The Message of the Quantum?

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Abstract. We criticize speculations to the effect that quantum mechanics is fundamentally about information. We do this by pointing out how unfounded such speculations in fact are. Our analysis focuses on the dubious claims of this kind recently made by Anton Zeilinger.

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Quantum theory has always invited rather extreme speculations about the nature of physical reality. John Wheeler [1], for example, famously conjectured that quantum mechanics suggests a "participatory universe" in which the present observations of experimentalists can give "tangible reality" to the distant past, that current actions can somehow *produce* the past physical structure of the universe, rather than merely *inform* us about it. It is a bold speculation, but one underpinned by nothing in quantum mechanics itself. Neither the experimental consequences of quantum mechanics nor any presently existing precise understanding of the theory support this astonishing suggestion. "Quantum mechanics" cannot justify this speculation because precisely formulated theories that recover the quantum mechanical predictions do not posit any such backward effect. So one sure check on claims about "the lesson of quantum theory" can be obtained by considering precise theories that recover all of the quantum predictions that have ever been verified. Several such theories exist.

Wheeler's rather obscure ideas appear to live on today in the remarkable suggestion that physics is only about information or, even more astonishingly, that the physical world itself just *is* information. The first suggestion would seem to contradict the everyday belief that physics is concerned with the physical structure of objects and the laws governing that structure: it is, therefore, about molecules and atoms and stars and electrons, among other things. Electrons can be *used* in systems that convey information, as in telephone lines, but that is a rather specialized set of circumstances, and physics should cover all of the universe, not just special systems. As for the suggestion that the physical world just *is* information, the suggestion sounds more mystical than scientific. If it were to be put forward as a serious proposal it would need both clarification and powerful justification. Unfortunately, when the topic of discussion is quantum theory, basic standards of clarity and argumentation seem to be abandoned, even in the most prestigious journals.

A conspicuous example has recently been published by Anton Zeilinger. He has put forward, in his essay "The message of the quantum" [2], some thoughts about the relationship between reality and information, very much in the spirit of the traditional "Copenhagen" view of quantum mechanics. He has accompanied his opinion with his personal summary of the conclusions that one should draw from quantum mechanics at the centennial of Einstein's annus mirabilis. Unfortunately, his claims are at best dubious, and most of them are simply wrong.

Zeilinger writes that "The discovery that individual events are irreducibly random is probably one of the most significant findings of the twentieth century." He claims, in other words, that determinism has been refuted, that it has been proven that (some) individual events in the quantum world are irreducibly random, rather than merely seeming random because of our ignorance. This conclusion has been challenged, most famously by Einstein. On what basis does Zeilinger conclude that Einstein was wrong? He presumably relies on the various no-go or no-hidden-variables theorems—of von Neumann, Bell, Kochen and Specker, and the like—which are supposed to show that quantum randomness can't be regarded as arising merely from ignorance. However, in his seminal paper [3] "On the problem of hidden variables in quantum mechanics," John Bell has shown that these theorems involve unwarranted assumptions, and thus don't justify the rejection of Einstein's view about the origin of quantum randomness.

Perhaps Zeilinger merely means that the predictions of quantum theory—or at least the experimental facts on which quantum mechanics is based—strongly support a nondeterministic formulation. But this view is easily refuted by the counter-example provided by Bohmian mechanics [4, 5], a theory describing the deterministic evolution of particles that accounts for all of Zeilinger's examples and indeed all of the phenomena of nonrelativistic quantum mechanics, from spectral lines to the two-slit experiment and random decay times. Thus, the experimental facts of quantum mechanics do not establish indeterminism. At best, which explanation of the experimental facts to prefer, Bohm's simple deterministic one or the convoluted indeterministic one of the Copenhagen view, remains our theoretical choice.

Zeilinger suggests that "one could find comfort" in the idea of determinism, if it were tenable. This suggestion, whatever its merits, gives entirely the wrong impression of the main motivation of the critics of the Copenhagen view. David Bohm and John Bell [3], two of its leading critics, did not hesitate to use stochastic theories—with irreducible randomness—when that served a purpose. Even Einstein, often inappropriately depicted as a stubborn adherent of determinism claiming that "God does not play dice," made it clear in his “Reply to Critics” [6] that he rejected the Copenhagen view not because of its indeterminism but because it fails to describe quantum phenomena in terms of objective events occurring independently of subjective perceptions.

Zeilinger writes that “John Bell showed that the quantum predictions for entanglement are in conflict with local realism.” In fact, realism was not among the assumptions Bell used for deriving the conflict with quantum mechanics, even though realism about spin observables—which is much more than realism in general—occurred in the argument as an implication of locality. What Bell proved is that the predictions of quantum theory for spin correlations are incompatible with locality, i.e., that quantum mechanics is irreducibly *nonlocal*, a point that Bell [3] repeatedly stressed.

In Zeilinger’s view, Bell’s result suggests, not that there is nonlocality, but that “the concept of reality itself is at stake.” What that is supposed to mean is left vague, but it is hard to see what the meaning could be that does not ultimately lead to the view that nothing exists objectively outside our minds. That is not a scientific view and there is nothing in Bell’s result to support it. And contrary to Zeilinger’s claim, it is not supported by the Kochen–Specker theorem either, as Bell was the first to point out: It cannot be maintained that the Kochen-Specker paradox supports the notion that there is a problem with “the concept of reality itself” when there are perfectly realistic theories, such as Bohmian mechanics or the Ghirardi–Rimini–Weber version of quantum mechanics involving spontaneous random collapse of the wave function [7], that account for all of the experimental facts on which that paradox is based.

Interestingly, Zeilinger draws the correct moral from the Kochen–Specker paradox when he writes: “even for single particles, it is not always possible to assign definite measurement outcomes independently of and prior to the selection of specific measurement apparatus in the specific experiment.” That is, in giving a physical account of a measurement, we must take account of the exact physics of the experimental situation. Indeed, Bohmian mechanics and the Ghirardi–Rimini–Weber version of quantum mechanics allow us to do precisely this, since they do not postulate some special physics for measurements. And once done, all the predictions come out right.

Most baffling, Zeilinger suggests that “the distinction between reality and our knowledge of reality, between reality and information, cannot be made.” After such a counterintuitive assertion, we naturally expect to find a mighty argument in its behalf. Here, however, is Zeilinger’s: “There is no way to refer to reality without using the information we have about it.” In other words, what we can say about reality, or better what we can know about reality, must correspond to our information about reality. In other words, what we know about reality must conform to what we know about reality. Does Zeilinger really believe that a tautology such as this can have interesting consequences?

The very concepts of knowledge and information imply a special kind of relationship between different things, appropriate correlations between a knower and what is known. Thus “the distinction between reality and our knowledge of reality” not only can be made; *it must be made if the notions of knowledge and information are to have any meaning in the first place.*

At a time when the forces of obfuscation in America are engaged in a campaign against the theory of evolution on behalf of Intelligent Design, it is perhaps worth asking Zeilinger how the idea that there is no difference between information and reality can be compatible with the emergence of information processing systems such as we are from a lifeless reality. And it is perhaps also worth asking the editors of Nature how, at a time when, rightly, papers on Intelligent Design are consistently rejected by peer-reviewed journals, an essay like Zeilinger's is not.

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