An Instrumentalist Critique of Evolution

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ABSTRACT

Why is it that the theory of evolution exerts such a powerful hold over both the scientific and popular imaginations? Indeed, why has science in general become the chief provider of 'revelation' in the contemporary world, relegating Christianity apparently to only a marginal role? This paper attempts to answer these questions. The first part involves a survey of developments in the philosophy of science, which show that the almost universally held interpretation of science as ***ontological*** *— that is, as being* ***descriptive*** *of what is really in the world— is simply untenable. We then proceed to describe an alternative interpretation of science as* ***instrumental*** *— that is, as a tool for changing the world through practical action — which avoids all the problems of the traditional view. This instrumentalist view firstly provides a specific philosophical critique of evolution. Secondly, it leads to a general critique of historical and contemporary understandings of science, and it is suggested that failure to recognise the instrumental nature of science is right at the centre of the conflict between science and Christianity which has occurred in the past three to four centuries.*

AN INSTRUMENTALIST CRITIQUE OF EVOLUTION?

The force of existing critiques of evolutionary theory from both an empirical and a Biblical point of view is such that one might think that a critique of the theory from another angle entirely is unnecessary or even unfair! Yet such is the aim of this present paper. What I wish to show here is that underlying the fallacy of the evolutionary hypothesis is a fundamental misunderstanding of science itself and what it tells us about the world. To put it in a nutshell, science has been interpreted **ontologically** rather than instrumentally — as describing or revealing the world's 'true essence', rather than as a tool for changing it through practical action. What follows then can be termed 'an instrumentalist critique of evolution'. Its value, alongside the other critiques alluded to above, may be that it leads to a wider critique, both of science itself, and of the scientific ideology — the widespread belief that science knows all the truth and has all the answers — that has so ruthlessly and successfully pushed Christian revelation to the margins in our increasingly secular and God-denying world.

THE TRADITIONAL VIEW OF SCIENCE — AND ITS SHORTCOMINGS!

What then, firstly, does it mean to say that science has been interpreted ontologically? As the word suggests,[1] it means that science has been seen as the search for descriptions of **true being** or **essence** — what really exists, **out there,** in the world. In philosophy of science this view would be referred to by terms like 'empiricist', 'realist', inductivist', 'reductionist' and 'naturalistic'.[2] To start with, the quantities and laws of science would be seen as describing things that **really** exist in the world, prior to and independently of scientific activity. Next, the laws would be considered to be discovered in an experimental process, which would start with the direct **empirical** observation of a suitable number of single instances of the law (for example, **this** acid turns the litmus red), then proceed via **inductive** inference to the law making a universal claim **(all** acids turn litmus red). Finally, the aim of science would be seen as explaining all phenomena by **reducing** them to underlying **natural** processes.[3]

This interpretation of science sounds familiar, even self-evident. One could say that it is the received view of

virtually all working scientists, and just about everybody else for that matter. But as far as being self-evident goes, any student of the philosophy of science knows that it is about as self-evident as evolution is to a creationist! No matter how obvious it looks, all attempts to clearly characterise and justify such a view have failed miserably, and the literature in the philosophy of science is full of schemes to solve its problems or devise alternative views. Unfortunately, while philosophers of science all agree that the received view won't do, no alternative has been universally or even widely accepted.

So what's wrong with the received view? It has come under siege from all sides. Firstly, there are the celebrated problems associated with the interpretation of the Quantum Theory in physics — the mathematical theory used to describe phenomena in the atomic and sub-atomic realms. Heisenberg's so-called 'Uncertainty Principle', in its most quoted form, states that as we reduce the uncertainty in our determination of a particle's momentum, we unavoidably increase the uncertainty in our location of its position, and vice-versa.[4] Niels Bohr went further and asserted that in fact many microscopic properties exhibit such 'complementarity' (for example, position and momentum, energy and time, the three angular momentum components), where decreasing the uncertainty in measuring one property necessarily increases the uncertainty in measuring others. The so-called 'Copenhagen Interpretation',[5] a loose synthesis of the ideas of Bohr, Heisenberg and others, and forming what might be called the received view among theoretical physicists, asserts that there are irreducible theoretical limits to our ability to have accurate knowledge of **all** properties of a microscopic system at the same time. Worse still, it throws doubt on whether the microscopic quantities used to describe such systems are actually properties of the systems themselves at all, or just of the macroscopic instruments used to measure them.

And the problems keep on coming. The so-called 'problem of induction'[6] questions how a scientific law making a universal statement can be proved by observation of any finite number of confirming cases: no number of times of the Sun rising in the morning can logically prove that the Sun will rise tomorrow morning. The original enunciation of this problem is probably due to David Hume (1711-1776), particularly in relation to our ability to have certain knowledge of causal laws. It seems that there is no purely logical basis on which we can be even practically confident of scientific laws, let alone absolutely certain. Responses to the problem range from Popper's 'falsificationism',[7] to appeals to some sort of underlying uniformity or lawfulness in nature. The classic example of the latter approach is Francis Bacon's (1561-1626) *novum organum,* which simply assumed the *a priori* existence of underlying **laws** or **causes** in nature. However, none of these responses has won wide acceptance, and each seems to have its own intractable problems.

Then there is the recognition that in science observational data is never purely or simply empirical, in the sense of merely describing incontrovertible and self-evident **facts.** Rather the facts themselves are always **theory-laden** — that is, constructed and interpreted through clusters of theories. On the one hand, theories lead to the development of new experimental techniques and instruments which are used to look for new 'facts' — previously unobserved and unobservable. On the other hand facts are interpreted in the light of theories, without which the facts would have no meaning or relevance. The observation of fossil 'facts' in evolutionary biology is a perfect example — a fragment of bone somehow acquires, with the help of the odd theory or two, a whole skeleton, flesh and blood, a habitat, an era and a place in the sequence of evolutionary chronology, not to mention a starring role in the latest blockbuster movie! Creation scientists, confronted as they often are by mainstream biologists' uncanny ability to interpret all data as confirming evolution, should be well aware of just how theory-laden observations can be. Significant critiques of traditional views of science from the point of view of theory-ladenness include Polanyi's notion of 'personal knowledge',[8] Kuhn's scientific 'paradigms',[9] and Feyerabend's 'epistemological anarchy'.[10]

The empiricist/realist interpretation of science is thrown further into doubt when it is noted that in actual scientific activity observation is always **interactive** rather than passive. Witness for example the extremes of 'observation' in a particle accelerator, where sub-atomic particles are sped up to huge velocities and smashed against thin metal foils. In the midst of the fragments left over, can we really say that Mother Nature 'reveals her secrets'? She might claim that it was a forced confession, that she just told us what we wanted to hear! In other words, were the fragments **really** there in the foil before we came along, or were they created by what we did? Going further, if as elementary particle physics asserts, material particles can be created from pure energy in such collisions, then surely it is more reasonable to interpret such 'elementary particles' as aspects of the response of matter to our action upon it, rather than antecedent constituents of it — as **artefacts** rather than facts.

The degree of **direct** interactivity of observation in fact reaches its peak in areas such as elementary particle physics, and decreases progressively as we pass through chemistry and biology, through eventually to the human sciences, where the subject matter (for example, human behaviour) of course becomes less amenable to direct experimental interference. Yet even in the latter areas there is always at least a conceptual interactivity, in the definition and choice of analytical categories under which to make observations. Scientific observation is **never** merely random, undirected, open observation; it is **always** narrow and specific, and often made under highly artificial and contrived conditions. The question always arises as to what extent our observations reflect our own intentions as well

as (or even instead of) what really is out there, empirically so to speak, before we came along.

Finally, what of the naturalistic reductionism of traditional views of science? If science is seen as merely describing what really is out there in nature, then surely what really is out there is itself an empirical question. The assertion that science must always find any particular type of underlying explanation or cause for anything it studies is then self-contradictory. It will find what it will find! Assuming that the cause will always be 'natural' is metaphysics, not empirical science. The empirical masquerade of evolutionary theory is a classic example: creationist, teleological or vitalist explanations of the living world are portrayed as unempirical metaphysics, while the evolutionary hypothesis itself is assumed to be empirical because it is natural. It might be natural, in some sense of that extremely ambiguous and dangerous word, but whether it or any of the other candidates truly explain life is, from a purely scientific point of view, an empirical question, not one that can be decided *a priori.* God's creative activity, or some sort of *elan vital,* are every bit as potentially empirical as natural selection.

So if the received view doesn't work, and science doesn't describe true being, what does it do? Answers which make science subjective or relative ring hollow, because one thing's for sure; evolution notwithstanding, science really works — otherwise several hundred years of technological advance are an illusion! How then can we give an account of science as theory-laden, interactive, **and** objective, all at the same time? The solution lies in recognising that scientific knowledge is **instrumental,** not ontological.

INTERPRETING SCIENCE INSTRUMENTALLY

Before we explore what it means to say that science is instrumental, a word of warning: there is instrumentalism and there is instrumentalism! Chalmers characterises it thus:

> '. . . *the aim of science is to produce theories that are convenient devices or instruments for connecting one set of observable situations with another Descriptions of the world involving observable entities do describe what the world is really like, but descriptions of systems involving theoretical concepts do not. The latter are to be understood as useful fictions facilitating our calculations.*'[11]

This view is identified as 'naive' instrumentalism, and is associated with the Copenhagen Interpretation of Quantum Theory, among other things. It involves a distinction between observational and theoretical statements which is impossible to maintain because of theory-ladenness; Chalmers in fact rejects it, developing later a more sophisticated 'radical' instrumentalism.[12] But neither the naive nor the radical version is the original version, which is due principally to the American philosopher and educationist John Dewey. Dewey (1859-1952), along with William James and C. S. Peirce, was a key figure in the American 'pragmatist' school of philosophy. He wrote and taught voluminously in a long career, and is probably best known for his writings in Education and Politics. Dewey's instrumentalism seems to have gotten lost in the literature, having been virtually ignored since its original elaboration in the 1920s.[13]

So what is 'true' instrumentalism — the original, uncut version? Dewey's thesis is simple to state, but involves a radically different way of understanding knowledge in general, and science in particular. He claimed that the statements of science — whether theories or purported facts — are **instruments** for changing the world, not passive descriptors of it. They describe observed patterns of **action upon** and **reaction by** the world, not things in the world that exist prior to and independently of observational interaction. To give a clear example of just how radical this view is, it implies that matter is not made up of atoms, but that rather it may be made up **into** atoms by the various experimental techniques of chemistry, physics, and so on, which involve the atomic theory. Atomicity then is not a property of matter *per se,* rather a property of matter's response to particular types of practical action upon it.

We earlier posed the question of whether **elementary particles** were facts or artefacts. Instrumentalism makes the bold assertion that **all** the objects of science are artefacts. The traditional interpretation, according to instrumentalism, confuses artificial constructs with antecedent reality. Consider what happens when you bang a car windscreen with a hammer — the glass shatters into small fragments. Do you then say 'aha! —that's how car windscreens are made — a whole lot of matching little bits of glass are carefully selected and then stuck together with an invisible glue'? Of course not! The fragments exist objectively, to be sure, but not **antecedently;** their existence is a **response** of antecedent reality (the windscreen) to our practical action upon it. The windscreen is not made up from the fragments; in fact it is created in a whole process, solidified from the liquid state, entirely independent of its fragmentation by our hammer. The fragments reveal nothing, directly, about the antecedent reality of the windscreen. The only sense in which the windscreen can be said to be **made up of** the fragments is an instrumental one — the fragmented structure may reveal a way in which windscreens might be artificially fabricated (though not in fact very useful in this case!), or may provide an analytical model for understanding and therefore controlling or modifying windscreen properties generally.

Of course the 'analysis' of a windscreen into glass fragments is not, as it turns out, a very useful one. The analysis of the human body into organ systems or bone structures, or organisms generally into cells, are examples of analyses which are in fact very useful. The analysed parts in these cases may appear to have greater claim to

antecedent existence, but the fact of their entirely interdependent genesis and development is well known — an organism is not put together from parts like a car on an assembly line! The particular way we analyse an organism depends ultimately on what we want to do with it — fix a bone or a metabolic problem in it, genetically engineer some of its characteristics so it will be more immune to a disease, or find a model for the way it synthesises a particular enzyme in order to produce the enzyme artificially. Is there an ultimately true analysis of an organism? Will medicine or agriculture be served by reducing it to 'ultimate constituents' such as atoms or even quarks? Of course not — unless we thoroughly confuse instrumental efficacy with ontological reality.

The point is that analytical systems in biology exist entirely relative to whole batches of experimental and theoretical techniques without which the systems are meaningless. Is the same true in the inanimate world? Consider the analytical system of Classical or Newtonian Mechanics, which combined with the Particle (Atomic) Theory of Matter, the Law of Universal Gravitation, and sundry other theories, purports to provide a complete 'description', at least to a certain level of approximation, of the motion of all material objects. All the basic 'descriptive' quantities of this system are instrumental rather than ontological. Mass, for example, is commonly understood as **amount of matter** (an antecedent reality), but this is not how it is measured or how it operates within Mechanics. The amount of matter in an object is simply not a measurable quantity. In fact, the way its mass is measured is by doing something like placing it on a spring balance. In doing so, we allow the force of gravity to act on the object, which responds by exerting a force on the spring, which in turn responds by being stretched. We then observe the extension of the spring scale. There is a cluster of theories and instrumental operations at work here. Only when the spring extension is calibrated via Hooke's Law ($F = kx$), the Law of Gravity ($F = mg$) and Newton's Second Law ($F = ma$) can it become a scale for measuring mass. Mass is therefore an objective property of a material object, but instrumental rather than antecedent. It determines, along with a whole batch of other quantities, how the object will behave in the context of the whole system of Mechanics: its motion, its response to forces, its mechanical relationship to other material objects, and so on.

It is possible to follow through this instrumental analysis for all the basic quantities of Mechanics. The basic reality of Mechanics is therefore instrumental rather than ontological: it embodies a whole cluster of practical operations on antecedent reality, not a description of it. The theories and laws of Mechanics correlate, summarise, and define these operations; they are properties of the operations and their interrelationships, not laws about how nature operates *per se*. They have absolutely no meaning apart from these operations. When Mechanics analyses reality into material objects (ultimately point masses) moving in time through empty three dimensional space, with all the properties of their motion specified by quantities such as velocity, acceleration and kinetic energy, it does not 'discover' some deeper, underlying, more real reality than the one we experience in day-to-day living. In fact it uncovers a less real one; an abstract 'reality' whose relationship to antecedent reality is primarily instrumental. Mechanics abstracts out those features of reality which are able to facilitate the mechanical manipulation and control of matter; hence the great breakthroughs in practical mechanics and technology which accompanied the development of Classical Mechanics in the 16th and 17th centuries. But the elevation of the theory to ontological status was and is a serious misinterpretation.

The preceding analysis can be extended to more recent developments in theoretical physics, which have claimed to be discovering new theories — quantum and relativistic — which describe a deeper, more real 'reality' than even Classical Mechanics. The strange and wonderful world of quarks, strings and vacuum fluctuations is in fact, on an instrumental interpretation, even less real and more abstract than that of Newton. This is clearly evidenced by the high-tech instrumentation associated with modern physics, and the incredibly artificial conditions under which the quantum/relativistic realm is 'observed' — for example, the violent world of particle accelerators we noted earlier. Theoretical physics is not, as is generally accepted, the **most** fundamental level of the scientific description of nature; in fact it is the **least** fundamental! It is the most instrumental, abstract, artificial level of science, the most theory and technology dependent. The reductionism of physics is not reduction to a deeper reality, but to a more artificially fabricated one. Quarks and gluons are no more fundamental antecedent 'building blocks' of matter than the glass fragments are of the shattered car windscreen.

So instrumentalism offers what is clearly a radical solution to the problems of the received view. Instruments like spades, microscopes, atoms or a classification key are entirely theory-relative, interactive **and** objective, all at the same time. And induction is no problem: we're interested in instruments that work for a particular task, not theories that are timelessly true. As we develop better spades, so we develop better theories! Proof and truth are practical not logical matters; a theory is true when it works and thus proves its usefulness, not when it describes how reality really or ultimately is. When, for example, Quantum Mechanics 'superseded' Classical Mechanics, it was not because a deeper, truer level of reality was being plumbed, but because a new realm of practical application was being opened up. The two theories exist side by side in the physicist's tool-kit, complementing each other rather than the later replacing the earlier.

It would take a lot more space than we have here to explore instrumentalism in detail. For the moment let us finish by clearing up what is probably the most common misinterpretation of what it means. Instrumentalism has

been seen as leading ultimately to a sort of relativism or solipsism in which the real world 'out there' is either forever inaccessible to our knowledge, or perhaps doesn't even exist! It ever condemns us, supposedly, to the shadowy 'virtual' world of sensory **phenomena,** the real world of *noumena* (to use the Kantian term) either forever closed to us or not existing at all. But clearly such an interpretation is absurd: it is as if reality was up for grabs, and in need of a philosophical theory to confirm its existence! In fact, instrumentalism celebrates objective reality rather than abandoning it. It asserts that our primary task in life is not to **know** the world, in some abstract, intellectual, ultimate sense, but to **interact** with it, to **experience** it in all its fullness. Knowing and knowledge are only (but not merely) a part of this interaction; a vital, instrumental part. The notion that knowledge, whether scientific, philosophical or theological, is descriptive of the world and reveals its 'true essence', was for Dewey the fallacious deposit of the class prejudices of the entire philosophic tradition from the ancient Greeks to the present day, a tradition which valued supposedly pure intellectual contemplation above the day-to-day necessities and hazards of experience and practical action.[14]

INSTRUMENTALISM AND EVOLUTION

Let us now turn to the issue of what instrumentalism has to say about evolution. Much hangs, from an evolutionary point of view, on the concept of natural selection. However, as is well known, selection was not first observed in nature, but in the use of artificial (that is, 'unnatural') selection in the breeding industry: the kind of direct intervention involved, with great success, in the breeding of horses, cattle, dogs and flowers. Artificial selection is obviously an instrumental 'law', a highly successful tool of practical action in bringing about particular desired results in breeding. The observations of selection in nature are, by comparison to those in the breeding industry and in botanical and zoological laboratories, very few in number. In fact, there were no observations at all until the early 1950s, with Kettlewell's observations of colour changes in the peppered moth, and only a few since.[15]

Somehow, however, a huge jump is made in evolutionary theory, with natural selection suddenly becoming the primary cause, not merely of species change, but of species origin, human intervention being replaced by interaction with the environment. In instrumentalist terms, such a jump, based, as creationists well know, on barely even a shred of empirical evidence, is a classic confusion of the instrumental with the ontological. Dewey claimed that such confusions were the bane of philosophic history, right from Plato and Aristotle down to the Logical Positivists of his own day. Interestingly he was himself an arch-evolutionist, failing to realise that the evolutionists' claim to have found the mechanism of life itself was exactly the sort of confusion he was talking about!

Why exactly can't natural selection explain life? The real problem is that while artificial selection is a synthetic, directed process, natural selection is a non-synthetic **non-process.** It would be completely overwhelmed by even the most minor of outside interruptions, let alone by major influences such as catastrophic natural events, some sort of *elan vital,* or even (dare we say it!) divine creation. Consequently, it can only be claimed to be significant in species origin if the additional **non-empirical** assumption is made that no other such influences were also in operation. Darwin accused his opponents of being misled by metaphysical or religious presuppositions, when in fact his theory was the most metaphysically conditioned of all![3]

It is a well-known fact in the breeding industry that there are definite limits to the sorts of changes that can be brought about by artificial selection. If artificial selection is thus limited, how much more limited is natural selection! This is mirrored by the fact that the observed cases of natural selection leading to speciation have involved changes in only minor characteristics such as colour. The chances of it leading to speciation with any significant morphological changes, let alone to the origin of all species, are zero, even if the time-span of biological history was infinite. Living organisms, from the highest levels of anatomy right down to the cell and molecular levels, exhibit a complexity and a unity which could not even in an eternity be created by any purely chance non-synthetic process. The only non-biological analogy to organisms, self-replicating automata, could be created not by chance but by the instrumental action of intelligent beings — namely us! So in fact, if they point to anything, artificial selection and the (still largely theoretical) construction of self-replicating automata point to intelligent instrumental action in nature, certainly not to pure chance.

BEYOND EVOLUTION: SCIENCE VS. CHRISTIANITY

Now such is an instrumentalist critique of evolution. It provides a theoretical philosophical basis for rejecting the theory. But one might say 'so what? — we believe the Bible, we've looked at the data, we know it's wrong anyway!' Well, if instrumentalism only impinged on evolutionary biology, such comments might be justified, but in fact the critique relates to all of science.

Even non-creationist Michael Denton can see that:[16]

> '. . . *the decline in religious belief* [in this century] *can probably be attributed more to... the Darwinian version of evolution than to any other single factor*

What he doesn't see, however, is that evolution's powerful influence is just the tip of the iceberg; the end of a process, not the start of it. Why was it exactly that evolution became within twenty years of the publication of **The Origin of the Species** the accepted view of the scientific community, in spite of the fact that all the empirical evidence was against it? Why is it that evolution has achieved the status of proven

fact in twentieth century society when it is really just a very shaky hypothesis? The answer is that evolution is ideologically rather than empirically driven. And what ideology? The one that says that science has all the answers, that it reveals true being, that ultimately we don't need God and science says he doesn't exist anyway! It is precisely at this point that the instrumentalist critique cuts in.

What we are beginning to come to here is the outline of an argument that implicates the ontological/instrumental confusion in an ideological tangle which has played a major role in the conflict between science and Christianity over the past three or more centuries, and which has resulted in the latter being left languishing at the margins in contemporary culture. Galileo, Newton, Bacon, Dalton and their contemporaries were nearly all God-fearing men of some description, but their work led to God's effective redundancy in astronomy, physics, chemistry and geology. Darwin's exclusion of God from any direct role in the creation of life itself was merely the logically irresistible culmination of this same movement. Yet underlying it from start to finish is the false epistemological assumption which, as we have seen, identifies science as the discoverer of ultimate reality. Remove this, and the whole edifice comes tumbling down!

A CHRIST-CENTRED EPISTEMOLOGY

The full elaboration of this argument obviously is yet to be explored. For the moment one question is just begging to be asked. If science, or intellectual knowledge generally, cannot reveal true being, is there anything which can? Jesus gave us a clear answer when He asserted that He was 'the way, **the truth** and the life'. It is **revelation,** through the redemptive work of Christ, that is the revealer of true being. A leading Protestant theologian recently wrote, after an in-depth analysis of the historical failure of theology and philosophy to ground knowledge on something else other than revelation:

> *'The co-eternal Word is thus the basis of any and all meaning as "foundation": not only of the faith of the believer, but of the very possibility of knowledge of any kind. If Christ is the mediator of creation, then he is the basis of created rationality and therefore of human knowledge, wherever and whatever; we might say, of all human culture'*[11]

And this from a writer who believes in evolution![18] How much more should we, as Bible-believing Christians, recognise the epistemological primacy of Jesus Christ? Yet as long as we hold science up as a competitor of Jesus, as an alternative revealer of true being, we fail to acknowledge Him as **the** truth, the **only** truth.

It is through Jesus then, through revelation, through His Spirit (the Holy Spirit) that true being is revealed. This is not a conclusion of the instrumentalist critique. It is a separate assertion, an assertion of faith! The critique only acts to remove a major stumbling block that stands in its way. It clearly exposes evolution as false, in principle as well as in practice (as we already knew). It does not denigrate science, but sees it for what it really, and only, is. And it opens the way for visions of our world which do not see atoms, fields, empty space, the Big Bang and survival of the fittest as fundamental realities, but which look beyond these limited instrumentalities to the living, divinely created and inspired reality that Jesus Himself saw as 'the Kingdom of God'.

FOOTNOTES AND REFERENCES

1. From the Greek: *on, ont-* being. The notion that underlying the sensible world there are true essences or being which are more real (or have a higher level of reality) dates from ancient Greek philosophy, and the search for such essences carried on in one form or another through the Middle Ages. Since the rise of modern experimental science, from the 1500s onwards, this search has gradually become the exclusive domain of science, and the influence of philosophy and theology in these areas has drastically waned.
2. Chalmers, A. F., 1976. **What is This Thing Called Science?,** University of Queensland Press, provides a useful introductory survey of the various ways in which science has been interpreted historically.
3. See, for example: Denton, M., 1986. **Evolution: A Theory in Crisis,** Adler and Adler, Maryland, p. 35.
   This arch-critic of evolution states that *'the fundamental aim of science is to reduce wherever possible all phenomena to purely natural explanations'.* This modern form of reductionism replaces earlier versions where the reduction was to **essences** (or **forms** or **ideas)** which were basically of an abstract philosophical or even theological nature.
4. Guillemin, V, 1968. **The Story of Quantum Mechanics,** Charles Scribner's Sons, New York, pp. 98-99.
5. d'Espagnat, B., 1989. **Reality and the Physicist,** Cambridge University Press.
6. Chalmers, Ref. 2, pp. 12-19.
7. Popper, K., 1959. **The Logic of Scientific Discovery,** Hutchison and Co. Ltd, London, provides the classic statement. See also the useful summary in Chalmers, Ref. 2, pp. 35-46.
8. Polanyi, M., 1958. **Personal Knowledge: Towards a Post-Critical Philosophy,** Routledge and Kegan Paul, London.
9. Kuhn, T. S., 1962. **The Structure of Scientific Revolutions,** University of Chicago Press.
10. Feyerabend, P. K., 1975. **Against Method: Outline of an Anarchistic Theory** of **Knowledge,** New Left Books, London.
11. Chalmers, Ref. 2, p. 115.
12. Chalmers, Ref. 2, pp. 129-131.
13. Dewey, J., 1930. **The Quest for Certainty: A Study of the Relation of Knowledge and Action,** Allen and Unwin, London, provides its clearest statement.
14. Dewey, Ref. 13, chapter 1.
15. Denton, Ref. 3, pp. 79-80.
16. Denton, Ref. 3, p. 66.
17. Gunton, C, 1995. **A Brief Theology of Revelation,** T. & T. Clark, Edinburgh, pp. 124-125.
18. Gunton, Ref. 18, pp. 69-71.

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