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Research Note — The Interpretations

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1. Thesis

Three modules led to this question. **Q1** showed: the formalism predicts measurement outcomes but tells no story about the in-between. **Q2** showed: the most natural story — that the answers were fixed from the start — is experimentally excluded. **W1** drew the balance of the procedure and expressly left this one question open.

The tested baseline model M1 reads: *“One of the interpretations is right, we just do not yet know which. The interpretation question is an ordinary empirical question, merely undecided; a better experiment will settle it.”*

This module’s claim: M1 is false, and **computably so**. The empirical equivalence of competing interpretations is not asserted here but **computed** — by explicit integration of the Bohmian trajectories.

A preliminary note on stance: this module takes **no side**. Whoever seeks a recommendation will find none. That is deliberate and is justified in section 8.

2. Assumptions

1. The Bohmian guidance equation can be integrated numerically.
2. The quantum equilibrium hypothesis holds (initial distribution = $|\psi|^2$).
3. Two distributions are empirically indistinguishable if their distance lies within sampling noise.
4. Structural costs of an interpretation can be listed even where they are not measurable.
5. The distinction decidable / undecidable / not sensibly posed is itself justifiable.

3. Mathematical model

M1 — “one is right”: There is an interpretation D^* that holds and a possible experiment E distinguishing it from the rest.

M2 — Bohmian mechanics. The wave function guides particles along definite trajectories: $$v(x,t) = \frac{\hbar}{m}\,\mathrm{Im}\!\left(\frac{\partial_x \psi}{\psi}\right), \qquad \dot{x} = v(x,t).$$ Under the quantum equilibrium hypothesis $\rho(x,0) = |\psi(x,0)|^2$ it follows for all times that $\rho(x,t) = |\psi(x,t)|^2$ (equivariance).

M3 — test criterion. Let $L_1 = \int |\rho_{\text{Bohm}} - |\psi|^2|\,dx$. The comparison is made **not** against a fixed threshold but against the noise level: $$\sigma_{\text{above}} = \frac{L_1 - \langle L_1^{\text{null}}\rangle}{\mathrm{sd}(L_1^{\text{null}})},$$ where L_1^{null} comes from samples of equal size drawn directly from $|\psi|^2$.

M4 — costs. To each interpretation D belongs a set of surrendered assumptions $K(D)$. By Bell: $\bigcap_D K(D) \neq \emptyset$ — every one gives something up.

Symbol	Meaning	Unit
v	Bohmian guidance velocity	m/s
L_1	distance between distributions	—
σ_{above}	deviation in noise units	—
$K(D)$	surrendered assumptions	—

4. Parameters

Scenario	Setup
A equivalence	4,000 trajectories, 900 time steps, $t = 0.05 \dots 4.0$; slit separation $d=2$, $\sigma_0 = 0.5$; 30 control samples
B costs	five interpretations: Copenhagen, many-worlds, Bohm, GRW, QBism
C limit	four kinds of question with one example each

Tolerance: $\varepsilon = 0$; the criterion in A is noise-referenced (3 σ).

5. Prediction

Scenario	Expectation
A	Bohm distribution within the noise range of $|\psi|^2$
B	every interpretation gives something up, none keeps everything
C	the four kinds are cleanly distinguishable

6. Falsification criterion

M1 is refuted as soon as two interpretations with **different ontologies** demonstrably make **the same** measurement predictions — for then no experiment can decide.

7. Competing models

- **K1 — one is right (M1):** tested baseline.
- **K2 — Copenhagen:** the state describes what is to be expected; measurement is a primitive.
- **K3 — many-worlds (Everett):** only the Schrödinger equation, all outcomes occur.
- **K4 — Bohmian mechanics:** particles with trajectories guided by the wave; explicitly nonlocal.
- **K5 — GRW / collapse models:** objective collapse; **makes deviating predictions** and is thus not a pure interpretation.
- **K6 — QBism:** the state describes an agent's expectations, not the world.

8. Domain of failure

- **Scenario A is the only part with genuine numerics.** Scenarios B and C are systematisations, not calculations. This is stated, not concealed.
- **The equivalence holds under the quantum equilibrium hypothesis.** Whether that assumption is itself justified is an open question of the Bohmian interpretation — a cost item appearing in scenario B.
- **One-dimensional model.** The computed double slit is a simplification; the equivalence is proved in general but here shown only in one case.
- **The cost list is not complete.** Further interpretations (relational quantum mechanics, consistent histories, transactional) are missing. The selection follows prevalence, not a substantive ranking.
- **No recommendation — and that is justified.** The choice among empirically equivalent interpretations is not a factual question. A workshop that insists on calculation has nothing to contribute here beyond the cost list. Whoever voices an opinion here leaves the procedure.
- **Not treated:** decoherence in detail, the role of time, relativistic generalisation of the interpretations, quantum gravity.

9. Simulation

Numerical evaluation in `hermeneus_simulation.py`:

1. Scenario A: integration of 4,000 Bohmian trajectories; comparison of the final distribution with \(|\psi|^2\); null comparison over 30 directly drawn control samples.
2. Scenario B: listing of the five interpretations by what is kept, surrendered and left open.
3. Scenario C: four kinds of question with example, status and lesson.

Results in `hermeneus_results.json`, plot as `hermeneus_szenen.svg`.

10. Result

10.1 A — empirical equivalence, computed

Quantity	Value
trajectories	4,000
\(L_1\) Bohm to \(|\psi|^2\)	**0.0971**
\(L_1\) pure noise (30 controls)	0.1024 ± 0.0102
Bohm above the noise	**−0.52 σ**
correlation	0.99448

The Bohm distribution is statistically indistinguishable from a sample drawn directly from $|\psi|^2$.

Assessment M1: refuted.

10.2 B — the cost list

Interpretation	gives up	open point
Copenhagen	a description of measurement itself	where does the Heisenberg cut run?
many-worlds	one outcome per measurement	where do the probabilities come from?
Bohm	locality, parsimony	why does quantum equilibrium hold?
GRW	the exact Schrödinger equation	parameters free — **and measurable**
QBism	the state as a description of the world	what then is the world?

Assessment M1: refuted.

10.3 C — four kinds of question

Kind	Example	Status
decided	local realism	excluded (2015)
still open	GRW parameters	constrained
undecidable in principle	**Copenhagen / Everett / Bohm**	**empirically equivalent**
not sensibly posed	superdeterminism	not falsifiable

Assessment M1: refuted.

11. Assessment

M1 (“one is right, we just do not yet know which”) is refuted in all three scenarios.

Scenario A is the centrepiece, and it is computed. Bohmian mechanics was not described but integrated: 4,000 particles guided by the guidance equation over 900 time steps. In this interpretation **every particle has a definite trajectory and goes through exactly one slit** — precisely what Q1 had refuted as M1.

And yet the final distribution is **statistically indistinguishable** from $|\psi|^2$: −0.52 σ from pure sampling noise, correlation 0.994.

That is the decisive point and it is no philosophical assertion: **an interpretation with trajectories and one without deliver the same measurable distribution.** No experiment at the double slit can distinguish them — not because experiments are too imprecise, but because both predict the same.

On the two corrections. The first version tested against a fixed threshold ($L_1 < 0.05$) and failed, although the distributions agreed. The error lay in the criterion: at 4,000 trajectories over 90 bins an L_1 of that size is pure histogram noise. **The same error type as in Q2**, where the locally realistic model appeared to exceed the Bell bound.

The null comparison then built in, however, drew the control sample on the **initial grid** (±8) — but by t_1 18.7 % of the probability lies outside it. The result was absurd: Bohm appeared **better than the truth itself**. Only a wider grid made the comparison valid. That an impossible intermediate result reveals the error is by now a pattern in this work.

Scenario B: none keeps everything. Five interpretations, five different prices. Copenhagen keeps one outcome per measurement and locality but surrenders a description of the measurement process — where the Heisenberg cut lies remains open. Many-worlds keeps locality, determinism and needs no extra postulate but surrenders the uniqueness of reality. Bohm keeps trajectories and determinism, paying with explicit nonlocality.

That is the real lesson from Bell: there is no interpretation that keeps everything. The question is not “which is right” but “which loss does one accept” — and that is not an empirical question.

A delimitation belongs here that is often blurred: GRW falls outside the frame. Collapse models modify the Schrödinger equation and thereby make **deviating** predictions — very small, but measurable in principle. GRW is therefore strictly speaking **not an interpretation but a competing theory**. It belongs in scenario C under “still open”, not “undecidable”.

Scenario C: four kinds of question. The workshop ends with a distinction running through its whole work.

Decided is local realism — excluded by Bell experiments. That is the ideal case: a position that looked metaphysical became measurable.

Still open are the GRW parameters. What seems undecidable today can be decidable tomorrow — if the theory makes deviating predictions.

Undecidable in principle is the choice among Copenhagen, Everett and Bohm. Here no better measurement helps, and scenario A shows why — not as an assertion but as a computational result.

Not sensibly posed is superdeterminism. A position compatible with every conceivable finding says nothing. That is Popper’s criterion, and it bites here.

“Undecidable” and “meaningless” are different things. The interpretation question is undecidable but not meaningless — the interpretations differ in what they explain and what they presuppose. Only that difference cannot be settled by measurement.

Why no recommendation stands here. It would be easy at this point to favour one interpretation — the most parsimonious, the most intuitive, the one fitting relativity best. That is precisely what is omitted.

The workshop has insisted on calculation 32 times. Where calculation was possible, it was done; where not, this was stated. The choice among empirically equivalent interpretations **cannot be computed**. Whoever voices an opinion here leaves the procedure — and does so under the appearance of continuing it. That would be the most dishonest ending this work could take.

The arc closes. Module 02 (cave allegory) posed the question whether we see things or their shadows. The perception strand showed that we see not the stimulus but the best interpretation. M1 (CATENA) showed that every measurement chain has the same structure. Q1 and Q2 showed that physics stands at the same place. W1 drew the balance.

And W2 ends where the procedure ends. Not with an answer but with a precise statement of where one ceases to be possible. That is the same section 8 that each of the 32 modules has — only this time for the whole workshop.

12. Next test

The workshop is concluded with this module. What remains are extensions of existing modules (v0.2) and preparation for publication.

Open point before submission: the 33 tools have so far only been validated for JS syntax and never really tested in a browser. This must be made up before a Zenodo submission.

Possible extension v0.2: further interpretations (relational quantum mechanics, consistent histories, transactional); decoherence quantitatively; the role of time in the interpretations; relativistic generalisation.

Appendix A — Cross-references

- Practice explanation: `PRAXIS-Hermeneus-EN.md` · Companion paper: `BEGLEITPAPIER-Hermeneus-EN.md`
- Tool: `HERMENEUS.html`
- Code: `hermeneus_simulation.py` · Plot: `hermeneus_szenen.svg` · Data: `hermeneus_results.json`
- **Connecting modules:** Q1 double slit (the gap), Q2 entanglement (the excluded filling), W1 balance, 02 cave allegory (the initial question), M1 signal chain
- **Concluded herewith:** 33 modules in 7 strands

Appendix B — External stocktaking

- **Bohm (1952)** — the pilot-wave interpretation.
- **Everett (1957)** — the relative-state formulation.
- **Ghirardi, Rimini & Weber (1986)** — objective collapse.
- **Bell (1987), *Speakable and Unspeakable*** — the critical appraisal of all positions.
- **Fuchs, Mermin & Schack (2014)** — QBism.

What the workshop note adds: the empirical equivalence is **computed** rather than asserted — with explicit integration of the Bohmian trajectories and a noise-referenced test criterion. The cost list deliberately contains no ranking. The delimitation of GRW as a competing theory rather than an interpretation is made explicitly.

Appendix C — Sources

- Bohm, D. (1952). A suggested interpretation of the quantum theory in terms of “hidden” variables. *Physical Review* 85:166–193.
- Everett, H. (1957). “Relative state” formulation of quantum mechanics. *Reviews of Modern Physics* 29:454–462.
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microscopic and macroscopic systems. *Physical Review D* 34:470–491.
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- Fuchs, C. A.; Mermin, N. D.; Schack, R. (2014). An introduction to QBism. *American Journal of Physics* 82:749–754.

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