An Epistemic Interpretation of Quantum Mechanics: Reconciling Determinism and Observed Randomness

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Abstract

This paper develops an **Epistemic Interpretation (EI)** of quantum mechanics, proposing that physical randomness arises from the interaction between subjective and objective layers of reality. Building on Penrose's hypothesis that certain aspects of consciousness and reality are non-algorithmically computable, the EI frames quantum indeterminacy as a manifestation of epistemic incompleteness rather than ontological indeterminacy. Within this view, the measurement problem is not a physical contradiction but a boundary phenomenon between two descriptive levels of reality. The EI maintains the deterministic evolution of physical systems while interpreting probabilistic measurement outcomes as epistemic projections of limited access to an underlying causal order. Recent discussions in epistemic models, relational quantum mechanics, and QBist approaches provide context for this proposal.

1 Introduction

Roger Penrose has repeatedly suggested that reality may encompass processes that transcend algorithmic computation [1]. His reflections on the non-computability of consciousness invite a broader question: If human cognition involves non-deterministic elements, could the apparent randomness observed in quantum phenomena reflect this epistemic limitation rather than an intrinsic indeterminacy of nature?

The proposed *Epistemic Interpretation (EI)* extends this idea to the physical domain. It assumes an objectively deterministic universe in which all events are causally linked, while randomness emerges when the subjective, non-algorithmic domain of cognition interacts with this objective order. Thus, quantum randomness is not a property of nature itself, but a result of the epistemic mode through which observers access it.

This approach aligns conceptually with recent efforts to separate epistemic and ontic elements in quantum theory [5, 6, 4]. Unlike purely Bayesian interpretations, the EI is not probabilistic by construction but interpretative, linking randomness to the boundary between subjective and objective realms of description.

2 Background and Existing Interpretations

The dominant interpretations of quantum mechanics provide internally coherent but mutually incomplete pictures:

- The **Copenhagen interpretation** treats randomness as an intrinsic feature of microscopic reality, yet the collapse of the wave function contradicts the deterministic Schrödinger dynamics.

- **Bohmian mechanics** restores determinism via hidden variables but at the cost of nonlocality [2].
- The **Many-Worlds interpretation** preserves linearity but introduces ontological excess [3].
- **Decoherence approaches** explain the disappearance of interference without resolving the measurement problem entirely.

All these frameworks fail to clearly separate physical dynamics from the epistemic act of observation. The EI seeks to address this boundary explicitly, framing the measurement problem as an epistemic—not ontological—transition.

3 Conceptual Framework of the Epistemic Interpretation

The EI rests on three foundational principles:

1. **Objective Reality:** The physical universe forms a globally deterministic, causally closed continuum.
2. **Subjective Reality:** Human cognition includes non-algorithmically predictable elements—a domain beyond formal computation, in Penrose's sense.
3. **Epistemic Interaction:** Randomness arises when these two layers interact and the subjective domain can access only part of the objective order.

In this framework, the observed quantum event does not reflect ontological indeterminacy but an epistemic projection of incomplete access. Once the interaction ends, deterministic evolution resumes.

This position resonates with epistemic-realist proposals [7], which suggest that quantum states encode information about physical systems rather than representing physical reality itself. However, the EI extends this idea by grounding epistemic incompleteness in a non-computable boundary of cognition, connecting Penrose's arguments to physical interpretation.

4 The Measurement Problem Revisited

The measurement problem arises from the tension between deterministic evolution (the Schrödinger equation) and stochastic measurement outcomes. In the EI, this duality dissolves: Measurement is not a physical process within the dynamics but an epistemic transition between two domains of reality. The apparent randomness reflects limited coherence between observer and system rather than an ontological collapse. The global causal structure of nature remains intact.

From this viewpoint, the observer's epistemic boundary is the source of stochasticity. Quantum probabilities thus quantify epistemic access, not physical indeterminacy—a perspective conceptually consistent with relational quantum mechanics [4] and QBist subjectivism [6], yet distinct in its emphasis on cognitive non-computability.

5 Deterministic Equivalence of Schrödinger and Path Integral Formalisms

Both the Schrödinger equation and Feynman's path integral describe the same deterministic evolution of a quantum system. In the path integral formulation, all possible paths contribute to a global amplitude; their phase relations can be interpreted as temporally distributed components of a continuous causal process. The integral does not represent simultaneous alternative realities but rather the coherent superposition of causally admissible transitions. Randomness emerges only when the observer projects this global structure onto a local temporal slice, losing epistemic information.

This interpretation aligns with information-theoretic perspectives suggesting that measurement-induced randomness is a form of epistemic entropy [8]. The EI thus reframes interference as a boundary effect of epistemic projection rather than as ontological multiplicity.

6 Discussion and Outlook

The EI treats quantum indeterminacy as a boundary phenomenon between knowledge and world. It replaces collapse with epistemic projection and interprets randomness as information loss during epistemic interaction. This view invites empirical and theoretical exploration: for instance, whether the observed entropy or algorithmic complexity of measurement outcomes correlates with the degree of epistemic coherence in a model.

In this context, Penrose's idea of non-computable consciousness gains a physical interpretation: it is not that the brain generates quantum fluctuations, but rather that the limits of epistemic access render a deterministic universe locally random. Randomness would then be the visible trace of epistemic limitation within a causally ordered world.

Future research may explore whether epistemic metrics—such as information-theoretic coherence or algorithmic incompleteness—can operationally distinguish epistemic from ontic randomness. Such work could connect epistemic interpretations of quantum mechanics with computational and cognitive models of information processing.

7 Conclusion

The epistemic interpretation offers a minimalist yet consistent framework to reconcile determinism with observed randomness. It modifies no equation of quantum mechanics but reinterprets their meaning: nature remains deterministic, while our epistemic access does not. The measurement problem, accordingly, appears not as an unresolved paradox but as the logical outcome of the boundary between objective and subjective reality.

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