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BOOK REVIEW

Mind from Matter? An Essay on Evolutionary Epistemology

By MAX DELBRÜCK; edited by Gunther S Stent. Blackwell Scientific Publications; 290 pp; Price: $ 14·95.

"How is it possible that mind came into being in an initially lifeless, and hence mindless, universe?"

"If it is by way of the evolutionary process of natural selection, then how did this process give rise to a mind capable of elaborating the most profound insights into mathematics, the structure of matter and the nature of life itself, which were scarcely needed in the cave?"

"How can the capacity for understanding and knowing the truth arise from dead matter?"

These in paraphrase are the questions that Max Delbrück poses to himself at the beginning of his essay "Mind from Matter?". The questions themselves are "canonical" and easily asked; but any one who attempts to shed light on, leave alone answer, them in anything more than a superficial manner must be unusually well-qualified and possess deep and intimate understanding of vast areas of knowledge. Before we may form and express an opinion on how successful the present attempt has been, or how close to our own expectations and hopes the answers come, we must begin by realizing how exceptionally well-qualified Delbrück was to have made the attempt.

Delbrück (sometimes with Erwin Schrödinger) is often accorded an almost mythical status in biology, a field to which he came via theoretical physics. He was born in Berlin in 1906, and began his professional scientific career as a student of physics working in the then frontier subject of quantum electrodynamics. He is known in this field for the study of the scattering of light by light, a process not explainable by classical physics but requiring a quantum description. The process is today called "Delbrück scattering". After obtaining his Ph.D. from Göttingen in 1930, he spent part of 1931 as a post-doctoral fellow at the Institute for Theoretical Physics in Copenhagen, bringing him into close contact with Niels Bohr and his newly fashioned ideas of the Complementarity Principle and the interpretation of quantum mechanics. In 1932 Delbrück came back to Copenhagen to listen to a now famous lecture by Bohr to the "International Congress on Light Therapy" on the theme "Light and Life". Here Bohr tried to argue that the complementarity principle, evolved by him to provide a consistent interpretation of the mathematical formalism of quantum mechanics, may have implications for the study of biology as well. The principle has essentially two components: the result of an observation and measurement of some property of a physical system cannot be dissociated from the experimental set-up used to make the measurement; as a result, if observations of two different properties require mutually incompatible or exclusive experimental arrangements, they cannot be measured simultaneously. Knowledge of one in the numerical sense requires renouncing simultaneous knowledge of the other. Such pairs of properties – for example, position and momentum of a point mass – are said to be complementary to one another; and it is by stating explicitly all possible experimental arrangements, plus the results obtained with each, that one obtains a complete description of the system. Bohr suggested that the desire to explain in detail the working of a living organism *at the atomic level* might call for experimental procedures that result in its being killed; therefore such an explanation of life, and the very fact of life itself, may be mutually incompatible and complementary to one another. This would result in life not being totally reducible to the physics and chemistry of atoms; and understanding it may require quantum mechanics *plus something else yet to be discovered.* As it has later turned out, Bohr's proposal was perhaps a too hasty and naive application of deep insights gained in one area of natural science to another; but it certainly had the effect of helping Delbrück decide to shift his interests from physics to biology. A few years later, at the Physical and Biological Congress in memory of Luigi Galvani held in Bologna in 1937, Bohr returned to this theme and spoke on "Biology and Atomic Physics". And his never-yielding struggle to come to terms with this problem is shown by the fact that, as late as 1962, at Delbrück's invitation Bohr spoke again on "Light and Life Revisited"!

It was this exposure to Bohr that evidently was the most important motivation for Delbrück to turn from physics to biology, and to devote himself to a lifelong quest for "the role played by single atoms in vital functions". Already in 1935 he, in collaboration with Timofeeff-Ressovsky and Zimmer, had proposed a theoretical model for the gene as a molecule, and especially its mutations as a quantum mechanical phenomenon. (This model, initially ignored, later received wide attention and appreciation thanks to Erwin Schrödinger's exposition of it in his lectures on "What is Life?" given in 1944 at the Dublin Institute for Advanced Studies). In 1937, Delbrück left Germany for the USA, where he spent the rest of his life as a scientist, most of it at the California Institute of Technology. In the 1940's he, along with Salvador Luria, Alfred Hershey and others, founded the "phage group". They devoted themselves to the study of bacteriophages, and in the process laid the foundations of quantitative molecular biology. It has been said that in this group Delbrück succeeded in recreating the special atmosphere for scientific research that had characterised Bohr's school in Copenhagen. The work of this group paved the way for the discovery in 1953 by Watson and Crick of the structure of the DNA molecule. Luria and Delbrück found in 1943 a technique for measuring mutation rates in bacteria; in 1969 they shared with Hershey the Nobel Prize for Medicine or Physiology.

Delbrück's concerns with the questions announced at the start of this review were of long standing. In 1949 he had written an essay on "A Physicist looks at Biology" – a hint that he viewed himself primarily as a physicist? He returned to this subject in his Nobel address in 1969, speaking on "A Physicist's Renewed Look at Biology – Twenty Years Later". The present book itself originated in a twenty-lecture extempore course on "Evolutionary Epistemology" given at Caltech during winter 1974–75, in which Delbrück wanted to examine whether Bohr's philosophy could be used as the basis for a world view. The course was repeated in 1976–77, on which occasion it was taped and transcribed. In this form Delbrück gave it the title "Mind from Matter?", and had hopes of editing and publishing it as a long essay. Various circumstances – including his own ill-health – came in the way, and he could not realize these hopes. In mid-1977 he condensed the entire material into a single lecture given at the 13th Nobel Conference held in the US, and later published it in *The American Scholar*. Delbrück died in March 1981. It was left to his close associates, notably Gunther Stent, and others to edit the text and make it accessible to a more general and less qualified audience than the ones he lectured to at Caltech.

Delbrück's treatment of his subject is divided into twenty chapters, each one relatively brief (presumably the content of one lecture) but providing an incisive thumbnail sketch of one area of science. The first four chapters are devoted to evolution over vastly different scales of time: cosmic evolution of the universe and the earth, with time periods varying from some ten billion years to half a billion; prebiotic evolution, upto about three billion years ago; followed by biological evolution over the past three billion years, with life forms based on photosynthesis and respiration appearing some two billion years ago. Human evolution and that of the brain occupy the next couple of chapters, followed by three more on the development of vision, perception, and cognitive faculties in infants as revealed by studies in developmental and child psychology. Then there are several chapters, eight in all, taking up a discussion of Kant's notion of a priori categories of experience, and of the growth of mathematics and physics down to modern times. The last three chapters are concerned with the inadequacy of the "Cartesian Cut" between the observing subject and the objective outside world; the origin and the phenomenon of language; and a summing up of the entire effort. Without question, this is a truly remarkable presentation, covering vast ground, and also trying to convey the unavoidable necessity of bringing all these varied areas of knowledge together in facing up to the original puzzle of the Mind.

To begin with, the attitude taken is that of naive realism: the world is "out there" with definite properties of its own, and our senses present a faithful picture of it to our consciousness. Against this perspective we learn how life appeared on the earth three billion years ago, some seven hundred million years after conditions suitable for it had already been in existence; the emergence of new forms of life, based on photosynthesising organisms; the growth of perception, and of the processes of speciation leading to the many branches of the tree of life. Throughout Delbrück emphasizes the two ways in which all life forms display both unity and continuity: in the material biochemical sense, and in the psychic sense of organisms capable of perceiving and reacting to their environment. The story continues to cover the evolution of fish, vertebrates, mammals and finally hominids (precursors of man) some two million years ago. Even though humankind as recognised today may be no more than forty thousand years old, Delbrück's story starts with the origin of the universe itself, the relics of the big bang and the life sequences of stars, to make the point that one has to be aware and cognisant of the entire evolutionary history of the universe to find out how Mind arose.

However by the time one comes to the evolution of the brain, vision, perception and cognition, one realises the limits of the standpoint of naive realism – it is too naive! There are two equally important aspects involved here. On the one hand, Delbrück recounts the discoveries of modern neurophysiology which disclose the actual manner of functioning of the brain – the story of vision in particular is most fascinating since by way of an example it shows that what the senses convey to the consciousness is a highly filtered, fragmented and processed version of what presumably "exists out there". What a remarkable feat that the mind is then able to *reconstruct* the external world! On the other hand, the picture of the world that we create for ourselves is suited only to our own "middle dimensions" – naturally, since in evolutionary terms this is precisely what is needed for survival! Delbrück describes in some detail the results and theories of Piaget, relating to the way concepts of space, objects with qualities of permanence and identity, time and causality, all appropriate to the world of middle dimensions, are created in infancy through continuous interaction with the environment. But the physical limitations of the concepts fashioned for this world are now well-appreciated: the concepts needed for understanding the very large and the very small both depart greatly from those adequate for everyday experience, for which reason we are constrained to call them counter-intuitive. Thus the original standpoint of naive realism has to give place to a more sophisticated "structuralist realism": both admit the existence of a real external world independent of the mind's experience of it; they differ in their understanding of the form in which the senses provide information to consciousness, and of the processing that occurs on the way.

This revised form of realism and the fact that so much processing of visual and other sensory inputs from the outside goes on in the brain, leads one to examine afresh Kant's ideas and to restate them in the much wider framework of evolutionary theory now available. Kant had hypothesized that all our experience of the world is structured or has to pass through filters or preexisting "categories of thought": thus one can only "see" the world through the "glasses" of permanent identifiable objects, Euclidean geometry of space, and Newtonian time and causality. In a way one is reminded here of Laplace's assumption that the entire universe is a clockwork fashioned after Newton's celestial mechanics – success leads to dogma. Kant sought to make Newton's discoveries an *inevitable* part of human experience! But then how could one explain that these supposedly a priori categories of thought fit the real world so precisely and beautifully? In a sense, Kant had no explanation – that had to wait for Darwin and the theory of evolution, making possible a reinterpretation. By distinguishing between phylogenetic and ontogenetic development – of the species and of the individual – Delbrück explains how what *seems* a priori for the individual is not so at all for the species, but is the result of long periods of adaptive evolution! One may say that Kant's notions were premature in their original form, and had to wait for evolution theory to supply a proper understanding.

Once one accepts this phylogenetic origin of the concepts and categories of thought appropriate to the world of middle dimensions and "everyday experience", there is really little difficulty in further accepting that these may need drastic modifications when we deal with realms far removed from daily experience. In this spirit Delbrück gives beautiful accounts of the development of both special and general relativity on the one hand, and of quantum theory on the other. These have forced us to change our intuitive views of geometry, simultaneity, time, determinism and measurability. One may only wonder – why do we have to yield on all fronts?!

Preceding these, Delbrück presents most fascinating accounts of the development of mathematics and Newtonian physics. The material on the paradoxes and problems of mathematics and logic is full of insight and understanding, dealing with questions of consistency and completeness of mathematical systems. It is conceivable that Delbrück's familiarity and feel for such matters date back to his Göttingen days and the influence of Hilbert's school. One has to learn, painfully sometimes, that many questions can be raised, and not all may be answerable! One wonders, with Delbrück, whether an incompleteness in a mathematical system created by Mind is an incompleteness in nature or not. He too leaves it as a question. The puzzling aspects of relativity theory are, to a sufficiently well-trained physicist, no puzzles after a while; but those of quantum mechanics do not go away so easily. The former retains the possibility of visualizing nature, the latter limits it. In every area, one learns repeatedly that one may transcend rather than answer the questions that at first naturally come to mind! A classic example is this version of the wave–particle duality of matter and radiation: "To the question whether an electron is really a particle or really a wave, quantum theory gives the resounding answer: Yes!"

In such a wide-ranging essay as this one, the reader is naturally drawn to intriguing parallels in developments in widely separated fields, which is one of the beauties of this book. To mention only a few: one sees at first how Newton had favoured a corpuscular theory of light, which however later had to yield to the wave theory. But with the notion of the photon, the corpuscular idea was revived, albeit in a new and deeper conceptual setting. In a similar historical sense, the Kantian idea of a priori categories, as already mentioned, needed a new and all encompassing framework provided by evolution theory to make sense; but what is a priori and what is not depends on the point of view adopted. Another parallel is between Einstein's initial suspicion of inconsistencies in quantum mechanics, later giving way to a belief in its incompleteness; and in Hilbert's desire to prove the consistency and completeness of mathematics, till Gödel showed that neither could be demonstrated! In the use of language, a product of the Mind, in both cases one has to walk a logical tightrope and, in Wittgenstein's words, "Whereof one cannot speak, thereof one must be silent."

All this of course makes for heady reading, but one must ask, what answers does Delbrück give to the three questions that prompted the entire exercise? In truth the situation is a little disappointing, at least to a physicist familiar with the nuances and exasperations of the quantum world view. It must have seemed exciting and exhilarating to physicists soon after the development of quantum mechanics to imagine that the revolutionary insights gained therein indicated that similar revolutions would be needed to understand the phenomenon of life. As Delbrück explains, physics is based on the capacity to, and the process of, measurement, which is a slowly learned art. Classical physics assumed that all properties of a physical system could simultaneously and at all times be reduced to numbers and a numerical description. But one had to learn that in truth nature is different. Only mutually compatible properties can simultaneously be reduced to the status of numbers, and that too in general only momentarily. On their own, physical properties – better not to say quantities – of a system have an abstract nonnumerical meaning as elements of a noncommutative algebra. Even the notion of reality in physical theory has undergone a subtle transformation, being bound up with the criterion of convenience of description. Is it not reasonable to expect that something qualitatively similar, something as deep, would be needed to understand Life and Mind? (Never mind the difficulties in accepting a quantum mechanical view of the world.) Alas, no! It somehow seems possible to understand the molecular basis of life–complicated though it may be–on the conceptual basis of a mechanistic physics and a naive realism. Unlike the case of atomic physics, there seems to be no need for a Bohrian revision of the conceptual structure specifically to understand life. Heisenberg had once remarked that there were no cheap solutions to the problems of interpretation with quantum mechanics, but it seems to have been otherwise with molecular biology! An embarrassingly simple–in principle–mechanical approach seems to suffice. In Delbrück's words: "It might be said that Watson and Crick's discovery of the DNA double helix in 1953 did for biology what many physicists had hoped in vain could be done for atomic physics: it solved all the mysteries in terms of classical models and theories, without forcing us to abandon our intuitive notions about truth and reality". In a manner of speaking this is a vindication of something that Paul Dirac wrote in 1931: "There are at present fundamental problems in theoretical physics awaiting solution, e.g., the relativistic formulation of quantum mechanics and the nature of atomic nuclei (to be followed by more difficult ones such as the problem of life),...."

As for the Mind, having so forcefully argued that evolution is the driving force behind a multitude of capabilities and actualities, at the end Delbrück is led to declare: "the difference between the mental and the physical is not at all a radical one, but one merely of degree". And furthermore: "The point of view of the evolutionist forces us to view mind in the context of other aspects of evolution.... In the context of evolution, the mind of the adult human... ceases to be a mysterious phenomenon, a thing unto itself. Rather, mind is seen to be an adaptive response to selective pressures, just as is nearly everything else in the living world.".

One may be forgiven for confessing to a feeling of being let down by these conclusions. Bohr's grand suggestions of 1932 turned out to be wrong. It may be that in the format of class-room lectures, in which Delbrück first presented his material, there was more opportunity for discussion and give and take, and clearer appreciation of the inevitableness of his final position, than the written record of those lectures can provide. Nevertheless, one salutes Delbrück for his role as the vehicle through which an attempt was made to apply Bohr's epistemology to problems of biology, and for his superb survey of the results.

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