The Principle of Conditional Provability: Constraints, Evidence, and Scientific Knowledge

Rameez Ali Khan[1]

[1]Scientific Officer
Institute: National Test House, India

Publication Date: 2026/01/01

Abstract: Scientific verification often lags behind theoretical prediction, raising fundamental questions about when and how phenomena become provable. This paper proposes the *Principle of Conditional Provability (PCP)*, which asserts that an event can be verified only when the constraints limiting its detection—both intrinsic (inherent to the event) and extrinsic (technological, methodological, or theoretical)—are sufficiently reduced. Conditional proofs are therefore context-dependent subsets of an idealized *absolute proof*, and the timing or absence of verification reflects epistemic and practical limitations rather than the non-existence of phenomena. Historical examples, including gravitational waves, exoplanets, the Higgs boson, and *Helicobacter pylori*, illustrate how constraint accessibility governs the appearance of proof. PCP complements existing frameworks such as Popperian falsifiability, Lakatosian research programs, and Bayesian inference by explicitly linking proof to the interplay of constraints, offering a predictive lens for frontier science. This principle formalizes the contingent and dynamic nature of scientific verification, clarifying methodology, guiding experimental design, and reframing non-detection as a reflection of accessibility rather than absence.

Keywords: *Conditional Provability; Intrinsic Constraints; Extrinsic Constraints; Scientific Methodology; Proof and Verification; Absolute Proof; Epistemic Accessibility.*

How to Cite: Rameez Ali Khan (2025) The Principle of Conditional Provability: Constraints, Evidence, and Scientific Knowledge. *International Journal of Innovative Science and Research Technology*, 10(12), 2052-2057. https://doi.org/10.38124/ijisrt/25dec1470

I. INTRODUCTION: PROOF, NON-DETECTION, AND SCIENTIFIC KNOWLEDGE

Scientific discovery often precedes direct empirical verification. Phenomena such as atoms, neutrinos, black holes, gravitational waves, and dark matter were theorized long before they could be directly observed. This recurring pattern raises a central epistemic question: *What determines when an event can be scientifically verified?*

Traditional scientific reasoning sometimes conflates non-detection with non-existence, particularly when technological, methodological, or theoretical limitations persist. Yet historical experience shows that verification often depends not on the emergence of new phenomena, but on the relaxation of practical constraints.

This paper introduces the *Principle of Conditional Provability (PCP)*, which formalizes this insight. PCP asserts that an event can be proven only when the constraints preventing its verification—both intrinsic constraints (inherent to the event itself) and extrinsic constraints (limitations of knowledge, technology, theory, or methodology)—are sufficiently reduced. Conditional proofs are thus subsets of an idealized *absolute proof*, representing what is accessible under current conditions rather than the totality of what could, in principle, be verified.

By explicitly distinguishing between *existence* and *provability*, PCP addresses a critical gap in scientific methodology. It clarifies why some proofs are historically delayed, why sudden verification occurs without ontological emergence, and how probabilistic reasoning can be integrated with practical limitations. This framework complements established epistemic approaches—Popperian falsifiability, Lakatosian research programs, and Bayesian inference—while offering a systematic method for predicting when phenomena may become verifiable.

The following sections define the principle rigorously, illustrate it with historical and contemporary case studies, and discuss its implications for scientific methodology, experiment design, and frontier research planning.

II. THE PRINCIPLE OF CONDITIONAL PROVABILITY (PCP)

An event can be proven only when the constraints preventing verification are sufficiently reduced or removed. These constraints are of two types:

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25dec1470

- Intrinsic constraints — inseparable properties of the event that determine how it interacts with possible verification methods. Intrinsic constraints are dynamic; their effective resistance to proof may vary depending on context and perturbation of extrinsic constraints.
- Extrinsic constraints — epistemic, technological, methodological, and theoretical limitations that can be actively altered by investigators.

Any proof sought in practice corresponds to a subset of the event's absolute proof, determined by intrinsic and extrinsic constraints. Conditional provability concerns what is actually accessible under current conditions, not the ontological existence of the event.

The principle is compatible with probabilistic reasoning and degrees of belief: while confidence in a hypothesis may grow based on partial evidence, the principle delineates which proofs are possible given intrinsic constraints and how extrinsic interventions enable verification.

PCP differs from accessibility-based or epistemic structural frameworks because it formally models the interplay of intrinsic and extrinsic constraints, predicts *when proof becomes possible*, and provides actionable guidance for experimental design, rather than just characterizing epistemic limitations qualitatively. While epistemic structural realism identifies what aspects of reality are knowable in principle, PCP predicts when and under what constraints phenomena become verifiable. Unlike context-dependent verification, which is mostly qualitative, PCP formalizes the interplay of intrinsic and extrinsic constraints, linking epistemology directly to experimental accessibility. In short, PCP moves beyond descriptive accounts to a predictive framework for the timing and feasibility of proof.

III. WHY THE PRINCIPLE IS NON-TRIVIAL

Explicitly distinguishing between proof and existence provides methodological clarity. Scientific reasoning frequently slides from non-detection to non-existence, particularly when constraints are not clearly identified. By formalizing this distinction, the principle explains why proof may be delayed or appear suddenly without implying the event itself changes or emerges.

IV. CONCEPTUAL CLARIFICATIONS

A. Event

Any occurrence, entity, or process that exists in reality, regardless of observability.

B. Proof

Justified verification or evidence accepted within a scientific framework, contingent on available methods and standards.

C. Absolute Proof

Absolute Proof is a theoretical, idealized verification that would hold independently of current technological, methodological, or epistemic limitations. Conditional Proof, by contrast, is what can actually be demonstrated under existing intrinsic and extrinsic constraints.

- ➢ Example: Consider measuring the velocity of a particle. In Newtonian mechanics, velocities are simply additive—a conditional proof valid under everyday conditions. However, at relativistic speeds, this additive rule fails, and proof of velocity addition must account for special relativity. Here, the intrinsic constraints (high-speed particle behavior) and extrinsic constraints (measurement tools, theoretical understanding) determine when conditional proof aligns with absolute proof.

D. Constraint

A factor that limits or prevents verification. Constraints include technological limitations, theoretical incompleteness, environmental interference, methodological gaps, or epistemic boundaries.

E. Intrinsic and Extrinsic Constraints: Dynamism and Accessibility

Constraints are divided into intrinsic and extrinsic types. Intrinsic constraints are inherent properties of the event that further govern how they can interact with verification methods. These are dynamic, varying with context, time, and interactions with external agents. They do not imply changes in the event's existence but in the effective accessibility of the event for proof.

Extrinsic constraints are limitations imposed by our epistemic situation, such as technology, theory, or methodology. Perturbations to these constraints can reduce intrinsic resistance.

This relational understanding explains why some proofs appear historically contingent. Proof is possible only when the dynamic intrinsic constraints align with sufficiently relaxed extrinsic constraints.

- ➢ *Example:* We know from second law of motion that force is proportional to acceleration. But it can only be measured i.e. proof exists if the applied force (External perturbation) exceeds the static momentum (Intrinsic constraints) of the particle.

V. MATHEMATICAL INTERPRETATION

A. Notation and Definitions

Let's denote:

- E - The event or phenomenon to be verified.
- C_i - Intrinsic constraints of the event (e.g., rarity, subtlety, temporal/transient properties).
- C_e - Extrinsic constraints (technological, methodological, theoretical limitations).
- $P_c(E)$ - Conditional provability, i.e., the degree to which EEE can be verified under current constraints.

We want $P_c(E) \in [0, 1]$ where:

- $0 \rightarrow$ proof is completely inaccessible

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25dec1470

- 1 → full (absolute) proof is achievable under current constraints

B. Constraint Function

We can define constraint functions for intrinsic and extrinsic constraints:

$f_i(C_i) \in [0,1]$ (resistance due to intrinsic constraints)
$f_e(C_e) \in [0,1]$(resistance due to extrinsic constraints)

- Both f_i and f_e increase with difficulty.
  - $f_i = 1 \rightarrow$ intrinsic constraints make proof impossible.
  - $f_i = 0 \rightarrow$ intrinsic constraints impose no barrier.

C. Conditional Provability Function

A simple formalization, which can be modified further, is-

$P_c\,(E) = 1-f_i(C_i)\cdot f_e(C_e))$

- If either f_i or f_e is high (close to 1), $P_c(E)$ is low.
- If both constraints are low, $P_c\,(E)$ approaches 1 (proof accessible).

➢ *Properties:*

- $P_c(E)=0$ if $f_i=1$ and $f_e=1$ (intrinsic + extrinsic barriers maximal)
- $P_c(E)=1$if $f_i=0$ or $f_e=0$ (no barrier on at least one side)
- Monotonicity: Reducing either intrinsic or extrinsic constraints increases $P_c(E)$

VI. THEORIES

➢ *Comparison with Other Theories*

The following comparison situates the Principle of Conditional Provability within well-established epistemic frameworks, highlighting its novelty and practical relevance. While Popperian falsifiability emphasizes in-principle testability, Lakatosian research programs focus on historical corroboration of predictions, and Bayesian epistemology addresses probabilistic belief updates, conditional provability explicitly accounts for the real-world constraints that enable or limit verification. By clarifying when proof becomes accessible, this principle complements and extends traditional approaches, offering a more general framework that integrates logical, historical, and probabilistic perspectives while directly linking them to practical conditions of scientific investigation.

Table-1: Relation of Different Frameworks to Conditional Provability

Framework	Focus	Relation to Conditional Provability	Example
Popperian Falsifiability	In-principle testability of theories.	Highlights practical accessibility: a falsifiable hypothesis may remain unprovable until constraints are relaxed.	Gravitational waves: falsifiable since 1916, verified only in 2015 with advanced detectors.
Lakatosian Research Programs	Historical progress via novel, corroborated predictions.	Explains delayed corroboration due to intrinsic/extrinsic constraints rather than theory failure.	Higgs boson: predicted decades before verification; proof required LHC technology.
Bayesian Epistemology	Probabilistic belief updating based on evidence.	Constraints limit available evidence; conditional provability clarifies when updates are actionable.	Dark matter: non-detection maintains prior uncertainty because detectors are not yet sensitive enough.
Conditional Provability (This Work)	Condition-dependent proof; verification requires constraints to be sufficiently reduced.	Complements other frameworks by linking epistemic principles to real-world verification conditions; guides research planning.	Exoplanets: detected only once telescopes and observational methods overcame constraints.

➢ *Comment on Generalization:*

The Principle of Conditional Provability can be viewed as a more generalized epistemic framework because it unifies insights from falsifiability, research programs, and probabilistic reasoning while explicitly addressing the dynamic interplay of intrinsic and extrinsic constraints. Unlike previous approaches, it provides a systematic method for predicting when and how proof becomes possible, guiding both the interpretation of historical results and the planning of future scientific investigations.

VII. CASE STUDIES ILLUSTRATING CONDITIONAL PROVABILITY

The Principle of Conditional Provability can be illustrated across diverse scientific domains, showing how proof depends on the interplay of intrinsic and extrinsic constraints rather than the existence of the phenomenon itself. Historical examples from physics, astronomy, and biology demonstrate that verification may be delayed or appear sudden, depending on when constraints are sufficiently reduced. The following case studies highlight how this principle explains the timing of scientific proof in non-obvious, non-tautological ways.

➢ *Higgs Boson Detection*

- Event: The Higgs boson exists and gives mass to particles.
- Intrinsic Constraint: Extremely short lifetime (~10^-22 seconds) and rare production in collisions make direct detection almost impossible.
- Extrinsic Constraint: Particle accelerators and detectors before the 21st century were insufficiently powerful or precise.
- Conditional Provability Insight: *The principle predicts that proof would only be possible when accelerators*

reach sufficient energy and detectors have enough sensitivity to observe decay products.

- Historical Outcome: Higgs discovery in 2012 at the LHC matches this prediction—proof was delayed by extrinsic constraints, not non-existence.

➢ *Exo-planet Detection*

- Event: Planets orbiting stars beyond the Sun exist.
- Intrinsic Constraint: Planets are faint and close to bright host stars, making them hard to observe directly.
- Extrinsic Constraint: Early telescopes lacked the resolution, and methods like radial velocity or transit photometry were undeveloped.
- Conditional Provability Insight: *The principle explains why direct detection lagged decades behind theoretical prediction, and predicts which observational advances would finally allow discovery.*
- Historical Outcome: First confirmed exoplanet around a main-sequence star (1995) was detected once extrinsic constraints (sensitive spectrographs) sufficiently relaxed.

➢ *Discovery of Helicobacter pylori as a Cause of Stomach Ulcers*

- Event: Helicobacter pylori bacteria cause most peptic ulcers.
- Intrinsic Constraint: H. pylori is difficult to culture because it requires microaerophilic conditions (low oxygen), and its presence is often patchy in the stomach lining. Early assumptions held the stomach was too acidic for bacteria to survive.
- Extrinsic Constraint: Before advanced culturing techniques, molecular diagnostics, and careful endoscopic sampling, scientists lacked the methods to reliably detect it. Prevailing medical theory also biased interpretation toward stress and lifestyle causes.
- Conditional Provability Insight: *The principle predicts that proof of H. pylori as an ulcer cause would be delayed until extrinsic constraints—culturing methods, diagnostic tools, and theoretical openness—were sufficiently improved, even though the bacterium existed all along.*
- Historical Outcome: H. pylori was identified in 1982, and its role in ulcers was confirmed only after extrinsic constraints (microaerophilic culture techniques, biopsies, and epidemiological studies) were addressed. Non-detection prior to this did not imply non-existence.

VIII. RELATION TO PHILOSOPHY OF SCIENCE

➢ *Falsifiability*

Falsifiability concerns testability in principle; conditional provability emphasizes testability in practice under real-world constraints.

➢ *Paradigms and Constraint Relaxation*

Paradigm shifts often coincide with relaxation of conceptual, methodological, or technological constraints, enabling proofs previously inaccessible.

➢ *Scientific Realism*

The principle supports moderate realism: entities may exist independently of current epistemic access, even without proof.

IX. CLARIFICATIONS AND ANTICIPATED OBJECTIONS

- Tautology Objection: By framing intrinsic constraints as dynamic and proof as a subset of absolute proof, the principle explains why proofs occur at certain times and not others, avoiding tautology.
- Probabilistic Reasoning: The principle is fully compatible with Bayesian inference and confidence-based reasoning. It delineates which proofs are possible under intrinsic and extrinsic constraints, without claiming existence or absolute proof.
- Solution vs Proof: Explanatory models (e.g., dark matter as a solution to galactic rotation curves) do not constitute proof; evidences requires constraints to be sufficiently reduced.

X. LIMITS OF PROVABILITY

Not all events will necessarily be provable. Some intrinsic constraints may remain insurmountable. Conditional provability is thus contingent, not universal.

XI. PREDICTION: CONDITION-DEPENDENT PROOFS

A central prediction of the Principle of Conditional Provability is that proofs are inherently tied to the conditions under which they are obtained. A proof valid under one set of intrinsic and extrinsic constraints may fail or become irrelevant under different conditions. Consequently, no single proof can universally justify a phenomenon or serve as a unifying theorem. As conditions change, new or alternative proofs may become necessary to establish verification. Historical examples illustrate this principle: observing a cell requires a microscope, not the naked eye; Newtonian mechanics provides accurate predictions at everyday speeds, but special relativity becomes necessary when velocities approach the speed of light. This prediction has broad implications: the reproducibility and generalization of proofs are limited by condition-specific constraints, and unifying theories must often rely on multiple, context-dependent proofs rather than a single, universal demonstration.

XII. PREDICTING VERIFIABILITY OF FRONTIER PHENOMENA

➢ *Life on Exo-planets (Bio signatures)*

- Event: Existence of extra-terrestrial life on exo-planets.
- Intrinsic Constraints:

✓ Life signatures may be rare or subtle.
✓ Biosignatures may be ambiguous or mimic abiotic processes.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25dec1470

- ✓ Detectable biosignatures are most likely to be produced by life forms capable of significantly altering their environment; simpler or non-interactive life may remain effectively unobservable with current instruments.
- Extrinsic Constraints:
- ✓ Current telescope resolution insufficient for detailed spectroscopy.
- ✓ Limited understanding of universal biosignatures.
- Prediction:
- ✓ *Next-generation telescopes (James Webb Space Telescope follow-ups, LUVOIR, HabEx) may detect chemical or atmospheric markers.*
- ✓ *Improved models of planetary atmospheres and habitability could guide observation strategies.*

➢ *High-Temperature Superconductivity Mechanism*

- Event: Fundamental mechanism behind high-T_c superconductivity.
- Intrinsic Constraints:
- ✓ Strongly correlated electron systems are extremely complex.
- ✓ Quantum many-body interactions are difficult to probe directly.
- Extrinsic Constraints:
- ✓ Limited computational and experimental tools for probing microscopic interactions.
- Prediction:
- ✓ *Advances in quantum simulation, AI-driven modeling, and ultrafast spectroscopy may reduce extrinsic constraints.*
- ✓ *Understanding could emerge once computational power and experimental resolution are sufficient.*

➢ *Consciousness and Neural Correlates*

- Event: Objective, scientific proof of the neural basis of consciousness.
- Intrinsic Constraints:
- ✓ Subjective experience cannot be directly measured.
- ✓ Conscious states may be emergent from distributed neural networks → hard to isolate.
- ✓ Extrinsic Constraints:
- ✓ Limitations of brain imaging (fMRI, EEG) in spatial/temporal resolution.
- ✓ Limited theoretical understanding of consciousness.
- Prediction:
- ✓ *Development of high-resolution, real-time brain mapping, combined with computational models, may allow testable predictions.*
- ✓ *Advances in AI modeling of neural networks may complement experimental access.*

XIII. SCENARIOS HIGHLIGHTING PCP'S DISTINCT PREDICTIONS

Table-2: PCP's Prediction

Scenario	Description	Popperian Falsifiability Prediction	Bayesian Prediction	PCP Prediction (Distinct)
Gravitational Waves (pre-2015)	Waves predicted in 1916; detectors insufficient until LIGO	Falsifiable since 1916 → could be tested in principle	Low evidence → prior probability remains unchanged until detection	Proof inaccessible until extrinsic constraints (detectors, noise reduction) allow verification. PCP predicts delayed verification despite falsifiability.
Exoplanet Discovery (pre-1995)	Planets theorized, but direct detection difficult	Theories testable in principle	Bayesian update small due to lack of data	PCP predicts conditional proof emerges only after extrinsic constraints (telescope resolution, observation methods) improve; early non-detection does not decrease belief in existence.
Dark Matter (current)	Observed via gravitational effects, not directly detected	Falsifiable? Only indirectly; some experiments may in principle falsify particle models	Bayesian probability remains uncertain, updated slowly with each non-detection	PCP emphasizes intrinsic constraints (weakly interacting) limit proof; non-detection reflects accessibility, not non-existence. Suggests alternative strategies for verification rather than mere probability updates.
Consciousness Neural Correlates (future)	Measuring subjective experience objectively	Some neural theories falsifiable in principle	Bayesian update occurs with partial neuroimaging data	PCP predicts proof requires overcoming both intrinsic (subjectivity) and extrinsic (imaging resolution, modelling) constraints. Early data may suggest nothing definitive; timing of proof depends on constraint relaxation.
High-T_c Superconductivity Mechanism	Complex electron interactions	Falsifiable in principle through experiments	Bayesian update with partial experimental evidence	PCP predicts proof contingent on reducing extrinsic constraints (better experimental probes, simulations) and

Scenario	Description	Popperian Falsifiability Prediction	Bayesian Prediction	PCP Prediction (Distinct)
				intrinsic complexity; early experiments may fail to produce proof despite valid theory.

➢ *Key Takeaways:*

- PCP vs Popperian Falsifiability:
  - ✓ Falsifiability is an in-principle concept: a theory is either testable or not.
  - ✓ PCP predicts delays in proof due to practical limitations, even when falsifiable. Non-detection does not imply the theory is false.
- PCP vs Bayesian Reasoning:
  - ✓ Bayesian reasoning updates belief probabilities based on evidence.
  - ✓ PCP adds a constraint-focused lens, clarifying that some evidence may be fundamentally inaccessible until constraints are reduced, so non-detection is not informative in the usual Bayesian sense.
- Distinctive Prediction:
  - ✓ PCP uniquely predicts the timing of verification based on the interplay of intrinsic and extrinsic constraints. This is not captured by Popper or Bayesian approaches.
  - ✓ PCP also guides experimental design by identifying which constraints must be relaxed to make proof possible.

XIV. GUIDING CONTEMPORARY AND FUTURE SCIENTIFIC INVESTIGATION

The Principle of Conditional Provability offers a practical framework for designing, prioritizing, and interpreting scientific research. By explicitly identifying intrinsic constraints (event-specific limitations) and extrinsic constraints (technological, methodological, or theoretical barriers), investigators can systematically assess which phenomena are accessible under current conditions and which require innovation. This approach can guide experimental design, emphasizing interventions that relax extrinsic constraints or exploit changes in intrinsic constraints to enable verification.

The principle also informs research prioritization and resource allocation. Experiments with insurmountable intrinsic constraints or immovable extrinsic limitations can be deferred or reformulated, while those where constraints can realistically be reduced become high-priority targets. Additionally, conditional provability reframes negative results: non-detection indicates constraint-limited accessibility rather than non-existence, preventing premature dismissal of viable hypotheses and supporting iterative methodological refinement.

By explicitly mapping constraints and their influence on proof, the principle aids in strategic hypothesis formulation and the development of technology or methodology aimed at overcoming verification barriers. It is particularly valuable in frontier science—such as particle physics, astrophysics, and neuroscience—where phenomena are rare, subtle, or transient. Overall, the principle provides a predictive and actionable framework, enabling scientists to anticipate when proof may become feasible, prioritize interventions, and interpret results within the context of condition-dependent accessibility.

XV. CONCLUSION

The Principle of Conditional Provability formalizes a key methodological insight: proof depends on the dynamic interplay of intrinsic and extrinsic constraints, rather than being a direct indicator of existence. A central prediction is that proofs are condition-dependent—as conditions change, previously valid proofs may fail, and new proofs may become necessary. Historical examples across physics, astronomy, and biology demonstrate that delayed or sudden verification often reflects changes in constraints rather than the ontological emergence of phenomena. This insight has profound implications for scientific practice: it emphasizes the need for multiple, context-specific proofs, challenges the assumption that a single proof can serve as a universal or unifying demonstration, and provides a disciplined framework for interpreting non-detection, reproducibility, and the historical contingency of scientific verification.

REFERENCES

[1]. Einstein, A. (1916). *The Foundation of the General Theory of Relativity*.
[2]. Popper, K. (1959). *The Logic of Scientific Discovery*.
[3]. Kuhn, T. (1962). *The Structure of Scientific Revolutions*.
[4]. Lakatos, I. (1978). *The Methodology of Scientific Research Programmes*.
[5]. Abbott, B. P. et al. (2016). Observation of Gravitational Waves from a Binary Black Hole Merger.