The Role of Epistemic Probability in Quantum Mechanics

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Quantum Theory has been fundamental to physical science since its development in the 1920s. However, accompanying the theory's predictive precision and applicability to technological development are philosophical controversies that have persisted to the present day. In response to the "weirdness" of quantum phenomena, many interpretations of the mathematics of quantum mechanics have been proposed. This paper examines perhaps the most radical of the mainstream interpretations: QBism. Reactions to the development of QBism have been both positive and fiercely negative; this account will not attempt to say whether the theory will win out in the end. Rather, the purpose of this essay is to expound the philosophical importance of QBism and examine its constructiveness to the current dialogue in the philosophy of physics. The paper first presents QBism and its key claims before moving to address the common objections to the theory. I then clarify misinterpretations of what QBism postulates and offer evidence for its value and potential for influencing the direction of theoretical investigation of quantum foundations.

QBism seeks to answer questions of interpretation regarding aspects of quantum theory that repeatedly lead to philosophical or conceptual problems, namely those about the nature of wavefunction superposition, quantum measurement, and entanglement. Fundamental to QBism is the viewpoint that a quantum state represents the *epistemic* state of the agent examining the system, rather than representing the *physical* state of the system. This epistemic state is represented by "specifying the agent's coherent degree of belief (credence) in each of a variety of alternative experiences that may result from a specific act the agent might perform."[1] For QBism, an agent's actions and experiences are a central concern to the theory – this lies in stark contrast to the longstanding notion that physical theories seek to represent reality independent of human minds. To make this characterization more precise, we can say that QBism is distinguished from other interpretations by its use of a subjective Bayesian conception of probability. It should be noted that the use of a Bayesian framework for handling statistical or probabilistic phenomenon in quantum theory is present in other places and need not be explicitly tied to QBism; this is one motivation for the reduction of the name from 'Quantum Bayesianism'. The subjective nature of QBism leads to the depiction of quantum theory as "a users' manual that any agent can pick up and use to help make wiser decisions in this world of inherent uncertainty"[1]. It is on behalf of this uncommon interpretation of quantum states as representations of degrees of belief that have led some philosophers to label QBism as a form of antirealism. However, the founders of the viewpoint would disagree with this characterization and would more closely align QBism with what they call "participatory realism", in which physical reality consists of more than what can be encapsulated by a third-person ("objective") account of it.

Let us now make more precise the claims of QBism. A primary tenet of QBism is that all probabilities, including those equal to zero or one, are quantifications of an agent's degree of belief in possible outcomes. Secondly, the QBist interpretation renders the Born Rule of quantum theory not a law of nature but an empirically motivated norm that an agent should follow so as not to render that agent's degrees of belief incoherent. Third, the theory holds that quantum measurement outcomes are personal experiences for the agent observing them; different individuals can agree upon an outcome of a measurement in quantum theory, but the outcome in itself is an experience solely of the individual agent. The last claim I will enumerate in this section is the refutation of the EPR sufficient condition for reality:

"If, without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity."[1]

The EPR conjecture was used to ground the group's argument for the incompleteness of the quantum mechanical description of reality, however, QBists reject this argument for quantum theory incompleteness by rejecting this necessary condition proposed by EPR. QBists identify probability 1 with subjective certainty or full belief, and thus do not grapple with the ontological question of when certain quantum physical quantities necessarily exist or not. Lastly, one must acknowledge that the depiction of quantum theory that the QBist is entitled to hold is one of a certain pragmatism. According to QBism, quantum theory is simply a tool to be utilized by agents to guide his or her expectations. The seems to typify quantum theory as a pragmatic application of probability theory that is influenced by some aspect of physical reality, but certainly not explanatory of physical reality itself. This view will be further analyzed in the further areas of this paper.

The sketch of QBism presented thus far is by no means the entire story, but to better illuminate the specific aspects that most require our attention I will move on to the critiques of the theory. A common reaction to QBism is to dismiss the theory as a form of solipsism. Mermin does well to recount that our individual experiences give us strong grounds, close to probability 1, to infer the existence of other individuals.[1] We communicate and interact with others and understand their inner worlds through language; this dialogue is also present in scientific inquiry as points out Mermin: "Science is a collaborative human effort to find, through our individual actions on the world and our verbal communications with each other, a model for what is common to all of our privately constructed external worlds. Conversations, conferences, research papers, and books are an essential part of the scientific process."[1] Other defenses of QBism from the solipsist critique exists, but despite their overall success there still remains the apparent restriction of the application of quantum theory to only the anticipation of one's own individual experiences, which seems at odds with the goals many scientists hold for generalizability of quantum theory. QBism has also faced criticism for appearing to be a form of instrumentalism. This objection is of primary interest in that this construal of QBism often leads to the misinterpretation of QBism as antirealist. Instrumentalism is often contrasted with realism in the philosophy of science, as the two viewpoints differ on the content, aims, and epistemic limits of scientific endeavors. The instrumentalism/realism contrast is most stark when considering unobservable phenomena (as in the case of quantum states), where one would typically associate the realist interpretation of science to interpret theoretical statements as true or false, and the instrumentalist to only see these claims as part of the account of what we use to accommodate and predict our observations (and not in themselves contain truth values). Fuchs argues that quantum theory has shown us that reality cannot be separated from us as individuals: we do not passively place bets on what will happen in future quantum states, rather we are active participants in the *creation* of that future reality.[1] This interplay between observer and reality is critical to understanding the value in the QBist approach to quantum theory, and physics in general.

A particularly poignant consideration surrounding QBism is whether it is explanatory. Quantum theory purportedly gives myriad explanations for phenomena we could not explain or understand without it. Timpson provides an illustrative example of the explanatory shortcomings of QBism: "… think of the question of why some solids conduct and some insulate; why yet others are in between, while they all contain electrons, sometimes in quite similar densities…. Ultimately we are not interested in agents' expectation that matter structured like sodium would conduct; we are interested in why it in fact does so."[1] (Timpson 2008: 600) A similar sentiment is found throughout critiques of QBism and this strikes me as the most prominent and unresolved dilemma facing QBists. They could perhaps bite the bullet and remain agnostic about the explanatory role of QBism, and point out that the alternative leaves one to meddle with the problems of measurement and non-locality. Perhaps QBists may be availed of this dilemma by developing a compelling theory of subjectivist scientific explanation; it is my opinion that this would be key to allowing QBism to gain more weight in the minds of many opposed to the view.

Now that we have explicated QBism's main claims and considered some of the critical objections, I would like to turn to a discussion of the philosophical importance of QBism. Both many of the strengths (the resolution of conceptual problems/paradoxes in quantum theory) and weaknesses (the lack of explanatory power) of QBism are inherently related to the employment of a subjectivist interpretation of the probabilities associated with quantum states. The reason this viewpoint is so radical is that this interpretation of the probability calculus has been confined to areas of human inquiry thought to be less foundational than physical science. What is at stake here is the ‘nature of reality’ for many scientists, and a view that quantum theory does not describe that reality independent of what an individual can rationally predict in his own experience is both uncomfortable and unsatisfying for many scientists and philosophers. This sentiment stems from the polarization of the use of probability theory in science, namely, that subjective probability theory is useful and valid for social science while an objective probability interpretation is valid for natural science. This is the view that Donald Gillies has come to embrace.[2] In his *Philosophical Theories of Probability*, Gillies presents and examines the various interpretations of the mathematical theory of probability: classical, logical, subjective, frequency, propensity, intersubjective as well as pluralist views of probability. Gillies divides these conceptualizations into two broad categories (of which we are already familiar): epistemological and objective. Gillies formulates his pluralist view of probability as a continuum on which the various interpretations lie, a patchwork of concepts connecting the abstract mathematics with things and ideas in the human world. This is a viewpoint that has largely accepted regarding probability in science and I will use the pluralist view in our analysis of QBism.

If one accepts a pluralist view of probability then it is natural to then try to discern in which contexts the application of each view is most appropriate. Gillies argues for the objective interpretation in natural science and the epistemological version in social science (particularly economics). Of interest to us here are his reasons for making this distinction. In response to De Finetti’s view that the subjectivist conception could be expanded to cover classical domains, including natural science, Gillies extols his opinion that, “I would argue that probability does really have a ‘more scientific and profound value’ in these [classical] domains”.[2] Gillies’ view is a common one in natural science- that the same mathematics of probability are somehow ‘more true’ when describing ontological, physical things than they are when representing belief states. In

Gillies' comparison of quantum physics and economics he makes the distinction precise, "In the case of Heisenberg's principle, it is only a question of *observations* influencing the subject matter. In the social sciences, it is *thoughts and beliefs as well as observations* which influence the subject matter." I want to highlight the inherent directionality of the influence that Gilles's posits here between observer and subject. He only acknowledges a one-way interaction in which there is some causal influence from the observer on the subject matter being observed, without any information or causal influence going from the phenomena to the observer. I find this to be an insufficient account of the nature of the interaction between observer and subject, especially in that he uses such a narrow and incomplete distinction to ground his division between where the objective/subjective interpretations are appropriate. Further, the difference between observation and observation + thoughts + beliefs is clearly negligible if we consider the observer/subject relation to have any symmetry, that is, bidirectional influence on each side of the relation.

At this point I would like to invoke the use of a perhaps crude, but useful metaphor for the sake of argument. The earth resides at just the right distance from the sun so that it orbits in the 'habitable zone', wherein the conditions are just so that life can flourish as it currently does. But there are other orbit distances from our sun and different conditions associated with the planetary orbits of each. Similarly, in the application of probability to social and natural science there exists a continuum, and philosophers and physicists have for some time divided parts of this continuum into analogs of the 'habitable zone(s)', in which our dominant ideas about the aims, abilities, and acceptable empirical results of science converge with our conceptions of truth, evidence, and explanatory value in philosophy. The current experimental findings and mathematical results in quantum mechanics do not fall within the habitable zone previously defined for physical science, and consequently we have struggled to understand how to best interpret the theory. We have coped by trying to conceptually coalesce the results into a way that fits into the habitable zone influenced by classical mechanics and Pythagoreanism for almost an entire century. There have been keen founders of quantum theory, namely Bohr and Heisenberg, whom have emphasized the inseparability of the phenomena with the observers and the instruments of observers in the quantum realm, yet most of the scientific community has not paid much heed to this idea. It is not the case, nor the argument of this paper, that QBism is the single theory that solves the issue of how to interpret quantum mechanics. The theory does, however, elucidate the deficiencies in our current conception of what physical reality is or can be known to be, and offers a self-consistent solution. In this way, I am not arguing for the need of a paradigm shift in a Kuhnian sense, where we need to displace our habitable zone by some distance or widen it, etc. I am arguing that the directionality inherent in the analysis and interpretation of physical and mathematical ideas of quantum mechanics should be explored in both directions, and theories that do this should be taken seriously. We should be attempting to understand what the specifications of our habitable zone are, and how that influences the results and interpretations of physical theories. QBism presents an option to interpret quantum theory in a bidirectional manner, in which physical reality is interconnected with the observers situated and participating in it.

This paper has presented a view of QBism that is positive, while not fully embracing or arguing for the superiority of the viewpoint. If one adopts the tenets of QBism, many of the problems in foundation quantum theory that have plagued physicists and philosophers are resolved. Inverting the argument, we can see this not just as reason to accept QBism, but rather to give evidence to the power of the subjective interpretation of probability in physical science. QBism presents a self-consistent interpretation of quantum theory that is powerful, despite seeming epistemically limiting at first. Physicists need not give up a realist view of physical reality, but rather can understand how to the role of probability can be more versatile in foundational science than previously conceived. The role of epistemic probability in quantum mechanics has been shown to bridge the gap between the agent and the reality that he/she is situated in and is interacting with. The account of this relationship, rather than being fully accounted for in QBism, has simply been shown to be relevant, powerful, and necessary in the philosophical investigation of quantum foundations.

References

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