing ones.

10. **Gödel's Incompleteness Theorem (Framework Usage)**

    Within this framework, Gödel's incompleteness theorem refers to the result that any sufficiently strong formal system contains true but unprovable statements. It is not a limitation of reality itself. It explains why no mathematical framework can be final and why axiomatic extension is always possible. Examples include unprovable arithmetic truths that require new axioms for resolution.

11. **Epistemic Capacity**

Epistemic capacity is the physical capacity of a system to select, instantiate, interpret, and use abstract structures. It does not create knowledge or abstract space. This distinction is necessary because knowledge exists independently, while epistemic agents merely access and use it. Examples include human cognition, scientific institutions, and machines capable of formal reasoning and model construction.

12. **Representation**

    Representation is an epistemic relation between an abstract structure and an empirical system. It is not intrinsic to abstract space or empirical reality alone. Representation exists only through epistemic activity. This concept is required to explain how models connect abstract rules to physical systems. Examples include equations representing motion or operators representing observables.

13. **Model**

    A model is an abstract structure used epistemically to represent selected aspects of empirical reality. It is not reality itself and not a subset of knowledge. A model is a role an abstract structure plays in epistemic practice. This definition is required to avoid identifying models with the systems they describe. Examples include classical mechanics, quantum mechanics, and quantum field theory.

14. **Domain of Validity**

    The domain of validity is the range of conditions under which a model's representational rules succeed. It is not a claim of universal truth. This concept is necessary because all models are limited by their assumptions. Examples include classical mechanics at low speeds or ray optics at large length scales.

15. **Silence vs. Inconsistency**

    Silence refers to a model not addressing a phenomenon, while inconsistency refers to a model contradicting observation within its domain. Silence is not error. This distinction is necessary to prevent the false rejection of valid models. For example, ray optics is silent about interference but not wrong where it applies.

16. **Axiomatic Self**

    An axiomatic self is a model-level representation of an empirical self constructed in abstract space. It is not the empirical self itself. This distinction is required because multiple models can represent the same system. Examples include the biological self, experiential self, or the wave model of light.

17. **Axiomatic Multiplicity**

    Axiomatic multiplicity refers to one empirical self having multiple axiomatic selves. It is not the existence of multiple realities. This concept is required because different aspects of a system require different models. A human can simultaneously be modeled biologically, cognitively, and experientially.

18. **Empirical Multiplicity**

    Empirical multiplicity refers to one axiomatic self applying to multiple empirical selves. It is not a loss of individuality. This concept is required because models generalize across systems. For example, the wave model applies to many light systems.

19. **Experiential Self**

    The experiential self is an axiomatic self modeling first-person experience. It is not a metaphysical substance or ontologically fundamental entity. This definition is required to treat experience as real without introducing dualism. Examples include the sense of “I” and subjective experience.

20. **Enlightenable Self**

    The enlightenable self is an axiomatic self capturing a system’s capacity for self-reflection, abstraction, and model revision. It is not a spiritual essence. This concept is necessary to explain meta-cognition structurally. Examples include humans and potentially advanced artificial systems.

21. **Empirical Limit**

    An empirical limit is a boundary on experimental access, not on reality itself. It is not an ontological limit. This concept is required because measurement is physically constrained. Examples include resolution limits, energy limits, and Planck-scale constraints.

22. **Epistemic Saturation**

    Epistemic saturation is a condition in which further refinement of models yields no empirically distinguishable outcomes. It is not completion or final truth. This concept explains why theories can feel final while remaining incomplete. Examples include highly successful but non-final physical theories.

23. **Illusion of Finality**

    The illusion of finality is the mistake of treating epistemic saturation as ontological completeness. It is not actual final truth. This concept is required to explain repeated historical claims of “final theories.” Examples include claims of a completed theory of everything.

24. **Advanced Mathematics (Framework Usage)**

    Advanced mathematics refers to abstract structures with greater expressive power. It is not “closer to reality” in an ontological sense. This concept is required because reality exhibits structures that require richer abstraction to represent. Examples include Hilbert spaces, functional analysis, and topology.

25. **Expressive Power**

    Expressive power is the capacity of a mathematical framework to encode relations, constraints, and distinctions. It is not aesthetic complexity. This concept is required because models cannot exceed the expressive capacity of their mathematical language. Examples include operators versus functions.

26. **Theory of Everything (Framework Interpretation)**

    Within this framework, a theory of everything is an epistemic illusion arising from saturation. It is not achievable in principle. This definition is required because abstract space is open-ended while empirical access is finite. Examples include repeated claims of final physical theories. [Pawar, 2026b, Pawar, 2026c, Pawar, 2026a, Pawar, 2026d, Pawar, 2026e, Gödel, 1931]

Appendix B: Advancement of Mathematics and Physical Models

Table 1: Advancement of Mathematics and Physical Models: Part I [Pawar, 2026b, Pawar, 2026c, Pawar, 2026a, Pawar, 2026d]

Aspect	**Classical Mechanics**	**Quantum Mechanics**
What reality is assumed to be	Macroscopic objects with definite positions and velocities	Microscopic systems with probabilistic outcomes and superposition
Ontology (what exists fundamentally)	Particles	Quantum states
Nature of physical state	Point in phase space	Vector in Hilbert space
Determinism	Fully deterministic	Fundamentally probabilistic
Measurement	Passive (does not affect system)	Active (disturbs system)
Degrees of freedom	Finite	Finite (usually)
Key failure of previous theory		Cannot explain atomic stability, spectra
Why new mathematics was needed		Classical math cannot express superposition or non-commutativity
Core mathematical framework	Calculus, differential equations, Euclidean geometry	Linear algebra, Hilbert spaces, operator theory, probability
Nature of abstraction	Functions on space and time	Abstract state space
Role of axioms	Few, intuitive	More axioms, abstract
Mathematical complexity	Low to moderate	High
Empirical success domain	Macroscopic, low-speed	Atomic and subatomic scales
Is the model complete?	No	No
What this framework shows	Limited abstraction → limited accuracy	More abstraction → better accuracy

Table 2: Advancement of Mathematics and Physical Models: Part II [Pawar, 2026b, Pawar, 2026c, Pawar, 2026a, Pawar, 2026d]

Aspect	**Quantum Field Theory (QFT)**	**Modern Theories (String, etc.)**
What reality is assumed to be	Fields as fundamental entities; particles as excitations	Extended objects; spacetime itself may be emergent
Ontology (what exists fundamentally)	Quantum fields	Strings, branes, higher-dimensional structures
Nature of physical state	State in infinite-dimensional field space	Geometric/topological object in higher-dimensional space
Determinism	Probabilistic with relativistic constraints	Often probabilistic, sometimes dual descriptions
Measurement	Field interactions, vacuum effects	Not fully understood
Degrees of freedom	Infinite	Often infinite + extra dimensions
Key failure of previous theory	Cannot include particle creation or relativity fully	Cannot include gravity consistently
Why new mathematics was needed	QM math cannot handle infinite degrees of freedom	QFT math fails at Planck scale
Core mathematical framework	Functional analysis, distribution theory, gauge theory, Lie groups	Differential geometry, topology, algebraic geometry, category theory
Nature of abstraction	Operator-valued fields	Geometry beyond physical intuition
Role of axioms	Many axioms, highly abstract	Extremely many, mathematically sophisticated
Mathematical complexity	Very high	Extreme
Empirical success domain	High-energy particle physics	Mostly untested / partially tested
Is the model complete?	No	No (even in principle)
What this framework shows	More axioms $\rightarrow$ broader applicability	No endpoint to refinement

Appendix C: Case Study II: Light

Table 3: Evolution of Models of Light and Mathematical Advancement [Pawar, 2026b, Pawar, 2026c, Pawar, 2026a, Pawar, 2026d]

Aspect	**Ray Optics**	**Wave Optics**	**EM Theory**	**Quantum Theory**	**QFT (QED)**
Primary question addressed	How does light propagate?	How does light interfere and diffract?	What *is* light physically?	How does light interact with matter microscopically?	What is light at the most fundamental level?
Ontological picture	Light as rays	Light as a wave	Light as electromagnetic field	Light as photons	Light as quantized field
Core assumption about light	Travels in straight lines	Is a continuous wave	Is an oscillating field	Comes in discrete quanta	Is an excitation of a field
Key phenomena explained	Reflection, refraction	Interference, diffraction	Polarization, propagation speed	Photoelectric effect, spectra	Particle creation, vacuum effects
Key phenomena NOT explained	Interference, diffraction	Photoelectric effect	Atomic spectra, quantization	Relativistic particle creation	(Still incomplete: gravity, Planck scale)
Mathematics required	Geometry, trigonometry	Partial differential equations	Vector calculus, field theory	Hilbert spaces, operators, probability	Functional analysis, gauge theory
Nature of mathematical objects	Lines and angles	Continuous wave functions	Vector fields	Operators on states	Operator-valued fields
Degree of abstraction	Low	Moderate	High	Very high	Extreme
Number of axioms/assumptions	Very few	More (wave postulates)	Many (field equations)	More (quantization, measurement)	Very many (symmetry, renormalization)
Why previous model failed	Cannot explain wave effects	Cannot explain energy quantization	Cannot explain discrete interactions	Cannot handle creation/annihilation	Still incomplete
Why new mathematics was needed	Geometry insufficient	Classical waves insufficient	Fields require vector calculus	Fields must be quantized	Infinite degrees of freedom
Empirical domain of success	Macroscopic optics	Classical optics	Classical EM phenomena	Microscopic light–matter interaction	High-energy physics
Status in this framework	Coarse approximation	Refined approximation	Structural improvement	Deeper abstraction	Still not final

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