ON THE CONCEPT OF REALNESS © Dan Bruiger 2019

The nature of reality would be an unthinkably ambitious topic even for a major tome, let alone for a slender essay. It has been a preoccupation of philosophy from time immemorial. The concept of *realness*, however, might be more manageable.[1] It raises the questions: by virtue of what factor(s) is something considered real, and, by whom? We admit that beauty may be in the eye of the beholder, that there is a subjective dimension to experience at least in the domain of esthetics and opinion. As far as knowledge in general goes, we know that propositions are subject to interpretation and debate, so that to some extent truth is also in the mind of the beholder. We say, casually, that people live in different realities, usually meaning that they experience *the* reality differently. But what can be said of realness itself? Is it a property of things in the objective external world or is it a quality of one's subjective experience? Or both or neither?

(A). What is realness?

I propose that realness is at least a category of experience, in the Kantian sense that space and time are *a priori* categories into which human perception is necessarily pre-cast. In modern times, this can be understood in genetic and biological terms. We experience the world as real because, simply, we wouldn't be here otherwise. That is, because the world holds over us the power of life and death, realness has come through natural selection to imbue our experience of the external world. Being able to experience the world as real is a survival tool. In other words, the experience of realness is our perceptual way to acknowledge, with a certain respectful wariness, that power that the external world holds over us.[2] Put in such a way, realness is a subjective *quality* of phenomenal experience (call it R_S), a judgment of the mind. This quality implicitly expresses the *relationship* of the organism to its world, which may or may not refer to an actual property of that world (call it R_O).

Of course, putting things that way is somewhat paradoxical. For, the obvious meaning of the real is that it is independent of the subject. Even as subjective experience, R_S normally tracks R_O, so that realness must certainly (also) be considered a property of things held to exist quite apart from the subject's perceptions—for otherwise it has little meaning. Realness is thus a category of our thought about existence as well as a perceptual category. These two ways of considering realness reflect two fundamental modes of cognition. Our primary mode is outward looking (R_O). We are natural born realists, whose biological focus is the external world. This is a condition of being an organism, dependent on its environment. Just as it is natural and necessary to view the world as real and external, so it is understandable for such thoughtful creatures to evolve a concept of objectivity, in which the world is conceived to exist and have certain properties regardless of how it is perceived by any creature.

---

[1] If *R* is the set of all real things, the property of 'realness' is the *intension* (definition) of that set, which must be satisfied to belong to the set; in contrast, we can say that 'reality' is the *extension* of that set, consisting of the things that satisfy the definition. In every cognitive domain, including science, there are criteria to decide which things are real. In the domain of perception, the sensory experience itself of realness is the judgment that the criterion in that domain is met.

[2] Just as pain is our perceptual way to acknowledge tissue damage and sweetness is our perceptual way to acknowledge the nutritional benefit of sugar.

At this point I would like to introduce a notion I call the Equation of Experience. This is simply the common-sense idea that all experience, thought, and action is a co-product of subject and object.[3] Self and world are entangled as co-determinants of our experience, thought and action. This is the origin of many human dilemmas, which perennially involve differentiating the influences that come from within and those that come from without. In a given situation, to what extent is our behavior subjectively motivated and to what extent is it objectively justified? Does the world determine our experience or do we determine it? The very ability to pose such questions presumes an ability to view perception not as a transparent window on reality but as a subjective or inner domain, a creation of the mind, a show (R_S). Husserl called this "bracketing" experience *as* experience. These two modes are complementary, giving us the capacity to monitor the world (including one's body as part of the world) and the additional capacity to monitor our monitoring. The ability to perceive the world as real gives us only naïve realism; but, as self-conscious beings, we have the further ability to question our perceptions, and even to question the questioning. This enables us to look before we leap, which is a handy ability for an intelligent social creature. Hence, realness is both a property of things and a quality with which the subject imbues the experience of things.

If subject and object are thus entangled, and experience is a co-product of both, how can we know reality independent of the subject? The answer is that we cannot. Insofar as realness (and perception in general) is an assertion of the mind to facilitate survival, one is not justified to believe that experience is a transparent window on the world. All we are entitled to believe is that R_S *tracks* or *maps* R_O in such a way that we do survive. For purely biological reasons, we are in the (naively realist) habit of ignoring the mediacy of R_S in order to *assume* the objective truth of R_O.

All this would be quite academic if it remained on an abstract level. But there are instances of this confusion of R_S with R_O that make a difference both in life and in formal thought—even in science. I have mentioned the common dilemma of having to sort out subjective from objective considerations in daily dealings. This applies to everything from negotiating personal relations, to labor disputes, to judicial arguments and international treaties. It is a growing challenge in interpreting and evaluating information in news and social media. We need to understand where others are coming from, where we are coming from ourselves, and what might be the objective (or at least intersubjective) concerns that form a common ground of mutual interest that can be the focus of cooperative problem solving.

In many ways, science purports to operate according to that ideal. Yet, science is hardly immune to confusions around the distinction between subject and object, especially since it was founded on the principle of excluding the subjective from its accounts of the world. In terms of the Equation of Experience, scientific method attempts to hold constant the subject "variable" in order to examine how experience (observation/measurement) varies as a function purely of the object.[4] That is, by standardizing the observer and experimental protocol, the idiosyncrasies of the individual observer are eliminated from the account of nature. Yet, there may remain influences deriving from observers in common, which elude this principle of excluding the idiosyncratically subjective. We have a common biology as human beings, and hold common cultural assumptions as a scientific community. It is fair and meaningful to ask what these commonalities themselves may impose on the scientific portrait of nature. This means

[3] This relation might be expressed symbolically as $E = f(s,o)$

[4] $E= f(o) = R_O$

identifying and questioning tacit assumptions and operating principles. These might include, for example: reification, the principles of 'sufficient reason' and 'identity of indiscernables', deductionism, determinism, mathematization, concepts of order and of probability, *ceteris paribus*, guidelines for premise selection, even the concept nature itself and the historical influence of creationism upon it. These will be discussed point by point in the next section.

(B). Tacit (collectively subjective) assumptions behind the objectivity of science

1. *Reification* is a psychological action that corresponds to the organism's need to organize perception in terms of discrete objects or material substances. Processes and relationships are thereby conceived as *things*, and issues are framed in ontological rather than epistemic terms.

Ordinary experience on the human scale is naturally extended to phenomena that lie outside that range of experience. Metaphor is the basis of thought. Since ordinary experience is normally of the external world, which we consider real, realness is often attributed to phenomena that are not literally visible but which we can imagine seeing. Realness then usually means a substantiality that consists in the ability to act causally upon other things and be acted upon. In science, this usually means that what is real must be able to interact causally with the observer. But not necessarily; despite such operationalist insistence, there remains the possibility that something can be considered real even though we don't interact with it. The notion of "other universes" (multiverse) is an example. There are intermediate cases, such as dark matter and black holes, which interact gravitationally but not electromagnetically.

The very idea of interaction presupposes the realness of interacting elements (R_O). This is in contrast to a more epistemic or operational view, which focuses instead on the results of observation (R_S). Observation may be pictured as an interaction (of instrument with system observed), but this is an interpretation according to the assumed theory, rather than an account of the observations themselves as data. This distinction becomes increasingly important as the train of inferences from data becomes ever more complex and tenuous. The interpretation of many modern astronomical observations and high-energy experiments involves numerous assumptions along the way. In both cases, results have only a statistical certainty. R_O bears *some* relationship to R_S, but it is by no means direct and straightforward.

The distinction has become crucial in quantum theory, where it was controversial from the start. Should the wave function be considered a tool to predict the macroscopic (visible) results of experiments? Or should it be considered a description of some invisible microscopic reality? Does it describe the state of a real system or the state of our knowledge?

2. The *principle of sufficient reason* suggests there should be an answer to every reasonable question about why the world is as it is. This was the faith at the core of Einstein's objections to the quantum theory as incomplete. Its success in familiar realms, however, bears no guarantee of success in unfamiliar ones. Similarly, the *identity of indiscernables* depends on the possibility to enumerate all properties or relations pertaining to the elements of a real system. However (as we shall see below), an unequivocal list of defining properties or relations is only possible within a *deductive* system (a model). It is misleading, if not false, to assumed that specified factors in a theory (such as the variables of a differential equation) exhaustively represent the real properties of a real system. It may be that the physical variables of a theory are neither exclusive nor exhaustive, or do not even pick out clearly identifiable real properties. *Defining* them

mathematically, on the other hand, *renders* them definite and seemingly comprehensive. Leibniz' two principles already assume that the natural world *is* a deductive system; they express a deductionist expectation that nature corresponds to our models.

3. *Deductionism* is the credo that nature can be formally modeled, even exhaustively, by defined constructs. Deductionism reduces reality to defined parts of some model—effectively a machine—a formal system in which the relationship between elements is purely logical. This is the basis of the philosophy of mechanism, since a machine is conceptually a deductive system. While such things are human artifacts and not found in nature, their appeal no doubt lies in appearing to offer a clear, complete, certain, and unqualifiable account. The perennial dream of a completed theoretical science—a theory of everything—assumes that physical reality is finally exhaustible in thought, that there must be a bottom to the complexity of nature and an end to inquiry about the fundamentals, if not the details, of physical reality. It assumes that the world is something definite (with, for example a calculable information content), and can be fully captured in mathematical expressions. This convenience may be the motivation behind the current reification of knowledge as "information", conceived as a new ontological basis of physics. (Since information is digital, the universe must be digital!) Though such assumptions may be functionally grounded in our evolutionary history, and may be psychologically persuasive, their validity remains open to question.

4. *Determinism* is the basis of the mechanist philosophy, and of the hope to predict all natural phenomena or events from first principles. This is expressed mathematically in differential equations, where an input of parameter values leads to a definite output. If you know the state of the system at one time, you can in principle know it at a future *or* past time. Deterministic systems are "reversible" simply because their equations are time-reversible. However, this time reversibility of *equations* does not imply that the real systems they model are in some sense dynamically reversible, much less that time itself can run backwards. In fact, there *are* no deterministic systems in nature, differential equations describe only fictional idealizations, and most real physical processes are irreversible. Idealization worked in classical physics because the systems studied (such as planetary orbits) are simple and relatively isolated from influences other than those few represented in the equations.

Such massive systems are also not significantly disturbed by observation itself. This latter condition, especially, could no longer be assumed in the microscopic systems studied in the quantum realm. Nevertheless, the equations there (like all equations) are deterministic by definition, even though they predict only the probable outcomes of experiments. The illusion of determinism fosters the misleading expectation that a deeper level of causality can be found, with equations that predict precise actualities. Yet, even on the macroscopic scale, the effectiveness of equations depends on the precision of measurable inputs. There is a residue of statistical error, which is an inevitable fact limiting knowledge (R_S)—which has not prevented it being viewed as merely incidental to the process of observation and as irrelevant to the theoretical precision of the world implied in determinism (R_O).

Determinism is a property of the well-defined machine, a literal or conceptual artifact. Real phenomena are not such artifacts. Hence, determinism is not an objective property of physical reality but a projection of wishful thinking that happens in special cases to pan out. It reflects the rational expectation that the world can be understood and precisely mapped, as proposed in the principle of sufficient reason. Since all models, even quantum models, are such artifacts, determinism applies to the model without applying to the reality it models. While causality is traditionally considered a metaphysical (rather than logical) relationship, the states of a deterministic system are *logically entailed* rather than caused in some metaphysical sense.

5. The *mathematization* of science is by now so taken for granted that many now assume physical reality to consist literally *of* mathematics. Platonism aside, mathematics is a descriptive tool. The purposes for which it is used, and the syntax it imposes as the language of science, powerfully influence our concepts of nature and relationship to it. Yet these influences tend to go unrecognized. The assumption that natural reality can be captured, in the special idealizations to which mathematics applies, is a corollary of the belief that reality can be contained in human definitions at all. There may be a scientific price to pay for such oversimplifications, as well as a cultural and ecological one.

Computerization provides a powerful new tool for science and society; it also provides the neo-mechanist metaphor of nature itself. The digital computer is the contemporary model for mind, or at least for "intelligence." But, the universe itself is also seen by some as a sort of computer. The digital computer is psychologically significant because it translates into technology an age-old dream to directly program reality. It reflects the architecture of human thought that went into creating it. This architecture is then projected back upon physical reality as its very organization. For example, while the universe presents discrete aspects to the observer, the computer's *definitional* discreteness is projected back upon nature as a fundamental property. Quantum discreteness (an empirical result and an unsolved mystery) should not be confused with, or assumed to follow from, the definitional discreteness of information (a digital concept).

6. The concept of *order* is relative to context and history. A pile of books on the floor may appear disordered (high entropy), compared to neatly shelved books in alphabetic order. However, the appearance of order depends on the intentions of agents involved. If the books had been carefully placed on the floor according to their relevance in a research project, for example, their order would be more significant than if they had remained alphabetized on the shelf. Entropy, like information, is treated as an objective property of real systems, without taking into account the human aims that shape its use. This is especially ironic since the role of information, in the ordinary sense, is to inform human agents, while entropy was originally conceived to measure the efficiency of machines.

Many properties of the actual universe, far from equilibrium, appear startlingly improbable as the result of a random shuffle of theoretical parameters. But this impression involves a dubious metaphor, which attempts to assimilate the complexity of the world to artificial situations such as a role of dice or shuffle of cards. Cosmologists calculate the vanishingly negligible odds that a universe supporting life could arise from "randomly chosen" values of parameters of the standard model of particle physics or the current model of cosmology. Given *one* universe, however, such calculations seem spurious; the very notion of a universe randomly generated among others is a theoretical fancy. The question of how initial conditions are "chosen" is ambiguous, since it is unclear who or what is selecting. In the literature, sometimes physical processes perform this service, yet sometimes it is the theorist who specifies the initial or boundary condition, as in the running of computer simulations.

Selection by chance may be likened to the outcome of unstable equilibrium. It seems more reasonable to explain the values of fundamental parameters by looking to *stable* equilibrium—

attractor states insensitive to initial conditions. Rather than an explanation designed to overcome a specious improbability, one should seek a scenario in which parameters or initial conditions tend toward the state concerned. Moreover, "parameters" must not be seen in isolation, as though they could be varied independently as in a controlled experiment; it is the total package of multiple causes that corresponds to the attractor state.

7. The principle of *ceteris paribus* ("all things being equal") evaluates effects where there are multiple causes, by examining one factor at a time with others assumed constant. Experiments, of course, are *designed* to allow one factor to vary in isolation, by deliberately excluding others. Factors in a computer simulation are controllable by definition. But the universe, so far as we know, is not a controlled experiment nor a simulation. Identifiable factors may operate in concert in real self-organizing processes, so that changing one necessarily changes others.

8. While there may be an indefinite number of factors at work in the real world, no explicit meta-rule guides the selection of basic premises, except perhaps Occam's Razor and notions of elegance or economy. Following Leibniz, for example, Chaitin proposes that natural laws are the most economical descriptions of the data.

It is possible to eliminate even such fundamental factors as time or space from physical description, but only by introducing other concepts judged to be yet more fundamental in some discretionary hierarchy. Abstract time (like abstract space) is as much a human artifact as the clocks that measure it. Time is *presumed* as a background in both classical and quantum physics, even for situations in which time-keeping processes may not yet exist, such as the very early universe.

9. The guiding metaphor of science for understanding (and imitating) nature is still the machine, the modern version of which is the digital computer. While scientific theories or models are conceptual machines, the universe itself is not literally a machine. The older metaphor of the universe as an organism had long been forgotten or suppressed, but may come back into fashion as the mechanist metaphor reaches its limits.

10. A guiding principle of the scientific revolution was the belief within the Semitic religions that the *material world has no immanent reality of its own.* It has only the *derived* reality of an artisanal creation or manufactured thing. In some religious doctrines, the very realness of things is God's doing and *not* an inherent property of the world; *everything*, including nature and one's own private experience, happens moment to moment by divine grace and decree. The Deists modified this article of faith to the extent that God created the world (a machine) then left it alone to follow prescribed rules until it eventually runs down like a clock (or breaks down). Newton borrowed from Plato the idea that the world would need to have its order restored periodically by divine intervention. He also left to God whatever he could not explain by mechanical principles, such as the force of gravitation as action at a distance and the stability of the solar system. Plato's primal chaos, Newton's God-of-the-gaps, and the 19th-century heat death of the universe all implied that matter is inert, without self-organizing or self-maintaining capabilities, in fact without any power or reality of its own, but only that bestowed by its Designer.[5]

---

[5] But this sentiment was not entirely universal. To Leibniz, *vis viva* (kinetic energy) was the immanent force that animates things in nature, an active power of things to affect one another—in modern parlance,

In contemporary science, the theorist replaces God as the agent who specifies the properties of the creation (i.e., the parameters of the theoretical model) and its initial state. The ultimate expression of this hubris is the notion that the universe itself is a simulation, perhaps programmed by aliens! It is far more plausible that the universe is self-organizing and self-maintaining, neither created by gods nor by aliens, and not necessarily decipherable by theorists.

The general conclusion is that science no more provides a transparent window on the world than does natural perception. Like the perceptual model, the scientific model tracks or maps the external world, in ways that complement and extend ordinary cognition. While every scientist knows this, it behooves us to understand what we can of the nature of this map, which must include its biological and cultural motivations. Ultimately, respecting the entanglement of subject with object, the scientific portrait of nature must include the agency of the scientist.

(C). Realness in the domain of ordinary cognition.

Scientific theory extends our vision of reality just as scientific instruments extend our sensory abilities. In the 19th century, Helmholtz inverted the metaphor by proposing that ordinary perception works, in a non-conscious way, like scientific theorizing does consciously. He called this perceptual modelling process ‘unconscious inference’. The brain’s job is to make sense of incoming sensory information, just as the scientist’s job is to make sense of data gathered in experiment or observation. It is important to keep in mind, however, that the scientist benefits from prior knowledge derived from ordinary perception, whereas the brain does not benefit from an unmediated exposure to the world. Quite the contrary, the brain is literally sealed within the skull and has no access to the external world except indirectly through its sensory inputs and motor outputs. The world to the brain is a black box, whose contents must be inferred. To the scientist also, the world is equally a black box, even if it appears open to ordinary perception.

The situation for the brain is that it must invent its model of the world (R_S) more or less from scratch—whether on the level of perception or scientific theory. The brain’s epistemic challenge is like that of piloting a submarine purely on the basis of instrument readings. The unique proviso of this metaphor is that the navigator (the brain) has never been outside the “submarine,” which has no portholes, hatches, or periscope![6] The navigator can do no more than coordinate instrument readings with each other and with control settings, learning to move safely by trial and error. Any notion of what lies outside the hull (even the concept of ‘outside’) is an act of imagination. What validates any such notion is that it works to steer clear of menacing “objects”—that is, to avoid damage or destruction.

Accumulated experience of what thus works is represented in a model that encapsulates that information. This internal model is dynamic and real-time, continually updated by new sensory data. The model of space populated by objects is, of course, projected as real and external—that is, not as an internal model—so that operating in the model is effectively operating in the world. A current metaphor for this process is virtual reality. The brain’s model of the world is a virtual reality that includes a representation of the body and the self.[7]

---

the ability to do work. Newton focused rather on *vis mortua* (momentum), any change of which he considered to be the passive result of forces applied from outside the system.

[6] Alternatively, consider the challenge of flying an aircraft by instrument (flying blind). The similar proviso is that the pilot has never been outside the cockpit, which has no window or door.

[7] I.e., an “avatar”: a character appearing in the VR to represent the player.

In this picture of the brain's situation, the apparent realness of the external world is a necessary by-product of the model doing its job successfully. This success belongs not only to the individual brain but also to the species through natural selection. The fact that we are here thinking about such things attests to the cognitive adequacy of the model. What about the cognitive adequacy of science?

(D). Realness in domains outside ordinary cognition.

Realness in the perceptual domain is a function of survival. Seeing the world as we do does not mean that the world "is" that way in some absolute sense, but that seeing it thus has facilitated, or at least has not prevented, our continuing existence as specimens and as species. Can the same be said for science as an extended form of cognition? Does science seek the truth of nature, human empowerment, or something else?

It seems obvious at first blush that science has greatly aided our species, at least as measured by reproductive success. In many ways, the median individual as a statistic also seems better off than in pre-scientific times. This apparent progress no doubt fuels enthusiasm for the benefits of technology and the ideology of progress and economic growth. However, the distribution of benefits into extremes of wealth and poverty makes it difficult to evaluate "progress." And, like the turkey being fattened for Thanksgiving, it is possible that we are lulled by this appearance into an acceptance that could lead to our doom. The best we can say is: so far so good.

Faith in science as the true (or at least useful) vision of reality is the counterpart of our faith in the testimony of the senses, which by and large have proven reliable for "practical" purposes of survival and reproductive success. Science has similarly proven reliable enough—so far. While the brain builds realness into perception as an expression of faith in its unconscious inferences, science has other, more formal ways to assess the adequacy of its models and its conscious inferences. The existence of such protocols does not free us psychologically from the need or desire to project realness into our formal constructs, as though doing so somehow lends support to them. Borrowing the realness of ordinary things does not prove our ideas about extraordinary things. Reification of concepts is a natural tendency. It extends the organization of the perceptual domain in terms of objects, substantiality, realness, etc. But that does not prevent it from being in error.

Are the theoretical objects of quantum theory real, in the way that we hold objects on the macroscopic scale to be real? Are the objects of cosmological theories real in that way? At both extremes of scale, we deal with things not directly perceivable with the natural senses; there are vulnerable long chains of inference from available data. Of course, ordinary perception (which seems so tangible, direct, and reliable) also involves chains of (unconscious) inference. The perceptual experience of realness reflects the tacit confidence the brain has in its unconscious inferences, grounded in the fact that the latter have permitted our survival. Yet, these pertain nearly by definition to the macroscopic domain available to the senses, in which our ordinary interactions with the environment take place. Is the brain entitled to such confidence in its *conscious* constructs, when they pertain to domains beyond the senses, such that the notion of realness should be applicable there?

Einstein's answer was a resounding yes. The famous EPR paper effectively defines a 'real' element of a system to be one that can be predicted with one hundred percent certainty.[8] That is, the theoretical model corresponds perfectly with the reality modelled, even if the latter is invisible or cannot be clearly conceived. This basically expresses faith in the principle of sufficient reason, to insist upon determinism and guarantee that the human mind can exhaustively map reality.

The debate between Einstein's realism and Bohr's more positivist approach reflects the general philosophical question of whether physics describes the world itself or human knowledge about it. A description can be complete if it refers to the state of knowledge, yet incomplete if it purports to describe reality.[9] In that sense, Bohr and Einstein were talking at cross-purposes. From a realist perspective, in terms of a black box, at a given time a macroscopic object is either in the box or not; there can be no intermediate state between an object being there and not being there, between an exploded and an unexploded bomb, between a live and a dead cat. A description of the box's content, as in a "superposition" of live and dead states, is not only incomplete but nonsense. However, the "box" is an artificial imposition, nonexistent in nature. From Bohr's perspective, in the microscopic realm the best we can do is to run a series of trials in which we predict that the bomb explodes on average half the time. Quantum theory describes the (statistical) type of knowledge we can have of that realm, given our macroscopic scale; it cannot be expected to describe a reality we cannot access in the familiar terms of the world we do access.

The Uncertainty Principle is not an effect of any intrinsic discontinuity in the world so much as an effect of scale: the medium of investigation is of the same order of scale as the objects of investigation.[10] The photons of light by which we see and measure ordinary objects scarcely affects them, but not so for microscopic objects. This is so whether the relative energies are thought of as discrete or continuous. The ambiguity of the phenomena (wave or particle) is itself reified as the "wave-particle duality."

The classical assumption (realism) is that objects or systems have their real properties apart from how (or whether) we observe them. That simply reflects common experience, in which the world seems to be there even when we are not looking: that is, it reappears the same or predictably different when we look *again*. A second measurement upon it is the same because the object did not change—but also because the first measurement did not alter it significantly, or in a different way than the second. This assumption cannot apply when the interaction itself significantly changes the phenomenon observed.

The two great revolutions of modern physics concern the medium and act of observation or measurement: in particular, the finite speed and the finite graininess of light. Both spelled the end of naïve realism, of an unmediated vision of the world in which the act itself of observation

---

[8] "*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.*" [A. Einstein, B. Podolsky, and N. Rosen "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" Physical Review Vol 47 May 1935 (italics theirs)] Apparently, Einstein himself was not happy about the appearance of this definition in the paper.

[9] Perhaps the shift in Einstein's campaign, from arguing against the consistency of the existing quantum theory to arguing against it completeness, might have been influenced by his chats with Kurt Gödel. According to Gödel's theorems, not all of *mathematical* truth can be formalized. It seems Einstein stopped short of concluding, in a parallel way, that not all of *physical* reality can be formalized.

[10] The ancient conundrum of the continuum versus the discrete is a separate issue.

played no part. Unlike in the middle scale humans had been used to, henceforth in the realms of the very large and the very small the medium of observation would play a crucial role. Yet, the general truth is that our knowledge is always mediated by some interaction. As Heisenberg famously put it: “What we observe is not nature in itself but nature exposed to our method of questioning.”