In Search of a Contemporary World View: Contrasting Thomistic and Whiteheadian Approaches

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Revising Whitehead's Notion of Society in the Light of Contemporary Physics

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Abstract: This article argues that Joseph A. Bracken's revisions of Alfred North Whitehead's derivative notion of "society" are plausible in view of developments in physics since Whitehead. In particular, Bracken argues that Whitehead's derivative notion of "society" should rather be a category of existence equiprimordial with "actual entity," and that contemporary actual entities in concrescence do influence each other as they directly prehend the society as a nexus. The article begins with Whitehead's view of the metaphysical project as empirical, tentative, and subject to ongoing revision. Next, the essay explains Whitehead's view of societies and contemporary actual entities. Following this is a survey of developments in physics since Whitehead that are relevant to his understanding of "society" and contemporary actual entities. The article then explains how Bracken differs from Whitehead on these points and argues that the physics developments corroborate Bracken's proposed revisions to Whitehead. The essay ends with a restatement of Whitehead's view of metaphysics as provisional and in need of ongoing revision.

Keywords: Alfred North Whitehead, Joseph A. Bracken, Process Philosophy, Process Theology, Process Thought, Metaphysics, Ontology, Philosophical Theology, Fundamental Theology, Thomism, Substance, Science and Religion, Physics

Introduction

Throughout his career Joseph A. Bracken has worked on revising the Whiteheadian notion of a "society" of actual occasions in ways that he holds are scientifically and philosophically necessary. Whitehead himself sought to construct a rigorously empirical metaphysics that included the revolutions in physics at the beginning of the twentieth century in addition to developments in modern philosophy. He repeatedly and unequivocally urged the tentative nature of metaphysics as always open to revision pending new data.[1] Here I attempt to demonstrate the plausibility of Bracken's revisions of Whiteheadian societies by: (1) summarizing Whitehead's position; (2) surveying some germane developments in physics since Whitehead; and (3) explaining how Bracken's revisions better accord with the data.

Substance and Actual Entity

As this treatment necessarily references Whitehead's category of actual entity, and as this category replaces Aristotle's first category of being, "substance" or *ousia*, I'll begin with a few words about substance and actual entity.

1 See, for instance, Whitehead, *Process and Reality*, xiv, 7–10, 14–17, 42, 146, 156.

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Aristotle defined his first category of being, *ousia* or substance, as that which is neither predicated of nor present in anything.[2] To this subject independence later western philosophy added causal independence (e.g., Descartes) such that a substance does not inhere in another subject and is its own reason.[3] A substance exists on its own and has only accidental relationships with other things.

In *Science and the Modern World* (1925) Whitehead's vision of a new first category of being took shape. By that time, new developments in physics already suggested that time and space are relative, matter is energy, beings and facts are tied to subjectivity and experience, and that relationality is essential—not accidental—to physical reality.

Whitehead saw how all of this put classical "substance" in jeopardy. He proposed a new first category of being, the "actual entity" or "actual occasion."[4] The actual entity is an infinitesimal, indivisible, non-temporal, event-like, subject and object of experience. It is perspectival, has its own "here now," and is internally constituted by its relationships with all other things. Whtitehead calls these internal constitutional relations "prehensions," and the self-constitution "concrescence."[5]

Substance and Society

Actual entities are the "building blocks of reality" behind which lies nothing else, the "final real things of which the world is made up," and, "the ultimate agents of stubborn fact."[6] "In separation from actual entities there is nothing, merely nonentity—'The rest is silence'."[7] All factuality and causality depends on an actual entity.

Actual entities perpetually come into being and subjectively perish. In so doing they create an extensive world. As indivisible they have no spatio-temporal extension.[8] This raises questions about the larger objects of our experience and the endurance of the same across periods of time. Whitehead's category of "nexus" and derivative notion of "society" deal with these questions.[9] A nexus is a set of actual entities in their interrelatedness, and is as "real, individual, and particular" and "factual" as its member actual entities. As such it is itself an object for prehension.[10]

Although "nexus" is a category of existence "society" is a "derivative notion of order," being a nexus enduring across time due to a "defining characteristic" or "common element of form." Hence societies are the "enduring objects" of our experience. Although actual entities do not endure or change, a society has an essential character making it the individual society it is and accidental qualities that vary in different circumstances.[11]

The societal form is perpetuated as successive member entities inherit it from their predecessors,

2 Aristotle, *Categories*, 2a11, 1:4.

3 Causal independence means existing or remaining in existence independently of another entity or entities' causal power(s). Subject independence means being able to exist without requiring another entity as a subject in which to exist, or, in other words, to not be a property, mode, or accident of some other substance. In classical western philosophy, causal independence is attributed to "primary" or "uncreated" substance (cf. Descartes' terminology), which was God in western forms of classical theism, including Thomism.

4 Whitehead, *Process and Reality*, xiii, 18–19, 22.

5 Whitehead coined the term "prehension" to specify the entity's internal relatedness to its world, consciously eschewing the word "apprehension" because the latter connotes a subject grasping an inert and vacuous object. Prehensions express the concrete facts concerning an actual entity's relationships to all other entities. These relationships are the causes of its constitution.

6 Whitehead, *Process and Reality*, 18, 27–38, 35, 43, 62–63, 80, 128–29, 227, 245.

7 Ibid., 43.

8 "[T]here is a becoming of continuity, but no continuity of becoming." In other words, "extensiveness becomes, but 'becoming' is not itself extensive" (ibid., 35).

9 Ibid., 34–35, 55, 55–57, 72, 83–84, 89–109, 110–111, 129, 192, 244.

10 Ibid., 20, 22, 24, 27, 63, 101, 114, 221, 251, 287. See also, Whitehead, *Adventures of Ideas*, 20–35.

11 Whitehead, *Process and Reality*, 35, 73, 109, 124–26. "The real actual things that endure are all societies. They are not actual occasions [actual entities]. . . . A society has an essential character, whereby it is the society that it is, and it has also accidental qualities, which vary as circumstances alter. . . . Thus a society, as a complete existence and as retaining the same metaphysical status, enjoys a history expressing its changing reactions to changing circumstances. But an actual occasion has no such history. It never changes. It only becomes and perishes" (Whitehead, *Adventures of Ideas*, 204).

making a society "self-sustaining" and its "own reason." The member entities exist by laws dominating the society that come into being through the analogous character of the members. These laws arise, dominate, endure, and cease, at which point the society is no more.[12]

Herein lies a key aspect of Bracken's revisions. According to Whitehead's "Ontological Principle,"[13] only what is actual can be a cause or reason. Entities contemporary from each other's perspective are not actual to one another and so cannot directly influence one another.[14] Therefore, only entities that are past from the perspective of a new entity are involved in the perpetuation of the societal form.

Whitehead on Contemporary Actual Entities

In treating "contemporary" actual entities Whitehead appeals to space-time relativity to show that an entity lies in multiple "durations" and that no two entities define the same "given" actual world.[15] A "duration" is a cross-section of the universe where an actual entity is "stationary" or not moving, and defines the immediately "present" condition of the world for that entity. Newtonian space-time assumed there is only one "duration" including an entity and all of its contemporaries. In reality an entity's immediate present lies in only one "duration" but the entity itself lies in an infinite number of "durations." Each duration in which an entity lies includes the entity and some portions of its one presented duration. No duration in which it lies includes all of its contemporaries.[16] Thus there is no absolute "present" in which all occasions lie but instead as many "presents" as there are actual occasions.

An entity's actual world is the community of entities that are settled, actual, and hence in the "past" from its own perspective. Only an occasion's settled past world causally influences it.[17] Because they are not actual but rather share its "presented duration" in a "unison of becoming," a concrescent entity's contemporaries do not belong to its actual world and so cannot causally influence it on account of "The Ontological Principle."[18]

Some Relevant Developments in Physics since Whitehead

Developments in physics since Whitehead may require reexamination of his notion of society and his view that contemporary entities are causally independent of one another.[19]

After Whitehead's Gifford Lectures and before his death, Einstein, Podolsky, and Rosen (EPR) tried to show that early quantum mechanics was not a complete physical theory.[20] Quantum theory predicts that

12 Whitehead, *Process and Reality*, 34–35, 89–91; Whitehead, *Adventures of Ideas*, 20–34.

13 Whitehead, *Process and Reality*, 18–19, 24, 40, 43, 46, 78.

14 Ibid., 61, 318.

15 Ibid., 65–66, 125, 320–21. Whitehead did not accept Einstein's theory of gravitation as based upon a space-time of variable curvature. He retained homogenous space-time and set up an alternative law of gravitation.

16 Ibid., 125–26, 320 –21; cf. Whitehead, *Science and the Modern World*, 119 –21, 124–25.

17 Whitehead, *Process and Reality*, 173, 176–78. See also, Whitehead, *Symbolism*, 39–50. In Newtonian space and time contemporary entities define the same actual world and hence have the "same" past, but relativity dictates that no two actual entities define the same actual world (Whitehead, *Process and Reality,* 65–66). What from the perspective of one entity lies in the past may be in the future of a contemporary entity.

18 Whitehead, *Process and Reality*, 61–66, 83, 123–26, 168–69, 318, 320. In discussing "perception in the mode of symbolic reference" Whitehead does say a percipient occasion can directly prehend the antecedent entities of its contemporaries perceived in presentational immediacy. This direct causal influence of its contemporaries' predecessors does amount to an indirect perception of its contemporaries (ibid., 169). Thus through the mediation of the past an occasion's "present" does causally enter into its constitution. Whitehead is clear, though, that contemporary occasions are causally independent, because causal efficacy is from the contemporaries' predecessors, not the contemporaries themselves (ibid., 321).

19 For time and space reasons this section contains short descriptions. Some of the (extensive) footnotes here give further explanations. My essay in the *Festschrift* for Joseph A. Bracken contains such a more detailed explanation of the Einstein, Podolsky and Rosen (EPR) Paradox and Bell's Inequalities. See, Pugliese, "Orthodoxy or Orthopraxy?"

20 Einstein, Podolsky, and Rosen, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" They defined a "complete physical theory" as one where every element of physical reality is accounted for in the theory.

when the momentum of one of two entangled but space-like separated[21] particles is measured the other's momentum is definitively known. Assuming the longstanding "principle of local action"[22] it is really the case that they could be measured at different momentums, said EPR. Because quantum theory does not contain the local but hidden variables necessary for explaining this possibility it is not "complete."

Almost thirty years later John S. Bell used a variant of the EPR experiment[23] to show quantum theory is incompatible with any explanation assuming local hidden variables (Bell 1964).[24] To summarize, the probabilities of a correlation predicted by quantum theory exceeded the upper-limits of those predicted using locality and hidden variable assumptions. This means either local hidden variables are at work and quantum theory is wrong or quantum theory is right and it is impossible for local hidden variables to be at work. Dozens of increasingly refined Bell-type experiments have since vindicated quantum over classical assumptions,[25] with a 1982 experiment that changed the measuring devices' positions at virtually the instant of measurement being seen as a watershed.[26]

Practically since the beginnings of quantum mechanics, physicists and philosophers have proposed an array of ways to interpret the results of quantum measurements. Many physicists do not concern themselves with this task,[27] but a number do. Importantly here, the results of Bell-type experiments are not in question. At stake is the interpretation of the results, including how to explain them.[28]

A number of interpretations of quantum mechanics have questioned the self-imposed limitations of Bohr and Heisenberg's popular Copenhagen Interpretation, which eschews questions of what is "really happing objectively" in a quantum measurement. Instead, these other interpretations claim a sort of metaphysical realism that demands some sort of answer to this question. After all, quantum measurements still involve "facts" and there is a precarious or felicitous slippery slope—depending on one's philosophical proclivities—from "fact" to ontology. With respect to the experimental violations of Bell's Inequalities, ontological realism implies some sort of "real" connection between the two space-like separated but entangled particles.

The experimental violation of Bell-type inequalities means that two space-like entangled particles are somehow connected. The problem is explaining how the entangled particles "know" each other's measured properties across a space-like separation.[29] Some have asked if faster-than-light (superluminal)

21 Space-like separation means separation that requires at least some time for light to traverse.

22 The "principle of local action" says that far apart objects cannot causally influence one another without being mediated by something in between. The problem here is that the speed of light is constant and the particles are space-like separated. Physics had long taken the "principle of local action" to be a blatantly obvious fact of commonsense.

23 Bohm, *Quantum Theory*, 611–23.

24 Bell, "On the Einstein Podolsky Rosen Paradox," 195–200.

25 Freedman et al., "Experimental Test of Local Hidden Variable Theories," 938–41; Clauser and Shimony, "Bell's Theorem. Experimental Tests and Implications," 1881–1927; Watson, "Quantum Spookiness Wins, Einstein Loses in Photon Test," 481; Weihs et al., "Violation of Bell's Inequality under Strict Einstein Locality Conditions," 5039–43; Rowe et al., "Experimental Violation of a Bell's Inequality with Efficient Detection," 791–94; and Gröblacher et al., "An Experimental Test of Non-local Realism," 871–75. The Watson experiment observed a correlation at over ten kilometers.

26 Aspect, Dalibard and Roger, "Experimental Test of Bell's Inequalites Using Time-varying Analyzers," 1039–43.

27 After the EPR paper appeared Bohr produced an explanation based on an aspect of the Copenhagen Interpretation of quantum mechanics and the "quantum postulate." In the former the measurement apparatus affects the measurement itself and in the EPR thought experiment there are two different apparatuses, one for each particle. In the latter, there really is no distinction between the system being measured and the measuring apparatus, so they must be treated as an indivisible whole. Taken together the Copenhagen Interpretation and the quantum postulate mean that in the EPR thought experiment the two measurements are on two different and incommensurable systems, each comprising its own measured particle and its own measuring apparatus affecting the measurement. These two "wholes" cannot be compared. The measurement is particular to each observed particle, so speaking of correlations in measurements between the two systems is impossible. Bohr's explaining away of the paradox was based on the EPR paper, not on the results of Bell-type experiments, since Bell's Inequalities and Bell-type experiments came later.

28 Various imperfections of Bell-type experiments, called "loopholes," have been identified. Each has been ruled out by an experiment, but no one experiment has ruled out all of them (Shimony, "Bell's Theorem"). The lack of absolute certainty is not particular to this evidence but is a general characteristic of the empirical method. It is simply impossible to guarantee one-hundred percent accuracy. The consensus of the scientific community, though, is that the evidence is sufficient to support Bell's Theorem.

29 "The central mystery of quantum theory is 'how does information get around so quick?' . . . Quantum phenomena provide prima facie evidence that information gets around in ways that do not conform to classical ideas" (Stapp, "Are Superluminal Connections Necessary?" 190–204).

communication explains the observed results of Bell-type experiments, but speaking of transmission of information at any speed implies classical separability. Also, in special relativity an infinite amount of energy is required for matter-energy to accelerate to the speed of light so it is impossible to transmit information (i.e., signals) exceeding such a speed. Thus only a small minority entertain the viability of superluminal communication as an explanation of the violation of Bell's Inequalities.[30]

John von Neumann, one of the founding fathers of quantum mechanics, later proposed a completely new way of understanding quantum measurement that also provides an explanation for the nonlocal state observed in the experiments violating Bell's inequalities. It essentially precludes classical separability.

In the early days of quantum mechanics Von Neumann formulated the mathematics that includes the "wave function," identified and named the related "problem of measurement," and helped develop "quantum logic."[31] In the 1950s Von Neumann did additional work on the problem of measurement.[32] Bohr's quantum postulate had already allowed for conflating the measured system and the measuring apparatus into one so that there really is no distinction between the system being measured and the measuring apparatus. Then they have one wave function and are an indivisible whole. Can we not erase the subject-object distinction between the experimenter and the measuring apparatus, just as the quantum postulate says we can collapse the distinction between the measuring apparatus and the measured system? He contended that any such subject-object distinctions are arbitrary abstractions.[33]

30 Special relativity does not forbid hypothetical particles with imaginary mass, like tachyons, from traveling faster than the speed of light. However, they are not accelerating and they decay spontaneously. In some cases, as with the Higgs boson, this decay process results in a stable configuration, but one with no tachyons. Some theorize that neutrinos are like tachyons but this is disputed. Some systems propagate faster than the constant speed of light but they do not transmit information. It is also possible for particles to travel faster than the speed of light refracted through a medium, but the speed of light refracted through a medium is always less than the speed of light in a vacuum. There is a hypothesis that unusually distorted regions of space-time may permit matter to reach distant locations in less time than light would reach them in undistorted regions of space-time, or "apparently" faster than light. This would be compatible with general relativity but current theories of matter only permit matter to travel at less than the speed of light in such distorted regions of space-time. Some wave transmission speeds, such as "phase velocity" and "group velocity," can exceed the speed of light but they do not transmit information. A wave's "front velocity" can never exceed the speed of light according to special relativity. For an explanation of the different types of wave velocities, see Léon Brillouin's standard work, *Wave Propagation and Group Velocity*. Apparent faster-than-light speeds violating special relativity have been measured in tunneling experiments, but how to interpret these results is disputed. These are associated with a group at Berkeley under Raymond Chiao (e.g., Steinberg et al., "Measurement of the Single-Photon Tunneling Time"), a group in Switzerland associated with Günter Nimtz (e.g., Nimtz, "Tunneling Confronts Special Relativity"), and another group in Switzerland (Eckle et al., "Attosecond Ionization and Tunneling Delay Time Measurements in Helium," 1525–29). See also, Razavy, *Quantum Theory of Tunneling*, 462. There is a consensus among physicists that these experiments have not observed speeds that are actually faster than the speed of light based on interpretations consistent with special relativity (e.g., phase velocity, group velocity, reshaping of the wave packet). See for instance, Diener, "Superluminal group velocities and information transfer"; Low, "Comments on apparent superluminal propagation"; Sokolovski, "Why does relativity allow quantum tunneling to 'take no time'?"; and Winful, "Tunneling time, the Hartman effect, and superluminality: A proposed resolution of an old paradox". Right before he died in 1990, Bell himself left open the question of whether the results of the Bell-type experiments actually violate special relativity (Bell, "La nouvelle cuisine").

31 In a quantum experiment the observed system is mathematically symbolized by a wave function. This wave function is the "coherent superposition" of all possible results of an interaction between the observed and measuring systems. The Schrödinger wave equation deterministically describes the development of the wave function and can be used to calculate the coherent superposition of all possibilities at any given point. A "probability function" can be used to calculate the probability of each possibility represented in the wave function actualizing at that specific point. At the moment a system is measured, the superposition of many possibilities "collapses" into only one actuality from the perspective of the subject performing the measurement. The system then continues to propagate according to the possibilities described by the Schrödinger wave equation, but then limited by the one determinate actuality that appeared during said measurement. The "problem of measurement" involves questions about the relationship between measurement and the collapse of the wave function. Does the subject performing the measurement "cause" the collapse? If there is more than one observer, then whose observation causes the wave function to actualize in collapse? Von Neumann saw a causal connection between the observer and the perceived wave function collapse.

32 Von Neumann, *The Mathematical Foundations of Quantum Mechanics*.

33 The unity of subjectivity and objectivity evokes the German idealists, part of whose project was responding to Kant. Kant's understanding of what space and time are was wrong in terms of relativity theory, and Whitehead had much to say about what he himself considered to be the philosophical errors Kant bequeathed to us.

Now when we do make these subject-object distinctions the experiencing subject could be anything and everything. We can predicate the experience of perception, or subjectivity, to every element of the physical world. For example a "thermometer" measures temperature. The experimenter's eye observes the thermometer. But we could also say the eye's retina is observing, or maybe the retinal cells. Quantum theory allows for the positing of experience and subjectivity to primordial events. Essentially all aspects of the physical world, at all levels, could be assigned a wave function including, in principle, any entity with subjectivity.

Further, whenever and however we divide up the world in this way, on the quantum postulate we can take the subject and object as one observing system. For example, not only the apparatus, the experimenter, the eye, the retina, the cells and their molecules and atoms, but also the parts of the measuring apparatus, parts of the surrounding environment, etc., can be represented by one irreducible wave function. Every level at which we divide up reality—inorganic as well as organic—is a system that can be mathematically depicted with its own wave function.

What Von Neumann is saying has implications for what we consider "closed systems" and what we consider "open" systems. A closed system is considered thermodynamically isolated and hence "separable." Technically, the Schrödinger wave equation applies only to closed systems. Thus whatever wave functions we use imply that what they describe are approximated as closed systems.

In reality, each "whole" system may be depicted as interrelated parts and vice versa. Two space-like separated particles in quantum entanglement may be depicted by their own wave equations and hence as separate systems. However, they may also be depicted together as one whole system with one wave equation. It is all a matter of how we divide reality up, so to speak. Von Neumann even mused that in a Bell-type experiment at the top of this interrelated hierarchy of divisions is the universe, which as a whole has its own wave function. Since von Neumann's work in the 1950s others have appropriated aspects of his points here, with their own variations. They all have this "holistic" element, however.[34]

Although different in other key ways such as in its determinism, David Bohm's particular "holism" is one of the most widely known denials of ultimate separability akin to von Neumann's. Bohm himself espouses a form of realism which says that the two space-like separated particles in quantum entanglement are objectively real and are really connected. Beyond the mathematical formalism of wave function depictions, in Bohm's model there is a robust ontological connection of the whole universe as one system connected at its deepest level as one unbroken whole, including all space-time and matter-energy.[35] Particles appear to be separated and discrete in what Bohm calls the "explicate order," but they are really connected at this deeper level, which he calls the "implicate" order. Concerning this interconnectedness, Bohm and Hiley write:

> Parts are seen to be in immediate connection, in which their dynamic relationships depend, in an irreducible way, on the state of the whole system (and, indeed, on that of broader systems in which they are contained, extending ultimately and in principle to the entire universe). Thus, one is led to a new notion of unbroken wholeness which denies the classical idea of analyzability of the world into separately and independently existent parts.[36]

This sort of "holism" is relevant to explanations of the violation of Bell's Inequalities because there are real particles and they are connected. Entangled particles comprise a simple irreducible fact that cannot be reduced to more fundamental nonrelational facts.[37] The number of physicists who are abandoning locality and separability assumptions to theorize a form of "holism" is growing.[38]

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34 Some variants of von Neumman's interpretation of quantum mechanics contribute to constructions of theories of downward causation in complex systems.

35 Bohm, *Wholeness and the Implicate Order*.

36 Bohm and Hiley, "On the Intuitive Understanding of Nonlocality as Implied by Quantum Theory."

37 Teller, "Relativity, Relational Holism, and the Bell Inequalities."

38 Shimony, "The Methodology of Synthesis: Parts and Wholes in Low-energy Physics"; Cushing and Ernan McMullin, *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem;* Finkelstein, *Quantum Relativity: A Synthesis of the Ideas of Einstein and Heisenberg*; Witten, "Duality, Spacetime and Quantum Mechanics"; Auyang, *Foundations of Complex Systems Theories*; and Jungerman, "Evidence for Process in the Physical World," 47–49.

There is also a part–whole reciprocity here. At measurement the wave function depicting the observed system collapses into only one determinate actuality. The depiction of the system then continues to propagate according to the possibilities described by the Schrödinger wave equation, but now limited by that one actuality. After the collapse there are still probabilities of possibilities for actualization in that system but they are now limited by the actuality observed.[39]

When we divide things up into one comprehensive system inclusive of the measured system plus measuring apparatus plus experimenter plus environment plus whatever else on the one hand, and the measured system considered discretely on the other hand, both have a wave function. We can speak of changes in both wave functions at the point of measurement.

If we have a more ontologically realistic instead of a mathematically formalistic interpretation, then we can say that at the moment of measurement the one broader, more inclusive, system affects the discretely considered observed system. There is a sort of "top down" causal influence of the whole on the parts. Because the more comprehensive system's wave function also changes at measurement there is also an influence of a part on the whole.

We may add an information factor to this point about mutual reciprocity between parts and wholes. A system's wave function contains information. The larger wave function including observers contains "knowledge" of the measured system's state. Measurement of an observed system changes this information and the observed system then propagates in a way that has been affected by the information obtained in the measurement.

John Archibald Wheeler, whose "delayed choice" experiments will be mentioned shortly, emphasizes this point about information. Due to the reliance of what an observed system "is" on the act of measurement, every observed system—particles, force fields, and even the space-time continuum itself—possesses not only its meaning and function but also its very existence from the answers to questions solicited by the measuring apparatus. From this he concludes that all physical things are information-theoretic in origin.[40]

There are a few more related developments relevant to the consideration of Bracken's revisions. In the 1950s Heisenberg did work on the philosophical interpretation of quantum mechanics. At that time he speculated that, although what is symbolized by a system's wave function is not actual, it is more than a mere idea (i.e., a "form" or "essence"), stating that the probability concept here is like Aristotelian *potentia* changed from a qualitative to a quantitative understanding.[41] In his 1955–56 Gifford Lectures Heisenberg spoke of "something standing in the middle between the idea of an event and the actual event, a strange kind of physical reality just in the middle between possibility and reality."[42]

In addition, quantum logic, which I will only mention here, says that in this ontologically real but non-actual state there coexist incompatible possibilities that are mutually exclusive in ways that violate the classical laws of logic. Garrett Birkhoff and John von Neumann did the initial work with quantum logic by

39 This is similar to what Whitehead calls "real potentiality".

40 Wheeler, "Information, physics, quantum: The search for links," 3–14.

41 Heisenberg, "The Development of the Interpretation of Quantum Theory," 13.

42 Heisenberg, *Physics and Philosophy*, 41. He also says: "The other problem concerns the ontology that underlies the modified logical patterns. If the pair of complex numbers represent a 'statement' in the sense just described, there should exist a 'state' or a 'situation' in nature in which the statement is correct. We will use the word 'state' in this connection. The 'states' corresponding to a complementary statement are then called 'coexsistent states' by Weizacker. This term 'coexistent' describes the situation correctly; it would in fact be difficult to call them 'different states,' since every state contains to some extent also the other 'coexistent states.' This concept of state would then form a first definition concerning the ontology of quantum theory. One sees at once that this use of the word 'state,' especially the term 'coexistent state,' is so different from the usual materialistic ontology that one may doubt whether one is using convenient terminology. On the other hand, if one considers the word 'state' as describing some potentiality rather than a reality—one may even simply replace the term 'state' by the term 'potentiality'—then the concept of 'coexistent potentialities' is quite plausible, since some potentiality may involve or overlap other potentialities" (ibid., 185).

showing how quantum phenomena violate the distributive law.[43] Today physicists like David Finklestein are carrying on this work.

Related to this non-actual but ontologically real potentiality are thought experiments that John Wheeler proposed in the late 1970s and early 1980s based on Bohr's wave-particle complementary principle.[44] His goal was to determine whether: (1) an observed photon system somehow detects the kind of measuring apparatus being employed and on that basis determines itself so that it will be measured as particle-like or wave-like to correspond with the measuring apparatus; or (2) the observed photon is neither in a determinate wave or particle state until the measurement is made.[45] In scenario one the photon exists actually as—not merely *observed* to be as Bohr's complementarity principle states—either a wave or particle that can change from one to the other. In scenario two the photon is neither until it is observed.

Subsequently, many "delayed-choice" experiments have been performed and their results have led to a consensus among physicists that a particle retains wave-particle duality until the measurement is made.[46] Related is how some interpret the results of some of the Bell-type versions of delayed-choice experiments to indicate reverse-time causality where one particle accesses the past light cone of the other. Most physicists reject this interpretation, though, because in a Bell-type experiment both particles may be considered one unified and indivisible state by means of one space-time independent wave function comprising both particles.[47]

The final relevant development I'll mention is quantum field theory. Notwithstanding its incompleteness and current lack of internal consistency, unlike quantum measurement theory quantum field theory is consistent with relativity theory and has been remarkably successful in explaining interactions between particles, as well as the creation and destruction of particles. In quantum field theory "particles" are not

43 Birkhoff and Neumann, "The Logic of Quantum Mechanics." Von Neumann would later write: "[T]he relation between the properties of a physical system on the one hand, and the projections [wave function] on the other, makes possible a sort of logical calculus with these. However, in contrast to the concepts of ordinary logic, this system is extended by the concepts of 'simultaneous decidability' [the uncertainty principle] which is characteristic for quantum mechanics" (Von Neumann, *The Mathematical Foundations of Quantum Mechanics*, 254).

44 Bohr's "principle of complementarity" states that an observed system cannot manifest both wave- and particle-like properties at the same time. Importantly, this speaks of observation, not an objective state of affairs. A system can never be observed both as a wave and a particle at the same time.

45 Wheeler, "The 'Past' and the 'Delayed-Choice' Double-Slit Experiment," 9–48. The proposal involves an initial apparatus set up to measure that will definitely measure the photon as either a particle or wave—say a particle—and then changing the environment somehow to definitely measure the photon as the other—in this case a wave. This is called a "delayed choice" experiment because the first scenario assumes the particle is either a particle or wave and then makes a choice when the measuring environment is changed.

46 These involve observations at multiple times and have observed a photon at one point exhibiting its particle nature only to end life by demonstrating its wave nature on account of environmental changes. Those who demur from the consensus that light actually does have wave-particle duality until measurement contend that the photon is actually a particle and "decides" to determine itself to be a wave. One recent Wheeler-type experiment (Maa et al., "Quantum erasure with causally disconnected choice") involved two space-like separated photons in quantum entanglement. The measured correlations of the two entangled photons still depended on the experimenters' choice of measurement apparatus for one photon even though all events on both sides that can be space-like separated are in fact space-like separated. The researchers concluded that the fact that it is possible to decide whether a wave or particle feature manifests itself even when space-like separated from the measurement apparatus rules out the view that a photon is in a determinate particle or wave state and then can "choose" to determine itself as the other state. In their explanation they appeal to the sort of interrelated and layered wave functions von Neumann described: "The fact that it is possible to decide whether a wave or particle feature manifests itself long after—and even space-like separated from—the measurement teaches us that we should not have any naive realistic picture for interpreting quantum phenomena. Any explanation of what goes on in a specific individual observation of one photon has to take into account the whole experimental apparatus of the complete quantum state consisting of both photons, and it can only make sense after all information concerning complementary variables has been recorded. Our results demonstrate that the viewpoint that the system photon behaves either definitely as a wave or definitely as a particle would require faster-than-light communication. Because this would be in strong tension with the special theory of relativity, we believe that such a viewpoint should be given up entirely" (ibid., 1226). Wheeler himself abided by the strict Bohr complementarity principle interpretation that quantum phenomena are neither waves nor particles but rather undefined until measurement.

47 One experiment observed one of the states of one particle actually determined eight nanonseconds before how the other particle would be detected eight seconds in the future (Kim et al., "A Delayed Choice Quantum Eraser").

material substances "out there" like infinitesimal three-dimensional spheres. Particles are occasional and ephemeral perturbations of a field, structuring their environmental field, interacting with other fields, and exhibiting "particle-like" traits due to the puncticularity and instantaneous interactions between fields.[48]

Bracken on Societies as Fields and Contemporary Actual Entities

Bracken proffers modifications to Whitehead's views of societies and contemporary actual entities that appear to be more consistent with these developments in physics since Whitehead. Bracken sees Whitehead as doing much to redress what Whitehead called the "Fallacy of Simple Location"— expressing the spatio-temporal relations of ultimate matters of fact as if they were first unrelated and independent (like classical substances), and entering into relationships only secondarily and externally.[49] That Whitehead makes the actual entity the first category of existence and society a derivative notion raises doubts, however, about whether "nothing exists in isolation"[50] for Whitehead and whether he fully avoids the substantialist isolationism he wished to extirpate.[51]

A fully social-relational ontology must, says Bracken, make "society" equiprimordial with "actual entity" and thus a category of existence, not a derivative notion.[52] Hence Bracken attributes greater ontological reality than does Whitehead to a society as an objective reality distinct from and irreducible to the sum of its constituent actual entities.[53] This attribution of a greater ontological status to society is a reason why many object to Bracken's revisions of Whitehead here.

Even from strictly within Whitehead's system and apart from the physics considerations just surveyed, Bracken would point to how Whitehead himself says that a society is a "self-sustaining" reality with "its own reasons."[54] In *Adventures of Ideas* Whitehead does explicitly say a society is more than a set of entities to which the same class-name applies—more than a mere mathematical concept—and that even though they are not "completely real things" in the same way that actual entities are, they are the "real ontological things that endure" with a "complete existence" "retaining the same metaphysical status."[55] If so, then a society must be more than a bare form, ontologically real, and in some sense exist in its own right.

In terms of the considerations from physics, since the early 1960s physicists have been comparing the actualization of a quantum state upon measurement—a "quantum event"— to Whitehead's description of the actual entity.[56] If von Neumann is correct then reality is comprised of innumerable systems, each describable by its own wave function. Not only does a particle's quantum state's collapse upon measurement

48 Born, *The Restless Universe*, 206; Born, *Atomic Physics*, 96–97, 102; Bohm, *Causality and Chance in Modern Physics*, 90; Heisenberg, *Across the Frontiers*, 114; and Heisenberg et al., *On Modern Physics*, 13.

49 Whitehead, *Science and the Modern World*, 58.

50 Whitehead, *Process and Reality*, 28.

51 Bracken, *What Are They saying About the Trinity?* 82–83; Bracken, *The Triune Symbol*, 20, 42–43, 59n18; Bracken, *Society and Spirit*, 39, 48–49, 123, 135–36, 140, 148, 159–60, 178n32; Bracken, *The Divine Matrix*, 151–52n8; Bracken, *The One In the Many*, 98–99, 124–25, 132–33, 153–54, 165; Bracken, *Christianity and Process Thought*, 16, 55–56, 60, 106; and Bracken, *Three Who are One*, 66–68, 74 113–16. Whitehead said *perichoresis* is an advance of the Greek Church Fathers over Plato but faults them for never incorporating it into their overall metaphysical schemes so as to apply the same metaphysical categories to God and the world (Whitehead, *Adventures of Ideas*, 168–69).

52 Bracken, *The One in the Many*, 3, 5; Bracken, "Intersubjectivity and the Coming of God," 381–400; Bracken, "Proposals for Overcoming the Atomism within Process-relational Metaphysics," 10–24; Bracken, "Spirit and Society: A Study of Two Concepts," 244–55; and Bracken, "Substance—Society—Natural System," 3–13.

53 Bracken, *Society and Spirit*, 14; Bracken, *The One in the Many*, 167. In a real sense "the whole is greater than the sum of the parts." Bracken finds corroboration for this in strong emergent properties in the sciences, as well as in systems theory's employment of supervenience and downward causation (Bracken *The Triune Symbol*, 18–19; Bracken, *Society and Spirit*, 52, 110; Bracken, *The Divine Matrix*, 61; and Bracken, *The One In the Many*, 136, 167).

54 Bracken, *Society and Spirit*, 51. He cites Whitehead, *Process and Reality*, 89. See also, Bracken, "Substance—Society—Natural System," 11; and Bracken, "Spirit and Society," 247.

55 Whitehead, *Adventures of Ideas*, 203–4.

56 See, for instance, Burgers, "The Measuring Process in Quantum Theory," and Shimony, "Quantum Physics and the Philosophy of Whitehead."

bring about a quantum event at only the most infinitesimal level. A particle plus a measuring apparatus, the particle plus apparatus plus any one of a plethora of other observers, this group plus yet any other observer, etc., constitute more and more systems, each describable by its own wave function irreducible to its parts.

If the many ways we can divide up reality can each similarly be depicted by a wave function that is both irreducible to its parts and propagates according to the same laws, then at least on the descriptive level all systems have a type of ontological equivalence in this regard. Of course, Whitehead would urge an ontological realism with respect to quantum states instead of the sort of anti-realism associated with the Copenhagen Interpretation. On such realism the descriptions of quantum states correspond to something in reality and so the ontological parity between all systems and events is more than descriptive. It is "real" in some sense.

Further, these systems are hierarchically nested and intimately interrelated. Whitehead does speak of the hierarchical relationships of societies, with the current cosmic epoch as a society at the top of the hierarchy,[57] and of course Bracken concurs. However, Whitehead did not satisfactorily explain their interrelationships, according to Bracken.[58] The full-fledged social-relational ontology at which Whitehead was aiming requires a degree of interrelation between societies on the level of that between actual entities.

Some who object to Bracken's revisions here appeal specifically to the "Ontological Principle"—only what is actual can be a cause or reason. In our survey of physics developments we have also seen how a facile sharp distinction between potency and act seems problematic. The coherent superposition symbolized by the wave function contains possibilities that are themselves noncompossible and would violate the logical law of the excluded middle if actual. At the same time, the wave function's mathematical depiction corresponds to experience, and when systems interact their wave functions become correlated in a way that also corresponds to experience. This means they "act" or "are of consequence" (i.e., have causal powers).[59] This further means that what on traditional terms would be a potentiality, not an actuality, is "more ontologically real" than classical potency. That the non-actual can be a reason undercuts the objection resting on the Ontological Principle.

Here, too, Bracken would argue that his revised view of a society does not violate the Ontological Principle even within Whitehead's scheme and apart from these physics considerations. For, Whitehead himself says that a society is a type of nexus, and a nexus is "real, individual, and particular," a "public matter of fact" for prehensions (causally efficacious internally constitutive relations).[60] Again, Whitehead says that a society is a "self-sustaining" reality with "its own reasons."

If societies are "self-sustaining" realities with their "own reasons," and if they are the "real ontological things that endure" with a "complete existence," then societies themselves must condition their own member entities, says Bracken.[61] Problems for Whitehead's presentation include the perpetual perishing of the non-temporal entities upon which a society depends, and that the noncontiguous nature of successive entities attenuate a society's real continuity.[62] If actual occasions are fleeting events then the societal form cannot both exist solely in them and endure across time.[63]

In an echoing of quantum field theory, Bracken defines a Whiteheadian society as an "enduring structured field of activity for its member occasions"[64] and "a context for the interaction of entities

57 Whitehead, *Process and Reality*, 90–92, 98, 327, 333.

58 Bracken, *Society and Spirit*, 50, 68; Bracken, *The One In The Many*, 135–40; Bracken, *God, Three Who are One*, 116.

59 This power to be of consequence is the etymology of "actuality" and was central to Whitehead's understanding of the relationship between causality and actuality.

60 Whitehead, *Process and Reality*, 20, 22, 31–36.

61 Bracken, "The Theology of God of Elizabeth A. Johnson," 31.

62 Bracken, *The One in the Many*, 148; Bracken, *Christianity and Process Thought*, 106–7; Bracken, *God: Three Who Are One*, 66–67, 113–14; and Bracken, "Intersubjectivity and the Coming of God," 391.

63 Bracken, "Proposals for Overcoming the Atomism within Process-Relational Metaphysics," 22n 3.

64 Bracken, *Society and Spirit*, 55, 58, 61–63, 68–69, 129, 149; Bracken, *The Divine Matrix*, 52–69; Bracken, *The One in the Many*, 147, 148–50, 154, 167; Bracken, *Christianity and Process Thought*, 17, 57–58, 106–7; and Bracken, *God: Three Who Are One*, 66–67, 77–78.

which is itself somehow structured by the interplay of those same entities."[65] In this way Bracken's more ontologically robust society plays a greater role than Whitehead's notion of society in the transmission of its law-like structure or defining characteristic from one generation of occasions to the next.[66]

Bracken does agree with Whitehead that: (a) the societal form is transmitted only through the concrescent member entities' objectified prehensions of the societal form in their predecessors; (b) past members impose the form on successive members; and (c) succeeding members embody the complex eternal object that is that societal form. So there is a society only by reason of the interrelatedness of the society's constituent entities. [67]

At the same time, because every entity is irreducibly particular in its own perspective each new societal member shares the society's form differently from its contemporaries and only imperfectly embodies it.[68] Bracken's difference from Whitehead here, then, is that instead of objectifying the societal form through prehensions of the form in their predecessors[69] new members directly prehend the societal structure by prehending the societal nexus as a public matter of fact. Continuity is insured in the direct prehension of the societal form as a nexus, not only as it is embodied in the society's member occasions.[70] Because nothing exists apart from actual entities, this prehension is of the form together with the society's constituent entities. This is not a prehension of all constituents individually but a prehension of a unified set or nexus, the members of which have the particular identity as members of *that* society.[71]

Bracken on Society and Substance

If actual entities replace substances for Whitehead, society is analogous to a substance for Bracken. Classical substance was meant to account for endurance across time while accidents explained change. Society has a similar function in Whitehead's philosophy.[72] In Aristotle's account a substance is an actuality in the order of existence and potentiality in the order of operation. A society as a nexus does constitute real potentiality for further actualizations of its new occasions as its societal form—its structure of formal intelligibility—is transmitted.[73]

On the other hand, a classical substance is essentially unrelated but Bracken says that societies, like actual entities, are essentially related. An additional difference is the reversal of the relationship between

65 Bracken, "Intersubjectivity and the Coming of God," 390–92. See also, Bracken, "Images of God within Systematic Theology," 370; and Bracken, 213.

66 Bracken, *Christianity and Process Thought*, 17, 107; Bracken, "The Issue of Panentheism," 213; Bracken, "Proposals for Overcoming the Atomism," 11–12; and Bracken, "Substance—Society—Natural System," 7.

67 Bracken, *The Triune Symbol*, 189; Bracken, *The Divine Matrix*, 61; Bracken, *Christianity and Process Thought*, 107; Bracken, *God: Three Who Are One*, 78, 114; and Bracken, "Substance—Society—Natural System," 7, 8. See, Whitehead, *Process and Reality*, 89.

68 Bracken, "Supervenience," 137–52; Bracken, "Authentic Subjectivity and Genuine Objectivity," 295, 295n14; and Bracken, "Energy Events and Fields," 161. See also, Bracken, "Intersubjectivity and the Coming of God," 390, 392.

69 Whitehead, *Process and Reality*, 25, 27, 41–42.

70 Bracken, "Proposals for Overcoming the Atomism," 13; Bracken, "Energy Events and Fields," 161; Bracken, "Substance—Society—Natural System," 7, 8; and Bracken, "Authentic Subjectivity," 291–95.

71 Bracken, "Proposals for Overcoming Atomism," 13.

72 "The real actual things that endure are all societies. . . . A society has an essential character, whereby it is the society that it is, and it has also accidental qualities which vary as circumstances alter" (Whitehead, *Adventures of Ideas*, 204).

73 In discussing the extensive continuum as actuality limiting abstract potentiality, Whitehead describes the extensive continuum as a "physical field" (Whitehead, *Process and Realty*, 66, 80; cf. 92) that, through its actuality, renders a more limited "real potentiality" instead of pure potentiality alone. He also refers to this cosmic physical field as a "substantial form" inherited throughout the vast cosmic society that constitutes the "primary real potentiality" conditioning every concrescence (ibid., 333): "The whole theory of the physical field is the interweaving of the individual peculiarities of actual occasions upon the background of systematic geometry. This systematic geometry expresses the most general 'substantial form' inherited throughout the vast cosmic society which constitutes the primary real potentiality conditioning concrescence" (ibid.). Here he has a footnote to F. S. C. Northrop's "Macroscopic Atom Theory," encompassing all of the finite entities ("atoms" for Northrop, actual entities for Whitehead) in the universe, which for Whitehead would be the actuality of the entire universe in the extensive continuum that he is discussing in this locus as constituting the "real potentiality" for all entities in concrescence (ibid., 333n3).

parts and whole, matter and form, in hylomorphism. Aristotle sees the material elements as a many united by one immaterial formal principle, which is active while the matter is passive.[74] In process metaphysics the one societal form is constituted by the society's member entities and is passive in that regard.[75] A society's unity is democratic, not top-down or hierarchical.[76] Further still, a classical substance reduces its parts to accidental modifications of the whole, thereby derogating from the parts' identities and reality. In contrast, a society preserves, even accentuates, its member entities' ontological integrity.

Bracken on Contemporary Actual Entities

Regarding contemporary actual entities, Bracken holds that when concrescent entities directly prehend the society as a nexus the societal form becomes a medium through which coeval entities can influence each other.[77] In *Process and Reality*, through objectification and transmutation, a conscrescent entity does feel its societal member entities as a nexus, albeit this is a unified set of antecedent entities, not contemporaries.[78] Some interpretations of Bell-type experimental results either revise what have been thought to be space-time limitations, even in special relativity, and some make such supposed limitations moot.[79] Either way, the indisputable results are at least *some sort of* connection between space-like separated but entangled particles.

Some physicists familiar with Whitehead have expressed doubt that his account of presentational immediacy can account for the sort of causal influence required by the violation of Bell's Inequalities.[80] Results of Bell-type experiments show how when one of two space-like separated entangled particles is measured so that its wave function collapses to determinately actualize a property, the same property of its partner particle is also determined. Even jettisoning the question of how this can be the case, despite space-like separation the partner particle's change from potential to actual is directly connected with the first entangled particle's actualization. According to Bracken, the mechanism is their common societal form.

Conclusion

Bracken's revisions to Whitehead's notion of society seem plausible in the light of some developments in physics since Whitehead. His position is of a piece with his desideratum of a thoroughgoing relational ontology in which "society" and "actual entity" are equiprimordial categories of being.

Were he alive today, would Whitehead be open to such revisions in the light of further developments in physics? He demanded that metaphysics be thoroughly empirical and pragmatic so that whatever we encounter in practice must lie within the scope of metaphysical generalization, and insisted that when it fails here metaphysical generalization is inadequate and requires revision. In 1929 Whitehead in wrote:

> In philosophical discussion, the merest hint of dogmatic certainty as to finality of statement is an exhibition of folly. . . . Whatever is found in "practice" must lie within the scope of metaphysical generalization. When the description fails to

74 Aristotle *Metaphysics* 1041b, 25–31, 2:1644; 1051b, 29–30, 2:1661.

75 Bracken, *Society and Spirit*, 54, 112; Bracken, "Substance—Society—Natural System," 8–9; Bracken, *God: Three Who Are One*, 114. *Book Z* of Aristotle's *Metaphysics* admits of an interpretation of substantial form where the form comes into being as it unifies the material elements into an organic whole, which differs from a competing Platonic view where form preexists and communicates unity from the outside (Tugendhat, *TI KATA TINOS*, 67–120, cited in Bracken, "Spirit and Society," 245).

76 Bracken, "Philosophical Foundations of Human Rights," 55.

77 Bracken, "Substance—Society—Natural System," 7–8; Bracken, "Spirit and Society: A Study of Two Concepts," 249, 255n2; Bracken, "Energy Events and Fields," 161; Bracken, "Proposals for Overcoming the Atomism within Process-relational Metaphysics," 12–13; Bracken, *The One In the Many*, 149; and Bracken, "Intersubjectivity and the Coming of God," 389, 392n29.

78 Whitehead, *Process and Reality*, 25, 27, 41–42, 251–53.

79 As Bohr said as early as 1934, quantum experimental findings necessitated "a final renunciation of the classical idea of causality" (Bohr, *Atomic Theory and the Description of Nature*, 60).

80 Henry P. Stapp, "Dialogue for Part III," in *Physics and Whitehead*, ed. Timothy E. Eastman and Hank Keeton, 187–95 (Albany, NY: SUNY Press, 2003), 195.

include the "practice," the metaphysics is inadequate and requires revision. There can be no appeal to practice to supplement metaphysics, so long as we remain contented with our metaphysical doctrines. Metaphysics is nothing but the description of generalities which apply to all the details of practice. . . . When we survey the history of thought, and likewise the history of practice, we find that one idea after another is tried out, its limitations defined, and its core truth elicited. . . . At the very least, men do what they can in the way of systematization, and in the event achieve something. The proper test is not that of finality but of progress.[81]

References

Aristotle. *Categories*. In *The Complete Works of Aristotle: The Revised Oxford Translation*. 2 Volumes, edited by Jonathan Barnes and translated by W. D. Ross, 1:3–24. Princeton: Princeton University Press, 1984.

Aristotle. *Metaphysics*. In *The Complete Works of Aristotle: The Revised Oxford Translation*. 2 Volumes, edited by Jonathan Barnes and translated by W. D. Ross, 2:1552–1728. Princeton: Princeton University Press, 1984.

Aspect, Alain, Jean Dalibard, and Gérard Roger. "Experimental Test of Bell's Inequalites Using Time-varying Analyzers." *Physical Review Letters* 49 (1982): 1039–43.

Auyang, Sunny Y. *Foundations of Complex Systems Theories*. Cambridge: Cambridge University Press, 1998.

Bell, John S. "La nouvelle cuisine." In *Between Science and Technology*, edited by A. Sarlemijn and P. Kroes, 97–118. New York: Elsevier Science Publishing Company, 1990.

Bell, John S. "On the Einstein Podolsky Rosen Paradox." *Physics* 1 (1964): 195–200.

Birkhoff, Garrett, and John Von Neumann. "The Logic of Quantum Mechanics." *Annals of Mathematics*, *Second Series* 37:4 (1936): 823–43.

Born, Max. *Atomic Physics*. New York: Hafner, 1957.

Born, Max. *The Restless Universe*. New York: Dover, 1951.

Bohm, David. *Causality and Chance in Modern Physics*. Philadelphia: University of Pennsylvania Press, 1957.

Bohm, David. *Quantum Theory*. New York: Prentice-Hall, 1951.

Bohm, David. *Wholeness and the Implicate Order*. London: Routledge, 1980.

Bohm, D. J., and B. J. Hiley. "On the Intuitive Understanding of Nonlocality as Implied by Quantum Theory." *Foundations of Physics* 5:1 (1975): 95–96.

Bohr, Niels. *Atomic Theory and the Description of Nature*. Cambridge: Cambridge University Press, 1934.

Bracken, Joseph A. "Authentic Subjectivity and Genuine Objectivity." *Horizons* 11 (Fall 1984): 290–303.

Bracken, Joseph A. *Christianity and Process Thought: Spirituality for a Changing World.* Philadelphia: Templeton Foundation Press, 2006.

Bracken, Joseph A. *The Divine Matrix: Creativity as Link Between East and West.* In the *Faith Meets Faith: An Orbis Series in Interreligious Dialogue* series. Maryknoll: Orbis, 1995.

Bracken, Joseph A. "Energy Events and Fields." *Process Studies* 18 (Fall 1989): 153–65.

Bracken, Joseph A. *God: Three Who Are One.* In the *Engaging Theology: Catholic Perspectives* series, edited by Tetha Wiley. Collegeville: Liturgical Press, 2008.

Bracken, Joseph A. "Images of God within Systematic Theology." *Theological Studies* 63:2 (June 2002): 362–73.

Bracken, Joseph A. "Intersubjectivity and the Coming of God." *Journal of Religion* 83:3 (July 2003): 381–400.

Bracken, Joseph A. "The Issue of Panentheism in the Dialogue with the Non-believer." *Studies in Religion/Sciences-religieuses* 21:2 (1992): 207–18.

Bracken, Joseph A. *The One in the Many: A Contemporary Reconstruction of the God–World Relationship.* Grand Rapids,: Eerdmans, 2001.

Bracken, Joseph A. "Philosophical Foundations of Human Rights: A Process Approach." *Cogito* 1:1 (March 1983): 51–73.

Bracken, Joseph A. "Proposals for Overcoming the Atomism Within Process-Relational Metaphysics." *Process Studies* 23 (Spring 1994): 10–24.

Bracken, Joseph A. *Society and Spirit: A Trinitarian Cosmology.* Selinsgrove: Susquehanna University Press, 1991.

Bracken, Joseph A. "Spirit and Society: A Study of Two Concepts." *Process Studies* 15 (Winter 1986): 244–55.

Bracken, Joseph A. "Substance—Society—Natural System: A Creative Rethinking of Whitehead's Cosmology." *International Philosophical Quarterly* 25 (1985): 3–13.

Bracken, Joseph A. "Supervenience: Two Proposals/Supervenience and Basic Christian Beliefs." *Zygon* 36 (2001): 137–52.

Bracken, Joseph A. "The Theology of God of Elizabeth A. Johnson." In *Things New and Old: Essays on the Theology of Elizabeth A. Johnson*, edited by Phyllis Zagano and Terrence W. Tilley, 21–38. New York, NY: Crossroad, 1999.

Bracken, Joseph A. *The Triune Symbol. Persons, Process and Community.* In the *College Theology Society Studies in Religion series.* Lanham: University Press of America, 1985.

Bracken, Joseph A. *What Are They Saying About the Trinity?* New York: Paulist Press, 1979.

81 Ibid., xiv, 13–14.

Brillouin, Léon. *Wave Propagation and Group Velocity*. New York: Academic Press 1960.
Burgers, J. M. "The Measuring Process in Quantum Theory." *Reviews of Modern Physics* 35 (January 1963): 145.
Clauser, J. F., and A. Shimony. "Bell's Theorem. Experimental Tests and Implications." *Reports on Progress in Physics* 41 (1978): 1881–1927.
Cushing, James T. and Ernan McMullin, editors. *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem.* Notre Dame: University of Notre Dame Press, 1989.
Diener, G. "Superluminal group velocities and information transfer." *Physics Letters A* 223:S (1996): 327–31.
Eckle, P., A. N. Pfeiffer, C. Cirelli, A. Staudte, R. Dörner, H. G. Muller, M. Büttiker, and U. Keller. "Attosecond Ionization and Tunneling Delay Time Measurements in Helium." *Science* 322:5907 (2008): 1525–29.
Einstein, Albert, Boris Podolsky, and Nathan Rosen. "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" *Physical Review* 47 (1935): 777–80.
Finkelstein, David. *Quantum Relativity: A Synthesis of the Ideas of Einstein and Heisenberg*. Berlin: Springer-Verlag, 1996.
Freedman, Stuart J., and John F. Clauser. "Experimental Test of Local Hidden Variable Theories." *Physical Review Letters* 28 (1972): 938–41.
Gröblacher, Simon, Tomasz Paterek, Rainer Kaltenbaek, Časlav Brukner, Marek Żukowski, Markus Aspelmeyer and Anton Zeilinger. "An Experimental Test of Non-local Realism." *Nature* 446 (2007): 871–75.
Heisenberg, Werner. *Across the Frontiers*. New York: Harper and Row, 1974.
Heisenberg, Werner. "The Development of the Interpretation of Quantum Theory." In *Niels Bohr and the Development of Physics*, edited by Wolfgang Pauli, 12–29. New York: McGraw-Hill 1955.
Heisenberg, Werner. *Physics and Philosophy: The Revolution in Modern Science*. New York: Harper Perennial, 2007.
Heisenberg, Werner, Max Born, Erwin Schrödinger and Pierre Auger. *On Modern Physics*. New York: Clarkson Potter, 1961.
Jungerman, John A. "Evidence for Process in the Physical World." In *Physics and Whitehead*, edited by Timothy E. Eastman and Hank Keeton, 47–55. Albany: SUNY Press, 2003.
Kim, Yoon-Ho, Rong Yu, Sergei P. Kulik, Yanhua Shih, and Marlan O. Scully. "A Delayed Choice Quantum Eraser." *Physical Review Letters* 84:1 (2000): 1–5.
Low, Francis E. "Comments on apparent superluminal propagation." *Annals of Physics* 7:7–8 (1998): 660–61.
Maa, Xiao-Song, Johannes Koflera, Angie Qarrya, Nuray Tetika, Thomas Scheidla, Rupert Ursina, Sven Ramelowa, Thomas Herbsta, Lothar Ratschbachera, Alessandro Fedrizzia, Thomas Jenneweina, and Anton Zeilingera. "Quantum erasure with causally disconnected choice." *Proceedings of the National Academy of Sciences Proc. Natl. Acad. Sci. USA of the United Sciences of the United States of America* 10:4 (January 2013): 1221–26.
Nimtz, Günter. "Tunneling Confronts Special Relativity." *Foundations of Physics* 41:7 (2011): 1193–99.
Pugliese, Marc A. "Orthodoxy or Orthopraxy? Recent Developments in Physics and Joseph A. Bracken as Revisionist Whiteheadian." In *Seeking Common Ground: Evaluation and Critique of Joseph Bracken's Comprehensive Worldview*, Festschrift *in Honor of Joseph A. Bracken, S. J.*, edited by Marc A. Pugliese and Gloria L. Schaab, 97–116. Milwaukee: Marquette University Press, 2012.
Razavy, Moshen. *Quantum Theory of Tunneling*. River Edge: World Scientific Publishing Company, 2003.
Rowe, M. A., D. Kielpinski, V. Meyer, C. A. Sackett, W. M. Itano, C. Monroe, and D. J. Wineland. "Experimental Violation of a Bell's Inequality with Efficient Detection." *Nature* 409 (2001): 791–94.
Shimony, Abner. "Bell's Theorem." In *The Stanford Encyclopedia of Philosophy* (Winter 2013 Edition), edited by Edward N. Zalta.
Shimony, Abner. "The Methodology of Synthesis: Parts and Wholes in Low-energy Physics." In *Kelvin's Baltimore Lectures and Modern Theoretical Physics: Historical and Philosophical Perspectives*, edited by R. Kargon and P. Achinstein, 399–424. Cambridge: MIT Press, 1987.
Shimony, Abner. "Quantum Physics and the Philosophy of Whitehead." In *Boston Studies in the Philosophy of Science*, Volume 2, edited by Robert S. Cohen and Marx W. Wartofsky, 307–30. New York: Humanities Press, 1965.
Sokolovski, D. "Why does relativity allow quantum tunneling to 'take no time'?" *Proceedings of the Royal Society of London, Series A* 460:2042 (2004) 499–506.
Stapp, Henry P. "Are Superluminal Connections Necessary?" *Il Nuovo Cimento* 40B (1977): 190–204.
Stapp, Henry P. "Dialogue for Part III." In *Physics and Whitehead*, edited by Timothy E. Eastman and Hank Keeton, 187–95. Albany: SUNY Press, 2003.
Steinberg, A. M., A.M., Kwiat, P.G. Chiao and R.Y. Chiao. "Measurement of the Single-Photon Tunneling Time." *Physical Review Letters* 71:708 (1993): 708–11.
Teller, Paul. "Relativity, Relational Holism, and the Bell Inequalities." In *Philosophical Consequences of Quantum Theory*, edited by J. T. Cushing and E. McMullin, 208–23. Notre Dame: University of Notre Dame Press, 1989.
Tugendhat, Ernst *TI KATA TINOS.* Freiburg im Breisgau: Karl Alber Verlag, 1958.
Von Neumann, John. *The Mathematical Foundations of Quantum Mechanics*, translated by Robert T. Beyer. Princeton: Princeton University Press, 1996.
Watson, Andrew. "Quantum Spookiness Wins, Einstein Loses in Photon Test." Science 277 (1997): 481.
Weihs, Gregor, Thomas Jennewein, Christoph Simon, Harald Weinfurter and Anton Zeilinger. "Violation of Bell's Inequality under Strict Einstein Locality Conditions." *Physical Review Letters* 81 (1998): 5039–43.

Wheeler, John Archibald. "Information, physics, quantum: The search for links." In *Complexity, Entropy, and the Physics of Information*, edited by Wojciech H. Zurek. Redwood City: Addison-Wesley, 1990.

Wheeler, John Archibald. "The 'Past' and the 'Delayed-Choice' Double-Slit Experiment." In *Mathematical Foundations of Quantum Theory*, edited by A. R. Marlow. 9–48. New York: Academic Press, 1978.

Whitehead, Alfred North. *Adventures of Ideas*. New York: Macmillan, 1933; reprint, Free Press, 1967.

Whitehead, Alfred North. *Process and Reality: An Essay in Cosmology*, edited by David Ray Griffin and Donald W. Sherburne. New York: Macmillan, 1929; corrected edition, New York: Free Press, 1978.

Whitehead, Alfred North. *Science and the Modern World.* New York: Macmillan, 1925; reprint, Free Press, 1967.

Whitehead, Alfred North. *Symbolism, Its Meaning and Effect.* New York: Macmillan, 1927; reprint, Bronx: Fordham University Press, 1985.

Winful, Herbert G. "Tunneling time, the Hartman effect, and superluminality: A proposed resolution of an old paradox." *Physics Reports* 436 (1–2) (2006): 1–69.

Witten, Edward. "Duality, Spacetime and Quantum Mechanics." *Physics Today* (May 1997): 28–33.