QBism and the Ithaca Desiderata

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Abstract

In 1996, N. David Mermin proposed a set of desiderata for an understanding of quantum mechanics, the “Ithaca Interpretation”. In 2012, Mermin became a public advocate of QBism, an interpretation due to Christopher Fuchs and Rüdiger Schack. Here, we evaluate QBism with respect to the Ithaca Interpretation’s six desiderata, in the process also evaluating those desiderata themselves. This analysis reveals a genuine distinction between QBism and the IIQM, but also a natural progression from one to the other.

In 1996, N. David Mermin proposed the “Ithaca Interpretation of Quantum Mechanics” [1]. Rather than a complete story about what quantum theory means, the IIQM was intended to be a set of desiderata, a list of goals that a future interpretation of quantum mechanics should meet in order to be considered satisfactory. In 2012, Mermin became a public advocate of QBism, an interpretation due to Christopher Fuchs and Rüdiger Schack [2–4]. This article evaluates QBism with respect to Mermin’s original six criteria. In four of the six cases, QBism qualifies directly, and in the remaining two, a solid case can be made that QBism satisfies the intuition behind the desideratum. From the viewpoint of QBism, each of the Ithaca desiderata puts a finger on a legitimate and important question. What holds the IIQM back is its insistence on allowing only a very limited kind of answer for some of those questions.

QBism can be briefly defined as follows [5]:

An interpretation of quantum mechanics in which the ideas of agent and experience are fundamental. A “quantum measurement” is an act that an agent performs on the external world. A “quantum state” is an agent’s encoding of her own personal expectations for what she might experience as a consequence of her actions. Moreover, each measurement outcome is a personal event, an experience specific to the agent who incites it. Subjective judgments thus comprise much of the quantum machinery, but the formalism of the theory establishes the standard
to which agents should strive to hold their expectations, and that standard for the relations among beliefs is as objective as any other physical theory.

This article was prompted by a paper of de Ronde, Fernández-Mouján and Massri which claimed that “there is no interpretation more distant from Mermin’s original set of desiderata than QBism” [6]. As the discussion to follow will hopefully make clear, this is untrue.

In what follows, we limit ourselves to brief quotations from Mermin’s prose, not just because Mermin’s writing tends to make other physicists’ look flat and forgettable by comparison, but also because for the present purposes, it is not necessary to establish that the interpretation of quantum mechanics is a significant issue. We take it as read that physicists should be concerned with the topic — a claim perhaps more controversial than any specific choice of interpretation. Thus, we proceed directly to Mermin’s six desiderata for an adequate interpretation, which he summarizes as follows:

1. Is unambiguous about objective reality.
2. Uses no prior concept of measurement.
3. Applies to individual systems.
4. Applies to (small) isolated systems.
5. Satisfies generalized Einstein locality.
6. Rests on a prior concept of objective probability.

After posing these criteria, the IIQM paper then presents two technical theorems and discusses their philosophical implications. The simplest approach is to address all of these topics in order.

1 Objectivity

First, quoting Mermin:

A satisfactory interpretation should be unambiguous about what has objective reality and what does not, and what is objectively real should be cleanly separated from what is “known”.

When confronted with the question of which elements of the standard mathematical apparatus of quantum theory correspond to objective reality and which do not, it is of course logically possible to reply, “None are fully objective — all are at least tainted by the subjective.” This was the position of E. T. Jaynes [7]:

[O]ur present QM formalism is not purely epistemological; it is a peculiar mixture describing in part realities of Nature, in part incomplete human information about Nature — all scrambled up by Heisenberg and Bohr into an omelette that
nobody has seen how to unscramble. Yet we think that the unscrambling is a prerequisite for any further advance in basic physical theory. For, if we cannot separate the subjective and objective aspects of the formalism, we cannot know what we are talking about; it is just that simple.

Jaynes believed that to unscramble the Heisenberg–Bohr omelette, “we need to find a different formalism, isomorphic in some sense but based on different variables” [8].

QBism is unambiguous about what is “known” (or, to put it better, believed) and what is objective. In particular, quantum states belong on the subjective side of the line, while for any individual agent, her personal experiences are empirical and incontrovertible [9]. Moreover, in QBism the quantum formalism itself encodes a normative standard that any agent should strive to attain. This standard is objective, even though the expectations held by any individual agent are their own subjective belongings. But making this clear requires a Jaynesian unscrambling: The textbook formalism, good as it is for so many things, isn’t the best suited for resolving this question. (This should be no surprise. The idea of a single picture of a theory that works equally well for all problems is antithetical to a physicist’s training and lifestyle.) Fuchs and colleagues have identified a certain probabilistic representation of the Born Rule as the cleanest statement of the objective normative standard that quantum theory expresses [10].

Mermin goes on to say, “Indeed, knowledge should not enter at a fundamental level at all.” In QBism, the term knowledge is deprecated, and belief or expectation are preferred: The latter terminology carries less of a connotation that different agents must necessarily come into agreement, as a matter of principle (though they may often do so in practice). According to QBism, expectation is a fundamental part of quantum theory, which is different from expectation (or “information” or “knowledge”) being a fundamental ingredient of reality itself. Before there were agents, there was reality, but there were no expectations.

A useful comparison can be made to special relativity. Consider Einstein’s postulates, and the dramatic tension between them: Inertial observers can come to agree upon the laws of physics, but they cannot agree upon a standard of rest. These axioms are conveniently expressed in terms of what agents can and cannot do, yet they are more than “mere” engineering, because they apply to all agents. Or, to say it another way, any agent should take heed of the theory when trying to realize their own aspirations. In QBism, the role of quantum theory is analogous.

Most of Mermin’s writings on QBism have addressed how it gives meaning to the mathematical formalism of quantum physics. Other QBist authors have put more emphasis on QBism as a project, that is, as a motivator for technical research [10,11]. (I myself fall into this latter group [5,12–15], since I have not yet attained that stage of a physicist’s career where one can safely write papers that lack equations. Quantum foundations, properly understood, is not just about pretty words, but a matter of Sylow subgroups, Galois fields and integral octonions [16–20].) What features of the natural world make quantum theory a good calculus of expectations? What internally consistent alternatives to quantum theory can be imagined, and how do they illuminate the particularities of quantum theory itself? In short, to quote the title Mermin gave to his second paper on the IIQM [21], “What is quantum
mechanics trying to tell us?” The project of QBism aims to answer exactly that, and the first step is to “be unambiguous about what has objective reality and what does not”.

## 2 Measurement

On the second desideratum, quoting Mermin again:

> The view that physics can offer nothing more than an algorithm telling you how to get from a state preparation to the results of a measurement seems to me absurdly anthropocentric; so does limiting what we can observe to what we can produce (“state preparation” being one of the things you can do with a “measurement apparatus”). Physics ought to describe the unobserved unprepared world. “We” shouldn’t have to be there at all.

The QBist answer is twofold. First, QBism discards the limitation on “what we can observe” — any action by an agent, interacting with the outside world, is in principle a quantum measurement. In his second essay on the IIQM, Mermin argues that “the very much broader concept of correlation ought to replace measurement in a serious formulation of what quantum mechanics is all about” [21]. QBism does the job more directly by broadening the concept of measurement itself. Any action taken by an agent upon the external world is, in principle, a quantum measurement, and any experience incited by an action is a measurement outcome. The supposed limitation of quantum theory’s validity to bench-top laboratory procedures simply does not exist. Second, the fact that the theory resists cutting the agent out of it is a statement about the character of the physical world. “We” don’t have to be here, but the fact that this particular theory is helpful to us now that we are — *that* says something about nature.

This item is the point of greatest divergence between QBism and the IIQM. (Mermin quipped in 2012, “Like Barack Obama’s view of marriage, my thinking about quantum foundations has evolved” [22].) From the QBist perspective, the IIQM reaches for objectivity too soon, thereby missing its chance to hear what the theory is trying to say.

## 3 Individual and Isolated Systems

Mermin states, regarding his third criterion,

> The theory should describe individual systems — not just ensembles.

QBism is fine with individual systems, because it adopts a school of probability theory intended for single-shot situations. This is a healthy thing to do, even in classical science [23–26].

Mermin elaborates as follows upon his fourth criterion:
The theory should describe small isolated systems without having to invoke interactions with anything external. [...] In particular I would like to have a quantum mechanics that does not require the existence of a “classical domain”. Nor should it rely on quantum gravity, or radiation escaping to infinity, or interactions with an external environment for its conceptual validity. These complications may be important for the practical matter of explaining why certain probabilities one expects to be tiny are, in fact tiny. But it ought to be possible to deal with high precision and no conceptual murkiness with small parts of the universe if they are to high precision, isolated from the rest.

QBism nowhere demands the existence of a “classical domain”, nor does it rely on the other kinds of dodges like radiation leaking away to infinity. It is of course capable of treating the time evolution of an open quantum system as it is at handling any application of the standard quantum formalism.

Mermin states his fifth criterion, an Einsteinian notion of locality, as follows.

Objectively real internal properties of an isolated individual system should not change when something is done to another non-interacting system.

Fuchs, in particular, has used exactly this argument to make the case that quantum states are subjective. The argument is essentially the reason Einstein gave for why quantum states cannot be intrinsic “physical conditions” of systems [27]. Einstein wrote,

Consider a mechanical system constituted of two partial systems $A$ and $B$ which have interaction with each other only during limited time. Let the $\psi$ function before their interaction be given. Then the Schrödinger equation will furnish the $\psi$ function after their interaction has taken place. Let us now determine the physical condition of the partial system $A$ as completely as possible by measurements. Then the quantum mechanics allows us to determine the $\psi$ function of the partial system $B$ from the measurements made, and from the $\psi$ function of the total system. This determination, however, gives a result which depends upon which of the determining magnitudes specifying the condition of $A$ has been measured (for instance coordinates or momenta). Since there can be only one physical condition of $B$ after the interaction and which can reasonably not be considered as dependent on the particular measurement we perform on the system $A$ separated from $B$ it may be concluded that the $\psi$ function is not unambiguously coordinated with the physical condition. This coordination of several $\psi$ functions with the same physical condition of system $B$ shows again that the $\psi$ function cannot be interpreted as a (complete) description of a physical condition of a unit system.

The QBist take on this simply replaces Einstein’s notion of probability for a personalist Bayesian one, and lets go of the desire to complete the description using hidden variables. (For further discussion, see [12, 28].) Plainly, QBism and the IIQM agree about Einstein locality.
4 Objective Probability versus Objective Indeterminism

Mermin gives his sixth desideratum as the following:

It suffices (for now) to base the interpretation of quantum mechanics on the (yet to be supplied) interpretation of objective probability.

In other words, “objective probability” is a rug under which as many problems as possible are to be swept — a rug whose existence is not known, but hoped for. According to QBism, no satisfactory interpretation of objective probability will ever be supplied. So, QBism is definitely at odds with this desideratum. But Mermin himself began to doubt that “objective probability” or “propensity” could be made a sensible idea, long before he adopted QBism. As he wrote to Fuchs in January 2006 [29],

You persuaded me quite soon that “objective probability” was problematic. Until I met you I had never taken the notion of subjective probability seriously, or even known very much about it. While I’m still not convinced (sorry) that you’ve got it right either, I’m much more aware that one of the pillars of the IIQM is much more fragile than I thought.

In QBism, the numerical value of any probability is the personal property of the agent who assigns it. However, the QBist world is one of objective, irreducible indeterminism. Physical reality so overflows with richness that no notion of “propensity” can ever be adequate. (For further discussion, see [10, §2.2] and [30, footnote 6].) The character of that deep and thoroughgoing indeterminism implies conditions which any agent who uses probabilities should strive to meet; we call those conditions quantum theory. Those looking for objectivity in the numerical values of probabilities are just looking in the wrong place [12].

5 Theorems

After laying out the six Ithaca desiderata, Mermin discusses two technical theorems. The first, which concerns the multiplicity of pure-state decompositions of a general mixed state, is often called the HJW theorem after Hughston, Jozsa and Wootters [31]. (The result has a prior history going through Ochs [32], Jaynes [33] and Schrödinger [34], and caused at least one statistical physicist to take strong issue with von Neumann [35].) Mermin uses this and Einstein locality to argue that different decompositions of the same mixed state must be physically equivalent:

If you take Desideratum (5) seriously, then there can be no more objective reality to the different possible realizations of a density matrix, than there is to the different possible ways of expanding a pure state in terms of different complete orthonormal sets. […] In the case of an individual system, the density matrix must be a fundamental and irreducible objective property, whether or not it is a pure state.
We have here a good example of how QBism echoes the IIQM while at the same time contrasting with it. Mermin’s argument here becomes a statement entirely in line with QBism when one performs the admittedly radical move of dropping the term “objective property”. In QBism, any quantum state, mixed or pure, is simply a catalogue of an agent’s expectations about what that agent might experience as a result of interacting with an external system. Consequently, just as Mermin was aiming for, there is no category distinction in QBism between rank-1 projectors and other density operators. The former simply enjoy the additional property of being extremal in the set of valid catalogues of expectation. Both QBism and the IIQM treat all quantum states on the same footing, but they differ on what that footing must be.

The technical program pursued by Fuchs and colleagues underscores this point, emphasizing that any quantum state on a $d$-dimensional Hilbert space can be represented as a probability distribution over the outcomes of a reference measurement [11–14,36]. Thus, pure states are not categorically different from mixed states, any more than, say, Gaussian curves are from other probability distributions. In the simplest case, that of a single qubit, an appropriate choice of reference measurement reveals that quantum state space (i.e., the Bloch ball) is isomorphic to the set $\mathcal{P}$ of four-element probability vectors that satisfies

$$\frac{1}{6} \leq \sum_{i=1}^{4} p(i)p'(i) \leq \frac{1}{3}, \forall p, p' \in \mathcal{P}. \tag{1}$$

Pure qubit states are exactly those that saturate the upper bound on their Euclidean norm (which, equivalently, is a lower bound on their Rényi 2-entropy). The constraints become more complicated in higher dimensions, but the principle remains the same [11–13].

Thus, we can observe a general prejudice in the community about which of the Ithaca desiderata are the most valued. Interpretations of quantum mechanics often rush to excise “measurement” from their vocabulary, but seldom to accord equal status to pure and mixed states.

Mermin states the second theorem as follows.

Given a system $\mathcal{S} = \mathcal{S}_1 \oplus \mathcal{S}_2$ with density matrix $W$, then $W$ is completely determined by the values of $\text{tr}WA \otimes B$ for an appropriate set of observable pairs $A, B$, where $A = A \otimes 1$ is an observable of subsystem $\mathcal{S}_1$ and $B = 1 \otimes B$ is an observable of subsystem $\mathcal{S}_2$.

As Mermin shows, this is provable from the standard formalism of quantum mechanics [37,38]. Since QBism is an interpretation of quantum mechanics, a way of investing the mathematics with meaning, this theorem is of course consistent with it. The result that, in Mermin’s phrasing, “the correlations among all the subsystems completely determine the density matrix for the composite system they make up” has come to be known as tomographic locality. Several approaches to reconstructing quantum theory from operational principles have invoked this as a postulate; there, its main role is to distinguish the orthodox quantum theory, with its complex Hilbert spaces, from its “foil theories” defined over real and quaternionic algebras [39]. However, tomographic locality is not the only postulate that
has been used in that role [15, 40–42]; nor has it played a major role in the QBist effort to reconstruct quantum theory [13]. For further discussion of related technicalities, see [28, §5] and [43], as well as [44, pp. 217–52, 499–500].

In the context of his original Ithaca desiderata, Mermin takes the meaning of the second theorem to be that “the fundamental irreducible objective character of an individual system is entirely specified by all the correlations among any particular set of the subsystems into which it can be decomposed.” The slogan of the IIQM was correlations without correlata [21]. Later, Mermin wrote to Fuchs about difficulties with this idea [29].

Not unrelated to [the problem with “objective probability”], the notion of “correlation” is not well defined, beyond my assertion that it means nothing more than “joint distribution”. But what does it mean to say that joint distributions are fundamental, while conditional distributions, which can be constructed from joints, have no physical meaning? And what are these joint distributions describing?

In an interview with Max Schlosshauer [45], Mermin said,

What led me to stop giving physics colloquia on the IIQM after only a year was the obvious question: “Correlations between what?” Abner Shimony aptly complained that the Ithaca Interpretation “had no foreign policy.”

Another reason why the technical side of QBism has placed less emphasis on these two theorems than the IIQM did is that they are not strictly specific to quantum mechanics. The Spekkens toy model, a theory defined explicitly in terms of local hidden variables, has both the multiplicity of mixed-state decompositions and tomographic locality [46]. If the slogan of the IIQM was correlations without correlata, then the motto of the Spekkens toy model could be correlations with concealed correlata: The model has local hidden variables, but the observer is constrained from ever having full knowledge about what values those variables take. The Spekkens toy model reproduces many things first discovered in quantum theory, such as teleportation and the no-cloning theorem, indicating that however intriguing and useful these features might be in particular applications, they are not where the essence of quantum theory lies. To find that, we have to dig deeper. Consequently, the theorems that the IIQM had centered appear more peripheral — not insignificant, but secondary, to be derived rather than assumed [13].

6 Conclusions

In summary, QBism meets four of the six Ithaca desiderata in a straightforward way, and in a more subtle fashion, it addresses the underlying concerns of the other two. Of the two theorems emphasized by Mermin’s original IIQM paper, QBism readily synergizes with the first and has no quarrel with the second. The technical research done under the QBist banner has placed less emphasis on that second theorem than the IIQM papers did, partly because other mathematical statements seem capable of standing in the same place.
The paper that prompted this commentary characterized QBism as “a neo-Bohrian, anti-realist and instrumentalist account” of quantum mechanics [6]. Being both neo-Bohrian and anti-realist would be a neat trick, since Bohr was a realist [47–49]. QBism is also realist — it is simply not naïvely realist about any particular mathematical element of the quantum formalism. It and Bohrian thought are two detectably distinct examples of participatory realism [30,50]. In fact, QBism has drawn as much upon the thinking of Einstein as upon Bohr [51], a point that our discussion of the locality desideratum suggested. As Fuchs declared [29], “When Einstein was right, he was really right!” QBism comes down in places closer to Pauli than to Bohr, while remaining not completely satisfied with any of the founders [10].

Whether “instrumentalism” has any meaning other than as a philosopher’s swear word, we leave as an exercise to the interested reader. It seems, though, that characterizing QBism as “instrumentalist” misses the animating force behind the interpretive effort: to take the question “What is quantum mechanics trying to tell us?” as the impetus for new physics. Directly identifying the surface-level elements of quantum theory’s mathematical formalism with physical reality is an easy path to start down, but one that sooner, rather than later, leads to confusion. The sought-after clarity recedes, leaving new vaguenesses to stand beside the old. The ethos of QBism is to resist the lure of easy answers. As Schrödinger once wrote [52],

In an honest search for knowledge you quite often have to abide by ignorance for an indefinite period. Instead of filling a gap by guesswork, genuine science prefers to put up with it; and this, not so much from conscientious scruples about telling lies, as from the consideration that, however irksome the gap may be, its obliteration by a fake removes the urge to seek after a tenable answer. So efficiently may attention be diverted that the answer is missed even when, by good luck, it comes close at hand. The steadfastness in standing up to a non liquet, nay in appreciating it as a stimulus and a signpost to further quest, is a natural and indispensable disposition in the mind of a scientist.

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