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Karl Popper's Science and Philosophy

Springer

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Preface

Of all philosophers of the twentieth century, Karl Popper stands out as the one who did most to build bridges between the diverse academic disciplines.

His first major work, *Logik der Forschung* (1934), concerns scientific method. Popper's ideas were formed in the intellectual climate dominated by the logical positivism of the *Wiener Kreis*; despite a great diversity in academic interests, the members of the Vienna Circle wanted to reaffirm the scientific ethos of the Enlightenment ideal. Excited by the revolutionary ideas of Einstein (whom they engaged in both scientific and philosophical discussions), they believed that philosophy must play an active role in this new era by drawing as close to science as possible. Although Popper shared these general ideals, he strictly rejected all the main pillars of the positivist philosophy of science: inductivist logic of discovery, the verifiability principle and the concern with meaning. In single-handed opposition to this influential philosophical movement, Popper offered new solutions: a hypothetico-deductive view of science, based on falsifiability as the demarcation criterion and a denial of the claim that scientific theories could be verified. It is fair to say that the radicalism of Popper's proposals caused an upheaval among philosophers of science, especially after the publication of his work in English in 1959.

With the advent of World War II, Popper applied his revolutionary methodological ideas to political philosophy. He became famous for his theory of the open society, in which he criticized authoritarian and totalitarian social systems based on the doctrine of historicism, that is, historical inevitability. The future is open, said Popper, and since we all are fallible so are our social and political systems. Holistic experiments, a willingness to sacrifice one's life for a higher good, must be avoided and replaced by a more modest piecemeal social engineering, in which mistakes can be corrected and society reformed without bloodshed. The same is true, he argued, for political regimes: Popular replacement of governments is the keystone of democracy, and democracy is—despite its many imperfections—the best form of government known so far.

Later, Popper focused on wider problems of the growth of knowledge. Rational discussion, he suggested, depends on a readiness to listen to critical arguments and should not aim to demonstrate truth. Scientific theories are guesswork, but by constantly subjecting theories to testing, science can progress. His methodological principle of criticism is thus the core of a dynamic but challenging epistemology, requiring an adventurous spirit and a willingness to make risky conjectures. Falsification—Popper's "negative methodology"—takes on a positive role that of uncovering new problems through the elimination of failed hypotheses. Popper shifted the focus of methodology from proving to undermining, from establishing to critical activity itself. In a broader philosophical sense, he proposed an antifoundationalist model of rationality that views all knowledge as conjectural, hypothetical and provisional.

Not surprisingly, Popper is one of the few philosophers of science who inspired scientists (especially the Nobel Prize winners Peter Medawar, Jacques Monod and John Eccles, in addition to the biologist Donald Campbell, the biochemist Günter Wächtershäuser and the mathematician Hermann Bondi), and he won recognition by the scientific establishment (he was elected a Fellow of the Royal Society in 1976). It was Popper's emphasis on scientific research as an adventure, in which scientists constantly and fearlessly attack received opinions in the search for the truth and for new and interesting problems, that was so much admired.

This is not a list of Popper's contributions; let us nevertheless mention his herculean success in presenting an axiomatic system for probability that provides a genuine generalization of (propositional) deductive logic, his success in developing the theory of logic as a theory of deduction, his defense of realism in quantum mechanics, his study of the body–mind problem and his involvement in discussions of evolutionary biology. His methodology and epistemology have been widely and vividly discussed, but his impact on scientific research and his contributions to it have received less attention. The aim of this book is thus to illustrate, and evaluate, the impact, both substantive and methodological, that Popper has had in the natural and mathematical sciences. An attempt is made to pinpoint the connections between these contributions and his central philosophical concerns. The topics selected are quantum mechanics, evolutionary biology, cosmology, mathematical logic, statistics and cognitive science. The approach is multidisciplinary, opening a dialogue across scientific disciplines and between scientists and philosophers.[1]

It is always fascinating to watch the moments of rupture when philosophy acquires a completely new impetus and challenges the established ways of perceiving the world. Karl Popper overturned the traditional values ascribed to reason and revolutionized the field of philosophy of science. Inevitably, his views provoked debates and disagreements. Our own goal here is not to glorify Popper but to invite the study of his best ideas and develop critical perspectives through the evaluation of his ideas and his work.

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[1]The impulse to investigate Popper's influence on science emerged at the Popper Symposium held at the CLMPST 2019 in Prague and supported by the Karl Popper Charitable Trust. Many thanks to Joseph Agassi who contributed with valuable comments and advice to this volume.

Contents

Biology

Cognitive Science

Karl Popper on the Evolution of Consciousness

Manjari Chakrabarty

1 Introduction

Some scholars (e.g., Skoyles 1992) feel that Popper's work has been widely acknowledged by the scientists but has had little impact on professional philosophers. Some others (e.g., Lindahl 1992) are of the opinion that Popper's influence on both the philosophers and the scientists has been considerable, or to borrow Bondi's (1992, 363) words, "…Popper's influence shines through." However, it wouldn't be incorrect to say that Popper's teachings and views on the evolution of consciousness (or minds) and on the consciousness-brain or minds-brains interactions have received comparatively little scholarly attention from mainstream philosophers of mind. His name does not appear in many introductory books and edited volumes on philosophy of mind (see, e.g., Churchland 1984; Lowe 2000a; Heil 1998, 2004).

Popper has been actively interested in the key issues related to the philosophical theories of mind and its relation to the brain, for many years. His first papers on the subject now reprinted as Chaps. "Language and the Body-Mind Problem" and "A Note on the Body-Mind Problem" of *Conjectures and Refutations* (1963) were published in the early 1950s. A more fully developed interactionist hypothesis—intertwined with his conjecture of three worlds—has then appeared in his 1977 publication *The Self and Its Brain*, written in three parts with John Eccles. Popper has proposed this (non-dualist) interactionist hypothesis mainly to address the classical problem of interaction, namely, how two very different entities such as minds and brains can possibly interact, from an evolutionary (biological) perspective. Ever since its first explicit presentation the said hypothesis has been disapproved by several philosophers (see e.g., Dennett 1979; Rooijen 1987; Settle 1989). One possible reason behind the philosophers' strong resistance to Popper's (non-dualist) interactionist hypothesis could be the growing dominance of some form

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Z. Parusniková and D. Merritt (eds.), *Karl Popper's Science and Philosophy*,
https://doi.org/10.1007/978-3-030-67036-8_16

of materialism or physicalism[1] in philosophical circles since late 1970s along with its tendency to reject all conceivable versions of consciousness-brain interactions. Besides, Popper and his co-author Eccles are often misrepresented by prominent philosophers (e.g., Lowe 2000b, 575) as 'interactionist dualists'. In such an intellectual climate it is hardly surprising that Popper's (non-dualist) interactionism remains an unpopular, and comparatively less well-examined position in the field.

In the early 1990s a 'new theory of mind' (Popper et al. 1993, 168), partly based on his earlier interactionist hypothesis, has been introduced by Popper. This new theory, presently known as the 'mental force field' hypothesis, characterizes minds as having important similarities with recognized physical forces (Popper et al. 1993). Although this novel hypothesis of Popper has been further extended by two Swedish philosophers B.I.B. Lindhal and P. Århem (e.g., Lindahl and Århem 1994) and has also been examined by some well-known neurophysiologists (e.g., Libet 1996; Jones 2013), it is yet to found a serious place in contemporary philosophical investigations into the nature of consciousness. Probably because of Popper's unconventional[2] portrayal of consciousness as an emergent, biological yet force-like phenomenon and his silence on the subjective aspect of consciousness (see e.g., Nagel 1974), his mental force field hypothesis doesn't interest many who attempt to define consciousness in terms of its characteristic privacy and qualitative nature.

In the present chapter, consisting of three sections, it is argued that a critical review of Popper's (non-dualist) interactionist hypothesis (supplemented by his mental force field hypothesis) is both urgent and necessary for a more comprehensive understanding of the evolution of consciousness and its dynamic interactions with the brain. The reasons assumed to be crucial for substantiating this core argument are stated below. First, a closer scrutiny of the hypotheses of Popper reveals how consciousness-brain interactions may plausibly be explained (without violating the laws of classical physics) and thereby a challenge may be posed to their apparently irrefutable rival, physicalism (the characteristic principle of which is the closedness of the physical world). The next two sections deliberate on the above reason.

The second reason concerns the philosophers' utter neglect of the burgeoning archaeological research on the evolution of (hominin) mental faculties, over the past decades. In an exchange of views (published in the journal *Mind and Language*) two of the most renowned philosophers of mind, Dennett (1996) and Fodor (1996), disagreeing fundamentally on the issues regarding the evolution of mental faculties, agree with each other on the point that these issues cannot be addressed 'until the data is in'. If only these philosophers took a moment to examine the experimental-archaeological literature, noted archaeologist Steven Mithen (1998, 5) argues, they could have seen that a huge amount of the relevant data is not only 'in' but has already

[1]Despite having very different histories the terms 'materialism' and 'physicalism' are used interchangeably here.

[2]Popper's hypothesis seems unconventional because it neither promotes the 'mind-as-computer' view nor the 'mind-as-brain' view (Jones 2010).

been subject to immense archaeological interpretation and analysis. Popper's (non-dualist) interactionist hypothesis is quite a unique philosophical account that focuses on the evolutionary (pre) history of minds or of the different levels of consciousness. Expressing his discomfort regarding the common, injudicious use of the phrase 'the conscious mind' (Popper 1994, 111), Popper has focused instead on the many different levels of consciousness and on their biological significance.

This underlying belief of Popper in the existence of different levels of consciousness points towards the question of the evolution of consciousness in a world hitherto purely physical in its attributes. Interestingly, the decades-old Popperian speculations about the evolution of minds—both prehuman and human—look strongly convergent with current experimental-archaeological research. The final section of the present chapter intends to bring to light the convergence of Popper's philosophical views and recent archaeological explorations that has gone largely unnoticed in the relevant literature.

On basis of the reasons stated above the present chapter concludes with the argument that Popper's (non-dualist) interactionist hypothesis (supported by his mental force field hypothesis)—is neither an explanation "… we can perhaps afford to ignore… in philosophical discussions related to causal closure principles and emergentism…" (Lowe 2000b, 575) nor one that "…fails to make serious contact with the best theoretical work of recent years…" (Dennett 1979, 91)—but is a serious contender in the philosophical battlefield that deserves more critical attention from the mainstream philosophers of mind.

2 In What Sense Is Consciousness Distinct from the Brain?

Two questions are most critical for Popper. First, in what sense is consciousness distinct from the activities and states of the brain? Second, how does consciousness—seen as distinct from the brain—causally interact with the brain? While Popper's (non-dualist) interactionist hypothesis puts more emphasis on the first question, his later (mental force field) hypothesis addresses the second question more directly. The present section attends to the first question and the second question will be considered in the following section.

Popper has explicitly stated that his 'tentative' but 'testable' (Popper 1994, 105) interactionist hypothesis complicates the process of explanation by construing consciousness as distinct from the brain. Physicalism, in contrast, seems 'intrinsically convincing' (Popper and Eccles 1977, 51) and hard to decisively refute because by denying the existence of consciousness as distinct from the brain it simplifies the explanatory task and wipes out a number of difficult problems (Popper 1994, 105). Nevertheless, physicalism is unacceptable to Popper because it dogmatically explains away one of philosophy's greatest riddles instead of seriously investigating it (Popper and Eccles 1977, 53).

Popper's answer to the question—in what sense is consciousness distinct from the activities and states of the brain—is implicit in his theory of three worlds (Popper and Eccles 1977; Popper 1979). Reality, for Popper (Popper and Eccles 1977; Popper 1979), is a tripartite phenomenon composed of an interacting triad of evolutionary levels, namely, world 1, world 2 and world 3. Each of these worlds or evolutionary levels is an irreducibly emergent[3] phenomenon and all three causally interact with one another. World 1 is the physical world of matter and energy including stars, planetary systems, physical bodies, forces, fields of force, living organisms and all organismic physical, chemical, biological processes. At some time in the distant past, prior to approximately 3.5 billion years, by processes not yet completely understood, life in the form of unicellular, micro-organisms (protobacteria) emerged from non-living matter. Life became complex progressively, as plants and animals of myriad forms and sizes evolved and interacted with fertile ecosystems.

During the evolution of life (in the form of microorganisms) on earth, some organisms became conscious (in a certain sense) and advantageously adapted to the contingencies of their environments. A new, i.e., qualitatively different realm of (primitive) conscious states and its attendant subjective experiences (e.g., feelings of pain, pleasure)—called world 2—emerged out of world 1 at a particular stage of evolution, though we cannot pinpoint that event. What makes world 2 as real as the physical world 1 is the fact that it causally interacts with the latter. The ability of causally acting on (ordinary-sized) physical bodies and being influenced by them is the core (and sufficient) criterion of reality for Popper (Popper and Eccles 1977, 9–11).

Out of the dynamic interplay of world 2 and world 1, probably at the stage corresponding to the appearance of some initial form of linguistic behaviour, emerges world 3—a distinct, extra-somatic, objective realm of human (also hominin) creation. Theories, propositions, the abstract yet objective contents of scientific, mathematical, or poetic thoughts, problem-situations and critical arguments have been described by Popper (1979) as the most fertile world 3 objects. Nevertheless, this world 3 or the 'world of culture' (Popper 1982, 54) includes myths, fairy tales, ethical values, social institutions, paintings, sculptures, and 'feats of engineering' such as, tools, machines, and scientific instruments (Popper 1979, 2). Manifestly, world 3 products are not genetically coded but can be modified, criticized, reinterpreted, and maintained (largely) by human beings. That world 2 is essentially instrumental in generating world 3 does not, however, call the reality of world 3 into question because world 3 can also act on world 1 (via world 2) and be acted upon (Popper and Eccles 1977).[4]

In the light of Popper's tripartite account of reality comprising of three distinct but 'somewhat overlapping' (Popper and Eccles 1977, 48) and interacting worlds or evolutionary levels, "…the question where physics begins and mind ends or where physics ends and mind begins…" appears much less significant (almost like a pseudo-problem) than the issue of interaction (Popper et al. 1993, 171–172). The real, important issue for Popper is that minds can interact with brains (Popper et al. 1993,

[3] As a preliminary, note that phenomena, which are based on certain processes but cannot be reduced to (or explained by the theories of) the underlying processes are often understood as emergent.

[4] For a detailed discussion see Popper (1979).

172). This Popperian conjecture might have provoked some scholars (e.g., Lindahl and Århem 2016) to interpret the distinction between minds or consciousness (the Popperian world 2) and brains or bodies (the Popperian world 1) epistemologically, leaving the issue of whether or not consciousness is material or physical in nature an open question. The reason being, introspection suggests that consciousness is something subjective, but the activities and states of the brain are not so (Lindahl and Århem 2016, 229). Consequently, consciousness cannot be identified (in an epistemic sense) with the activities or states of the brain. This epistemic interpretation offered by Lindahl and Århem (2016) looks promising. For, though we would still have to explain—how it is possible, at least in principle, for something objective (e.g., a change in a certain neuronal electromagnetic field in the brain) to cause something subjective (e.g., an occurrence of an unpleasant sensation), and for something subjective (e.g., the occurrence of the unpleasant sensation) to cause something objective (e.g., a change in a certain neuronal electromagnetic field in the brain)—such an epistemic account wouldn't be affected by what is called the thermodynamic argument—the accusation that any action of world 2 on world 1 would violate the principle of the conservation of energy. However, what this interpretation tends to undervalue is the evolutionary significance of both world 1 and world 2. It is not evident how an epistemic reading of the Popperian distinction between world 2 and world 1 could help us approach the problem of consciousness-brain interaction from an evolutionary-biological perspective.

Conversely, Popper's hypothesis may be interpreted as providing a description of minds (world 2) being irreducibly or ontologically different from, but still interacting with, the brains (world 1). An interpretation like this is obviously prone to serious difficulties. For critics would want to know: "…how the mechanics of energy transfers work when non-physical minds move our bodies, and when non-conscious brains create conscious minds…" (Jones 2013, 11). This critical query most likely assumes that any interactions between non-physical minds and non-conscious brains would lead to violation of the first and/or second law of thermodynamics. Several attempts have been made to offer a plausible explanation of minds-brains interaction and a scrutiny of such attempts is indeed crucial for exploring any solutions to the above query. But before undertaking this task in the next section, a problem with the ontological interpretation of the Popperian distinction between minds and brains needs to be attended. The distinction between 'non-physical minds' and 'non-conscious brains' as drawn by Jones (2013, 11) seems much sharper than what Popper has proposed. Though Popper has occasionally used words such as 'immaterial' (Popper and Eccles 1977, 178) or 'incorporeal' (Popper et al. 1993, 168) to characterize minds, his emphasis on the possibility of minds' sinking into physiology is unmistakable. This is perhaps nowhere more evident than in the following remarks of Popper (Popper et al. 1993, 171–172):

> …What is very interesting is that mind may, in a sense, sink into physiology. Take a typical case, you learn to play the piano, or you learn to ride a bicycle, or you learn to drive a motorcar; in this there is a stage at which you are very conscious of everything that happens; everything is done consciously. This stage soon disappears. Mind becomes unconscious… it sinks into physiology. It sinks and becomes physiological … nobody can really deny that

> this happens, that there is a mergent process, a process where mind and brain are no longer really distinguishable.

Jones' (2013) reading of Popper reflects a common tendency among scholars (see e.g., Dennett 1979; Lowe 2000a) of ignoring Popper's non-dualistic framework while addressing the problem of consciousness-brain interactions. Popper, on the contrary, has approached the issue of interaction from an evolutionary-biological perspective that critically involves his conceptual framework of three worlds or evolutionary levels, each one having a long prehistory and none being homogeneous (Popper 1994, 111). The chief virtue of this tripartite schema presupposed in Popper's interactionist hypothesis is that it illuminates two significant points at one go. First, consciousness, as explained by Popper, not only interacts with the brain or its neurophysiological processes but also with its own objective products belonging to world 3 (Popper and Eccles 1977; Popper 1982). Close interactions among all three worlds in a mutually reinforcing way is a driving force in biological evolution, including the evolution of consciousness (Popper 1982). Second, this Popperian account of an interacting triad of evolutionary levels helps clarify several issues related to the emergence of novel, (i.e., qualitatively different) structures or phenomena.

Given Popper's distinctive emphasis on consciousness being an emergent phenomenon, and given the weakness of the above ontological and epistemological interpretations, the distinction between minds or consciousness (world 2) and brains (world 1) should better be seen as a distinction between an emergent phenomenon and its underlying, basal phenomena. The explanation of consciousness as a phenomenon emerging from, yet not fully reducible to, certain neurophysiological brain processes neither entails that consciousness is essentially something subjective nor that it is utterly non-physical in nature. The lurking doubts about how consciousness (as an emergent phenomenon) causally interacts with the brain (the underlying basal structure) would of course not immediately disappear, but in light of Popper's view of emergent evolution the aforesaid problem of interaction does appear to be more tractable. What is worth-remembering, Popper has not employed the concept of emergence merely as a productive tool for formulating significant theoretical claims about certain domains. For him, the assertion that a given phenomenon, say consciousness, is an emergent phenomenon, or that consciousness emerges from neurophysiological processes, is to say something significant, explanatory, and illuminating about consciousness and its relation to neurobiological processes.

The issue of emergence has a long history within philosophy (though its precise characterization is still contested in the existing philosophical literature), but its position within science seems both recent and tentative. The middle years of the twentieth century witnessed spectacular advances in physics and biology, particularly in the elucidation of the fundamental structure of matter (e.g. atomic, nuclear, and subatomic particle physics and quantum mechanics) and the molecular basis of biology. This progress has no doubt encouraged the scientists to believe that if the universe consists of elementary particles, and all entities are structures of such particles, then everything in the universe ought to be (in principle) explicable and predictable in terms of particle-structure and particle-interaction. This common intuition of the scientists seems to have promoted a reductionist approach—roughly speaking, the approach of explaining a phenomenon by appealing to the properties of the next level down—on the one hand, and have led to the criticism of 'emergentism' (Kim 2006a, 190)—a set of doctrines concerning the existence and characteristics of emergent properties formulated during the first half of the twentieth century—on the other.

Few would deny the power and efficacy of the reductionist approach as a methodology. As physicists have probed ever deeper into the microscopic realm of matter, the arrows of explanation will point downward (Weinberg 1994). In this way the behaviour of gases is explained by molecules, the properties of molecules are explained by atoms, which in turn are explained by nuclei and electrons. Emergentism, in contrast, though largely ignored in mainstream philosophy during the mid-twentieth century, has undergone something of a revival (as a concept) since the early 1990s (Kim 2006a, 190). However, despite the growing philosophical literature, there is little consensus on the exact content of the concept of emergence.

Let us first decide on a serviceably clear concept of emergence before examining Popper's view of consciousness as an emergent phenomenon. Kim's (2006a, 197–198) account of emergent phenomena seems clear and robust enough for the purposes on hand. Supervenience and irreducibility are considered by Kim (2006a) as two necessary conditions of emergence. Popper's explanation of emergent properties as causally dependent on but autonomous from their underlying base, though not sufficiently precise, looks quite compatible with that of Kim. While some contemporary writers (see e.g., Taylor 2015) identify an apparent tension between the features of dependence and autonomy, Popper hasn't hesitated to include these mutually non-exclusive features in his account of emergent evolution.

It is sometimes argued (e.g., Van Gulick 2001) that an emergent property does not 'supervene' on the microstructure of an object. For, an emergent property of a whole is not determined by the properties and relations characterizing its parts. If the connection between an emergent mental phenomenon, say pain, and a certain configuration of neural conditions from which it emerges, is so irregular or coincidental, one may ask following Kim (2006a), what reason could there be for arguing that pain 'emerges' from that neural conditions rather than another? Emphasizing supervenience as a necessary component of emergence, Kim (2006a, 193) states the condition of supervenience as follows: If property M emerges from properties $N_1, \ldots, N_n$, then M supervenes on $N_1, \ldots, N_n$.[5]

Supervenience, though necessary, is not sufficient for emergence. The surface area of a sphere supervenes on its volume, but it does not emerge from it. On the contrary, according to most advocates of emergence (including Popper), consciousness both supervenes on and emerges from physical-biological conditions. Thus, something must be added to supervenience to yield emergence. The basic idea explained by

[5]Kim (2006a, 193) defines supervenience as follows: to say that M supervenes on $N_1, \ldots, N_n$ is to say that any system that has the base properties $N_1, \ldots, N_n$ will necessarily have the supervenient property M.

Kim (2006a, 194) is that if M emerges from $N_1, \ldots, N_{2,}$ then although M supervenes on the N_s, M is not reducible to, explainable in terms of, predictable on the basis of, or derivable from, the N_s. Therefore, according to Kim (2006a, 197), property M is emergent from properties $N_1, \ldots, N_n$ only if (i) M supervenes on $N_1, \ldots, N_n$, and (ii) M is not functionally reducible with $N_1, \ldots, N_n$ as its realizers. Thus, supervenience and irreducibility in the sense explained above are two necessary conditions of emergence. Given these necessary conditions, it is immediately clear that emergent properties must have some causal power, and this includes their capacity for projecting causal influence downward, affecting the course of events at a purely physio-chemical level.

This very idea of an emergent structure operating causally upon its sub-structure in a direct downward fashion appears incoherent to many, including Kim (2006b). We seem to understand upward causation well, that is, how the sub-structure of a system cooperates to affect the whole system. Difficult is to envisage how a higher-level, emergent structure operates causally upon its sub-structure. Resisting the extreme reductionist tendency to explain everything in terms of causally interacting elementary particles, Campbell (1974) showed how a change or action from above can also affect the set of sub-structures. For example, the average velocity of a group of atoms can influence the average velocity of the neighbouring groups of atoms and can thereby influence the velocities of many individual atoms in the group. Taking his cue from Campbell, Popper (1978, 348) has tried to explain downward causation as 'selection' operating on the randomly fluctuating elementary particles. The randomness of the movements of the elementary particles provides the opening for a higher-level structure to interfere from above (Popper 1978).

The most recurrent and profound problem relating to emergent properties' capacity for projecting causal influence downward arises from the closed character of the physical domain having the following implication: if a physical event has a cause, it has a physical cause; and if a physical event has an explanation, it has a physical explanation (Kim 2006a, 199). Arguably, this causal closure principle of the physical domain is presupposed by most working scientists, including of course physicists. If the scientists encounter a physical event for which they are not able to identify a physical cause or explanation, it is highly unlikely that they will consider positing a non-physical cause to explain it. To deny this principle basically amounts to denying the in-principle completability of theoretical physics (Kim 2006a, 199–200).

Popper (Popper and Eccles 1977, 15) has never questioned the physicalist premise that nothing can happen unless permitted by the physical laws and by the preceding (physical) state. He has only objected to what we commonly infer from it. From the point of view of human knowledge, he (Popper and Eccles 1977, 15) has cautioned us, it would be misleading to conclude from the above seemingly indisputable physicalist premise that the future is and always was foreseeable (in principle, at least). To combat the physicalist view of the completeness of the physical world Popper (Popper 1979a) has come up with a simple argument based on his conjecture of three worlds. He was quite sure that the physicalists (or materialist monists) would not readily accept his pluralist conjecture (Popper 1979a). They would assert either there is only world 1 or even if there is a world 2 or a world 3, neither can act on world 1 (Popper and Eccles 1977, 51).

Nevertheless, Popper's argument begins by stating what seems undeniable, namely, that we live in a physical world (world 1) which has been greatly changed by making use of science, i.e., scientific conjectures or theories (world 3 entities) as instruments of change (Popper 1979a). Next, assuming 'kickability' as a sufficient condition for reality (Popper 1994, 47), the argument concludes by asserting that scientific conjectures or theories can, therefore, exert a demonstrably causal or an instrumental effect upon physical things (Popper 1979a, 8–9). The very existence of objective problems together with the fact that its discovery and solution by means of scientific conjectures or theories may lead to obvious changes in world 1 implies that the physical world 1 is neither closed nor complete but open towards world 3 with world 2 acting as an intermediary (Popper 1979a).

The basic outcome of Popper's conjecture of three interacting worlds is no different from 'emergentist pluralism' (Ellis 2006, 85)—a philosophical position that assumes the emergence of many levels of reality in the natural world. In addition, the objects at these various levels that can be shown to have a causal effect in the material world of particles are assumed to have their own types of reality. These include human concepts, plans, intentions, information, emotions, as well as socially constructed features such as chess rules (Ellis 2006, 84–85). Ellis' (2006) analysis of emergence is almost a replica of that of Popper's, excepting its key philosophical implication. Ellis (2006, 84–85) seems unsure about whether true emergence is ever possible. That is, whether the creation through physical and biological processes of completely new types of structure without any kind of precursor is the creation of a completely new kind of order, or whether emergence in the physical world is simply the realization of pre-existing potential and hence not a truly creative event. Ellis' (2006) worry reminds us of the common argument of the critics of emergence, namely, that evolution is a fact, but evolution cannot be 'emergent' or 'creative.'

Popper, in contrast, has described emergent phenomena as 'altogether unpredictable' (Popper and Eccles 1977, 22) and compared their novelty with that of a great work of art (Popper and Eccles 1977, 22). Two promising insights regarding the possible emergence of genuinely novel structures may be distilled from Popper's writings. The first one relates to his (Popper and Eccles 1977, 25) firm belief that there can be invariant physical laws and emergence of new properties as the former is not sufficiently complete and restrictive to prevent the latter. Even if we admit that newly emergent entities create new fields of propensities, one of Popper's critics asks, can we really escape the idea of preformation or several preformationist possibilities (Popper and Eccles 1977, 31)? Popper's answer to this question is simple but noteworthy. That we may have an infinity of such open preformationist possibilities is reason enough to dispense with preformationism (Popper and Eccles 1977, 31).

The second Popperian insight relates to his recognition of a 'whole' as distinct from 'mere heaps' (Popper and Eccles 1977, 20). A 'whole,' for instance, a living organism, is an emergent macro-structure which is more than a mere heap or sum of its parts in the sense that though it emerges out of interactions between its underlying, constituting parts is neither completely predictable nor reductively explainable (at least in any straightforward manner) in terms of those parts (Popper and Eccles 1977, 21). The examples of living organisms or other such emergent structures, as per Popper, make the existence of downward causation obvious, and by implication, challenge the 'complete success' (Popper and Eccles 1977, 20) of any reductionist program.

The tension between reductionism and emergence is easily visible. For any attempt to minimise this tension, a brief overview of weak and strong versions of both emergence and reductionism may be helpful (Davies 2006b, xi). It goes without saying that the physicists' ability to break apart atomic particles into smaller and smaller fragments and to probe ever deeper into the microscopic realm of matter is essential for our understanding of the properties of matter or the fundamental forces that shape it. One might be tempted to know, whether the reductionist account of nature is merely a fruitful methodology—a weak form of reductionism known as methodological reductionism—or whether the whole really is, in the final analysis, nothing but the mere sum of the parts. This later, stronger form of reductionism is sometimes known as ontological reductionism (Davies 2006b, xii). While many scientists, particularly physicists, are self-confessed strong, ontological reductionists, a minority of scientists (see e.g., Davies 2006a; Ellis 2006) today find the basic claim of ontological reductionism contestable.

The contrast between 'weak' and 'strong' versions of emergence is also to be noted. The position of weak emergence recognizes that one may not be able to deduce merely from the principles that govern a class of systems how a specific individual system will in fact behave (Davies 2006b, xii). However, direct inspection or simulation may enable us to determine the behaviour of complex systems, such as human behaviour or even that of a simple organism (e.g., a bacterium). Strong emergence, on the other hand, is a far more contentious position as it asserts that the micro-level principles are quite simply inadequate to account for the system's behaviour (as a whole). Evidently, strong emergence cannot succeed in systems that are causally closed at the microscopic level, because there is no room for additional principles to operate that are not already implicit in the lower-level rules. For instance, a closed system of Newtonian particles cannot exhibit strongly emergent properties, as everything that can be said about the system is already contained in the micro-level dynamics including the initial conditions (Davies 2006a).

There are 'three loopholes' that make strong emergence conceivable (Davies 2006b, xii). The first is if the universe is taken as an open system, the system as a whole would then be determined partially by the micro-level dynamics and partially by the constraints imposed by the external, global principles—principles which may 'soak up' the causal slack left by the openness (Davies 2006b, xii). The second possibility comes into sight if the system is interpreted as non-deterministic—quantum mechanics being the popular example—and unique rather than belonging to a homogeneous ensemble. The final possibility arises if the laws of physics operating at the base level are understood as intrinsically imprecise due to the finite computational resources of the universe. Similar possibilities—commonly perceived as unorthodox departures from standard physical theory—have also been considered by Popper (Popper 1974, 1982, 1988) long ago. The very fact that such possibilities are being assessed by contemporary scientists increases the prospect for a stronger argument for emergent evolution.

Nevertheless, the important challenges that no ardent supporter of emergence (not to mention Popper) can avoid are as follows: an emergentist must either provide sufficient and compelling reasons for rejecting the causal closure principle or else show that downward causal efficacy of irreducible emergent properties is consistent with physical causal closure (Kim 2006a, 199–201). If any emergentist accepts the challenge and gives up the causal closure principle, then a further challenge would be to offer a credible explanation (that goes beyond supervenience and irreducibility) of how minds are related to the activities of the brains. Saying that minds emerge from brain-processes but are not reducible to them doesn't say enough about their relationship. Whichever option is adopted, the 'friends of emergence' (Kim 2006a, 201) are indeed in trouble because of the philosophers' lingering, unargued, uncritical allegiance to the causal closure principle.[6]

Just as the friends of emergence, as per Kim (2006a), have only two choices, the majority of the physicists today are also faced with two challenging options: either to extend the scope of physical description to encapsulate higher-level causal effects, such as the causal effects of conscious plans and intentions, emotions or thoughts in the real physical world; or to decide that these kinds of issues are outside the province of physics, which properly deals only with inanimate objects and their interactions (Ellis 2006). Whichever option is adopted, their ambitious aim of providing a causally complete description of all interactions that affect the real physical world or a 'theory of everything'—a unified theory of fundamental forces and interactions such as String Theory (see, e.g. Greene 1999)—seems to be in trouble. At minimum, physics must be related somehow to the world of thoughts and feelings before it can make any claim to provide causal completeness—which presumably a true 'theory of everything' aims at.

A review of the widely accepted causal closure principle seems necessary for any discussion about the challenges faced either by the friends of emergence or by the critics of emergence. As things now stand, the task before Popper (as an emergentist) is to explain how minds or consciousness as novel, emergent phenomena having distinct, irreducible causal powers arise from and interact with the brain without any violation of the causal closure principle of the physical domain, or more specifically, of the laws of classical physics (e.g., first and/or second law of thermodynamics). This very question—how consciousness and brain can possibly interact—remains one of the most 'mysterious' and 'intractable' problems in philosophical investigations of the mind-brain relationship (Libet 1994, 120). The following section attempts to show how far the Popperian hypotheses can reasonably demystify the problem of consciousness-brain interaction.

[6] For a review of different formulations of the causal closure principle see (Lowe 2000a).

3 Does Consciousness-Brain Interaction Necessarily Violate Physical Laws?

In his 1977 book *The Self and Its Brain,* Popper has only briefly addressed the problem of detecting neural activities related to consciousness (Popper and Eccles 1977, 117–120). Hypothesizing about the possibility of there being a one-to-one relationship between certain conscious experiences and certain brain processes Popper has commented that to be linked with consciousness—'a teaming process of unimaginable complexity' (Popper and Eccles 1977, 120)—the whole brain must be in high activity. His later writings suggest that both in the phylogeny and in the ontogeny of humans, self-consciousness appears with the higher functions of language and interaction occurs between the self and the speech centre of the brain (Popper 1994, 131–132). His latest mental force field hypothesis introduces a striking analogy between minds and physical forces and indicates a new possibility of how minds and brains can interact (Popper et al. 1993).

In a wide-ranging interview (Popper et al. 1993) published near the end of his life, Popper has come up with the proposal that conscious minds should be understood literally as a field of forces. To somewhat demystify the existence of minds he has drawn attention to several similarities between conscious minds and physical forces (or fields of forces). Minds, like forces, have at least six properties: (i) they are located in space and time (ii) they are unextended in space but extended in time (iii) they are incorporeal but existing only in the presence of bodies (iv) they are capable of acting on bodies (v) they are dependent upon bodies, and (vi) they are capable of being influenced by bodies' (Popper et al. 1993, 168). Later he has added two more properties that minds have in common with physical forces, namely (vii) minds are intensities and, they have (viii) minds have extension through a span of time (Popper et al. 1993, 168).

Objecting to our common understanding of forces as 'mere appendices to matter' (Popper et al. 1993, 169) Popper has argued that the forces, though related to biochemical substances or physiological entities, can, apparently, obtain a certain autonomy and independence from these sheer substantial processes with which they are related and with which they interact. Similarly, minds—something like a complex of forces—can make themselves independent of the physiology and can have a certain amount of life on their own (though the physiology is always present). This (partially) explains why minds or conscious processes (world 2) are seen by Popper as emerging from, but not fully reducible to their physical-chemical basal structure (world 1).

Popper has also developed an idea of mind as (at least partly) a force field. The complicated electro-magnetic wave fields which are part of the physiology of our brains, represent the unconscious parts of our minds, and conscious minds—our conscious mental intensities, our conscious experiences—are capable of interacting with these unconscious physical force fields, especially when the problems to be solved require what we call 'attention' (Popper et al. 1993, 179). Our force-like minds (or mental experiences) always point to something, always intend to bring something about. This characteristic feature has been referred to by Popper as 'intentionality' (Popper et al. 1993, 172), which like a vector always points to something and has the power, to bring something about.

This mental force field hypothesis of Popper seems quite a thought-provoking attempt to account for the causally effective nature of minds or consciousness. Conscious processes—assumed to emerge as a function of appropriate neural activities in the brain—seem capable of acting back on certain neural activities through unconscious (i.e., purely physiological) physical force fields (Popper et al. 1993, 172). The argument implicit in this latest hypothesis of Popper is as follows: if it is acceptable that physical forces can influence bodies, and bodies can influence physical forces, then, the interactions between consciousness (which is quite similar to physical forces) and the neuro-physiological activities of the brains would not be too mysterious or difficult to explain (Popper et al. 1993).

During the last twenty-five years several elaborate field theories of mind have been proposed (for a review, see Jones 2013). In many of these theories, electromagnetic fields of the central nervous system are taken to be crucial to the explanation of conscious experiences. Different components of the brain's electromagnetic field are understood to be relevant to consciousness, and in fundamentally different ways—e.g. as being identical with or being the substrate of consciousness. The currently competing theories of the neural basis of human consciousness vary considerably as to which brain areas and activities are suggested to cause conscious experience. Popper's mental force field hypothesis no doubt supplements these theories by emphasizing important similarities between minds and physical forces and indicating some possible ways of minds-brains interactions.

In spite of these interesting suggestions of Popper, the following question might still arise: is there any compelling reasons for believing that consciousness does causally interact with certain neural processes of the brain (through unconscious force fields) rather than being merely supervenient on those brain processes? Arguably, the strongest objection against any form of interaction concerns its explanation of the causal efficacy of consciousness in a way that entails violation of physical laws (e.g., the first and/or second law of law of thermodynamics). The said objection rests on the persisting belief that consciousness can act on the brain only if the physical realm is causally open. Popper's (1984a, 21–22) own reply to the problem mentioned above, namely, does the very possibility of consciousness-brain interaction necessarily violate physical laws, is quite promising, but Averill and Keating's (1981) analysis of the same is more instructive for the present purposes.

In the history of physics both the first and the second law of thermodynamics have appeared in different forms. Rudolf Clausius, for instance, formulated the first law as stating that 'in any closed system (a steam engine, for example) the total amount of energy is constant' and the second law as stating that 'heat cannot pass from a colder to a hotter body on its own accord; for this to happen some external cause must come into operation' (Ronan 1983, 447). The point we need to note is, laws of (classical) physics are open to different interpretations.

In *The Open Universe*, Popper has referred to the first law as 'the law of conservation of energy' and the second as 'the law that asserts that entropy can only increase'

(Popper 1988). He (Popper 1988) has argued that the first law holds only with (more or less) good approximation for organisms, since living organisms are not closed systems (like steam engines). He has also hypothesized about the existence of 'purely mental forms of energy, convertible into electrochemical forms' (Popper 1984a, 21). What's more, the possibility of non-energetic influences upon energetic processes has been considered by Popper on account of certain interpretations of de Broglie's particle-wave theory postulating the existence of empty pilot waves that can interfere with non-empty (energy-carrying) waves (Popper 1984a, 21–22). The second law, according to Popper (1984a, 22) has been refuted by Brownian movement.

Averill and Keating's (1981) explanation of the problem relies upon a standard textbook of mechanics, namely, Herbert Goldstein's *Classical Mechanics,* to deal with theoretical physics. Interestingly, Averill and Keating's (1981) analysis avoids making any reference to closed systems, but it does make several references to the presence or absence of external, especially mental, force. Considering Popper's late construal of the force-like nature of minds, Averill and Keating's (1981) discussion about mental force (and not mental energy) seems most suitable for our purposes. The basic claim of the interactionist position has been stated by Averill and Keating (1981, 102) in the following way: consciousness (or a non-physical mind) can initiate behavior by exerting a force which moves a brain-particle.

In the opinion of some critics (e.g., Dennett 1978, 252; Corman 1978, 274) of interactionism, first of all, the motion of the brain-particle resulting from such a non-physical force would change the total energy and/or the total linear momentum of the brain; and secondly, if the resulting motion changed the total energy and/or the total linear-momentum of the brain, then either the conservation of energy law or the conservation of linear-momentum law would be violated. In addition, the assertions of Cornman (1978, 274) mentioned below are also note-worthy:

(1) If the mind exerts a force F on the brain, and F changes the resistance at certain synapses, then the total linear-momentum of the brain is changed due to F.
(2) If the total linear-momentum of the brain is changed, then 'some net external physical force' affects the brain.

Let us now consider the text-book formulation of the law of conservation of linear-momentum for a system of particles. In Goldstein's *Classical Mechanics* the law has been stated as: 'If the total external force is zero, the total linear-momentum is conserved' (Averill and Keating 1981, 103). Clearly, Goldstein's interpretation of the law does not entail (2). For, it has no such implication that if the total linear-momentum of a physical system, say, the brain, is changed, then 'some net external physical force' is affecting the brain (Averill and Keating 1981, 103). Besides, notice that the said law as formulated by Goldstein may hold for all kinds of forces, regardless of their source, and not just the 'physical forces' whose source is a physical object.

The possibility of the (non-physical) mind's exerting a force F on the brain is thus not denied by the law of conservation of linear-momentum as articulated in Goldstein's classic text. An interactionist may retain the law and reject (2). Cornman's (1978, 274) has rightly inferred that any force exerted by the non-physical mind on the brain has to be external to every physical system (including the brain) and therefore such a force would not be one of the 'only appropriate physical forces,' such as gravitational forces (which require mass) and electromagnetic forces (which require electrical charge). However, it does not necessarily follow from Cornman's observation that such a force is 'not appropriate to mind-body interaction' (Averill and Keating 1981, 103).

Cornman's basic error, according to Averill and Keating (1981, 104), consists in using a much stronger statement of a physical law than is necessary for the development of physics. Moreover, this stronger formulation of the said law has (metaphysical) implications which beg the question against interactionism. In contrast, Goldstein's interpretation of the same law does not require that the source of a force which changes the total linear-momentum of a system must be physical, and hence does not have any implication like the following:

(3) If X exerts a force F on a physical system S, and the total linear—momentum of S is changed due to F, then X is physical.

An interactionist can, therefore, reject (3) but retain the conservation law for linear—momentum (Averill and Keating 1981, 105).

Consider another example of a physical law. The dilemma often faced by many interactionists is whether to reject the principle of conservation of energy, or to show how energy may be conserved in the brain when consciousness exerts a force on the brain. The popular interpretations of law of conservation of energy—also known as the First Law of Thermodynamics—has the following implication (Averill and Keating 1981, 106):

(4) If X exerts a force F on a physical system S, and the total energy of S is changed due to F, then X is physical.

In the textbooks of physics, the said law is formulated as (Averill and Keating 1981, 106): $\Delta U + L = Q$.

where ΔU is the change in energy of a system, L is the work done by the system during the change ($-L$ is the work done on the system), and Q is the heat flowing into the system during the change. More generally, Q is the amount of energy that is received by the system in forms other than work (Averill and Keating 1981, 106).

This textbook-formulation of the law does not entail (4) as no clue is provided about the source of the force that does the work ($-L$) on the system. Hence it neither assumes that there is a change in energy in the source of the force, nor that the source of the force is part of a physical system. Here again the same kind of error is repeated—the use of a statement of a physical law that has question-begging implications and is stricter than is required for scientific research (Averill and Keating 1981, 106). An interactionist faces no difficulty in rejecting (4) and retaining the law as formulated in one of the standard textbooks of mechanics.

Now, if, as explained by Averill and Keating (1981), the possibility of the non-physical mind's acting on the brain entails no violation of the physical laws mentioned above, then the main objection against interactionism, which now seems to rest on the philosophers' preconceived beliefs about physical laws, loses ground. Given that physics doesn't necessarily rule out the key claim of interactionism, one may want to ask the critics (of interactionism) whether or not it is a prejudice to reject the very conceivability of an interactionist hypothesis without examining the conventional formulations of physical laws that the hypothesis arguably conflicts with.

The mistake plaguing the conventional interpretations of the said physical laws is of importance no doubt, but that doesn't stop one from inquiring if Popper's (non-dualist) interactionist hypothesis offers anything new. Are there reasons different from those already discussed in the existing literature (e.g., Lindahl 1997) for revisiting his decades-old hypothesis? The originality of Popper seems most evident in his attempts at explaining the evolution of consciousness' (adaptive) functions from lower to higher organisms. Popper is not the first one to formulate an evolutionary (philosophical) argument for mind-brain interaction (see e.g., James 1879), but he is one of those rare philosophers who has reflected on the evolutionary origins of the mind, both pre-human and human, has identified the initial appearance of mind-like behaviour (e.g., alertness, eager) of organisms very early in evolution and hypothesized about how the mind-like behaviour of organisms gradually evolved into exploratory (trail-and-error), partly-conscious behaviour (e.g., anticipation of future needs, preference for certain kinds of food or locations for breeding, actively searching for new ecological niches) of higher organisms and how that partly-conscious behaviour of higher organisms developed into conscious behaviour (e.g., creation of world 3 entities) of human beings, though we cannot determine exactly when (Popper 1982). What's more, Popper (1982, 45) is probably the first philosopher to argue that the emerging minds—pre-human and human—play an active part in biological evolution and especially in their own evolution.

Popper has developed his argument by presenting a neo-Darwinian interpretation of the process of adaptation. Adaptation, according to him (Popper 1982) is a process based upon reciprocity and the activities of the living organisms. Activity is a movement with an aim and, therefore, without aims, such as striving for food, or for a higher or lower temperature, adaptation is inconceivable. The living organisms strive for food or for a higher or lower temperature by actively selecting and changing their own environment, their ecological niche, like birds build nests, or humans construct structures that broadly enhance their evolutionary fitness. What is usually perceived as the (more or less) passive reactions of the organisms to the environmental stimuli has been explained by Popper (1984b, 244) as exploratory actions of the organisms. Through many trials over millions of generations the organism learns to exploit environmental change as a stimulus and invents the ability to react to it as stimulus (Popper 1984b, 244). Simply put, what turns something into a stimulus is the 'eagerness' of the organism to respond or react according to its internal state (Popper 1984b, 244–245). Popper (1982, 40) has described such active, exploratory behaviour as 'mindlike' or 'partly conscious' and argued that with more and more complex forms of life conscious aims (e.g., preference for certain locations for breeding, or for certain types of food or for certain kinds of mates) appeared from these mind-like, exploratory behaviour.

Promising though it may seem, Popper's non-dualist interactionist hypothesis involves some speculative premises, which are neither conclusively verifiable nor sufficiently precise. His speculation about all[7] living organisms being active explorers or about how the mind-like, exploratory behaviour of lower-organisms effectively evolves into conscious behaviour of higher organisms is a case in point. The virtues of Popper's tentative, old-fashioned (non-dualist) interactionist hypothesis, however, lie in its openness to critical experimental-archaeological scrutiny (if not to strictly scientific tests). The next section discusses in what way Popper's hypothesis can be subjected to experimental-archaeological investigations.

4 The Archaeological Implications of Popper's (Non-dualist) Interactionist Hypothesis

The epistemic underpinnings of Popper's (non-dualist) interactionist hypothesis is rooted in its 'anti-behaviourist' and 'anti-psychologistic' character (Popper 1979b, 114). The said hypothesis presupposes the crucial distinction between knowledge in the objective sense (world 3) and knowledge in the subjective sense (world 2) on the one hand, and indicates how the problems concerned with the acts of production differ from the problems concerned with the (objective) structures or products (Popper 1979b, 114), on the other. The problems connected with the products or structures (world 3) themselves, according to Popper (1979b, 114) are more fundamental because they illuminate production behaviour and psychology (world 2). The conventional approach of studying minds or consciousness (world 2) for acquiring information about their (objective) products has a scientific appeal because it proceeds from causes to effects. Popper (1979b, 112), in sharp contrast, has argued that the reverse approach is more significant. That is, one can learn more about minds and their behaviour (world 2) by examining the effects generated or products caused by minds. This observation of Popper—that the objective approach of examining world 3 can help throw light upon world 2 mental or conscious processes—holds immense significance for archaeological investigations.

The voluminous record of stone-tools (e.g., a hammer-stone or a hand axe) shaped and used by the prehistoric hominins is widely seen by archaeologists today as the most enduring source of evidence for the initial emergence of (some form of) hominin conscious-cognitive behaviour (see, e.g., Wynn and Coolidge 2016; Moore and Perston 2016). There is a considerable archaeological literature on the cognitive dimensions of specific hominin technical activities such as stone knapping (e.g., De Beaune 2004; Nowell and Davidson 2010) or, more generally, stone-tool making (e.g., Stout and Chaminade 2009; De la Torre 2011; Wynn 2009; Wynn and Coolidge 2016, 2017). These studies strengthen the archaeological intuition that the stone-tools shaped and used by ancient hominins played a seminal role in the evolution of the early hominin conscious-cognitive abilities. However, within archaeology and the

[7] There are a few cases such as the adaptation of bacteria to penicillin where the catastrophic changes do not allow the organism to be active as all members of the population are killed (Popper 1982, 41).

study of hominin evolution, stone tools are typically described as mere end-products or by-products of the hominin minds (or conscious-cognitive abilities). Evidently, the causal arrow assumed in this standard perception is one way—from minds (or conscious-cognitive abilities or processes) to tools or cultural products. Among major issues that have arisen in the past few decades are questions regarding the critical role of stone-tools in the evolution of hominin mental or conscious-cognitive faculties.

Experimental-archaeological investigations (e.g., Stout et al. 2008; Stout and Chaminade 2007, 2009, 2012) into the neural corelates of prehistoric (lower Palaeolithic) tool-behaviour leave the impression that conscious-cognitive processes are correlated, if not totally identical, with certain neurophysiological processes of the brain. This experiment-based approach uses new experimental techniques to unravel the connection between stone-tool production and brain-processes. On the other hand, some present-day researchers known as cognitive archaeologists (e.g., Malafouris 2013) draw inspiration from the philosophical hypothesis of the extended mind (Clark and Chalmers 1998) and have interpret cognitive-processes not as essentially brain-bound but as processes transcending the cranial boundary and incorporating extra-somatic, environmental resources. This latter (more theoretical) approach puts special emphasis on the 'explanatory and transformative power' (Malafouris 2013, 57) of such extra-somatic resources (e.g., stone-tools) and paves the way for a deeper interaction between contemporary philosophical and archaeological research on the evolution of consciousness.

Popper's (non-dualist) interactionist framework let the archaeologists explain and emphasize the efficacy and transformative potential of human or hominin products without adhering to the philosophical thesis of the extended mind, objections to which are neither rare nor negligible (see e.g., Rupert 2004). It isn't archaeologically essential to interpret stone-tools as genuine extensions of hominin conscious-cognitive processes for emphasizing the critical impact of the former on the latter. This insightful tripartite account of Popper, crucial for understanding the prehistory of minds, is completely ignored by contemporary archaeologists (e.g., Malafouris 2013). Besides, Popper's description of consciousness as an emergent (biological) phenomenon—dependent upon yet not completely reducible to underlying neurophysiological processes—also enables the archaeologists to avoid the controversies related to 'neurocentrism' (Malafouris 2009, 258)—a physicalist-style attempt to reduce all the properties of cultural products to the properties of the brain—without falling into the old Cartesian trap of thinking about the brain as something physical and consciousness as purely non-physical.

Following Eccles (Popper and Eccles 1977, 450) one might want to ask Popper: how far back in the human prehistory can we recognize the origin, the most primitive World 3 entities? The very beginning of World 3, in the view of Popper (Popper and Eccles 1977, 451), is to be detected not in the earliest tools made by the hominins but in the initial development of some form of hominin linguistic behaviour. For, prior to some (primitive) kind of linguistic behaviour, stone-tools could not be regarded as objects of 'criticism and of deliberate improvement' (Popper and Eccles 1977, 451).

Experimental-archaeological reconstructions (see, e.g., Toth 1987; Toth and Schick 2009; Stout 2011) of the manufacturing-process of prehistoric Oldowan stone-tools reveals that Oldowan raw materials had been examined at the source, selected stone resources had been transported for initial flaking at a second location, and selected flaking-products had been transported for use at a third location. Wynn and colleagues' (Wynn et al. 2011, 195) more recent research on the long-distance transport of various raw materials is also indicative of the Oldowan hominins' capacities for high-level planning or anticipatory behaviour and of these ancient hominins' selectiveness in the use of those raw materials. Capitalizing on the archaeological evidence of hominin preference for certain types of stones as suitable for flaking one might take the deliberate hominin rejection of certain kind of raw materials as some sort of criticism or as a 'forerunner of criticism' (Popper and Eccles 1977, 451). Conversely, if criticism proper is supposed to arise only with some kind of linguistic behaviour, and if language-processing is assumed to be a functionally specialized and anatomically discrete module within the brain, then Popper's speculation about hominin linguistic competence being critical for hominin tool behaviour and consequently for the origin of world 3 definitely calls for additional supporting evidence.

Fortunately, experimental-archaeological data informing possible evolutionary connections between hominin linguistic and tool behaviour are available today. Three possible types of co-evolutionary interaction involving shared neural substrates, shared social context and shared reliance on general capacities are highlighted in the archaeological literature (e.g., Stout 2010). The intersection of language and manual-praxis networks in Broca's area—originally identified as specifically responsible for the faculty of spoken language—now provides one of the best-known examples of complex functional-anatomical overlap in human neocortex (Stout and Chaminade 2012). It is also recognized that the frontal 'language-relevant' cortex—extending across the entire inferior frontal gyrus (IFG)—contributes not simply to linguistic functions (e.g., the comprehension and production of syntactic, semantic or phonetic structure), but to a range of non-linguistic behaviours from object-manipulation to sequence-prediction (Stout and Chaminade 2012). Such evidence of functional-anatomical link between hominin tool-behaviour and language-competence, indicating (though not proving) specific co-evolutionary relationships between them, appears broadly compatible with the Popperian assumption that an objective, 'criticizable' world 3 (Popper and Eccles 1977, 451) probably co-evolved with development of hominin linguistic behaviour.

To further dissect the tripartite interactions of the distinct evolutionary levels one may consult recent research on neuroplasticity and the plasticity of human minds. The plasticity exhibited by human cortical maps—not only during the early-developmental period when synaptic densities are maximum in most brain-regions but also during adulthood—is associated with anatomical and not, as traditionally assumed, only with functional changes. Stout and Chaminade's (2007, 2009) experiments using positron emission tomography (PET) are worth mentioning here. Their (Stout and Chaminade 2007, 2009) comparative assessments of previously inexperienced subjects making Oldowan-style stone tools both before and after completing four-weekly practice sessions in stone-tool manufacture demonstrate noticeable functional changes in brain activation patterns following the practice sessions. The 2006 study of Hihara and colleagues also shows how two weeks of tool-making training forges a novel cortico-cortical connection linking the intraparietal area and temporoparietal junction (TPJ). These results attest to the possibility of interactions between neuro-physiological (i.e., world 1) processes and stone tools (world 3 products) via training or learning (a world 2 conscious-cognitive process).

Mithen and Parsons (2008) have argued, in a similar vein, that the human brain is being continuously re-shaped, re-wired, and re-modelled under the influence of cultural practices. Their analyses of the brain-anatomy of skilled musicians and non-musicians show how prolonged instrumental practice leads to an enlargement of the hand-area in the motor cortex. Such evidence of neuroplasticity is an important driving force behind their understanding of the human brain as a dynamic bio-cultural system or 'an artefact of culture' (Mithen and Parsons 2008, 415) subject to constant functional and structural changes. The possibility of three-way interactions among brain-processes (world 1), musical instruments (world 3 products) and instrumental-practice or training (a world 2 conscious-cognitive process) once again seems implicit in this novel construal of the human brain.

True, the evidence of neuroplasticity is not sufficient for establishing (causal) interactions among three Popperian worlds; but it does hint at the causal openness of the (world 1) brain-processes. If, as studies (e.g., Mithen and Parsons 2008; Stout and Chaminade 2007, 2009) suggest, the volume of the corpus callosum of a pianist seems connected with prolonged hours of piano-practice, or functional changes are visible in brain activation patterns following four-weekly practice sessions in stone-tool making, then the evolutionary impact of several long-term cultural practices in the structural and functional modifications of human (or hominin) brains would certainly be undeniable. This could be one of the reasons why the developing field of neuro-archaeology seems committed to an interactionist (and not a reductionist) view of mind-brain relations (Malafouris 2009, 258).

Jeffares' (2010) provocative suggestion that the ancient stone tools—often seen as mere end-products of extinct hominin minds—can, in some cases, causally trigger cognitive processes, or new cognitive capacities also hints at the plasticity of human minds. His (Jeffares 2010) vision of the critical role of the first recognisable stone tools in structuring early hominin cognitive processes has been shared by other contemporary archaeologists. For example, Malafouris' (2015), distinctive emphasis on the extraordinary projective plasticity of the mind and its reciprocal openness to cultural influence (and variation) attracts notice. Being a product of evolution, the human mind is undoubtedly constrained by several inherited genetic structures, brain circuits etc. but these genetic constraints cannot determine its developmental trajectory a priori (Malafouris 2010). Popper's conjecture about the causal openness of world 2 coheres with the (cognitive) archaeologists' hypothesis of the remarkable plasticity of the mind.

There exists credible, though not conclusive, experimental-archaeological evidence today for contending that (i) the (human) brain is not a long-evolved, fixed biological entity but an evolving plastic organ actively interacting with the physical environment (instead of passively adapting to it), with the conscious-cognitive processes (emerging from it) and with the extra-somatic products brought out by those processes; and that (ii) the human mind (despite its neuronal and somatic bases) shows remarkable plasticity in relation to the wider ecological, social, and technological environment. In light of this recent experimental-archaeological evidence, Popper's thoughts on the complex, tripartite, interactions among world 3 (e.g., stone-tools), world 2 (e.g., conscious-cognitive processes) and world 1 (e.g., the brain-regions associated with tool making activities and learning) do not seem mere guesswork.

An important clue about a close connection between prehistoric tool-behaviour and the development of hominin conscious-cognitive traits may also be found in a relatively old hypothesis of Washburn (1978). Washburn (1978, 201) has argued that technological progression from no stone-tools to simple Oldowan tools to skilfully shaped and increasingly refined Acheulean bifacial cutting-tools is correlated with the doubling or, as Stout (2011) more recently suggests, nearly tripling of hominin brain size (i.e., endocranial volume). Assuming Washburn's (1978) hypothesis to be correct, one may also expect to see an increase in the neurological complexity of hominin brains. Since fossil record of direct evidence for evolutionary changes in gross neural anatomy remains scant, Washburn (1978, 202) has concluded by simply suggesting that increasing brain-size does seem to be correlated with the increasing complexity of stone-tools over hundreds of thousands of years. Today, Orban and Caruana's (2014) recently found functional magnetic resonance imaging (fMRI) data, which correlate the presence of a new neural apparatus located in left anterior supramarginal gyrus (aSMG)—a region of the brain most likely involved in the execution of tool actions—with the emergence of *Homo habilis* (arguably the principal Oldowan tool maker), seem to lend support to Washburn's (1978) hypothesis.

The relationship between increased brain-size and lower Palaeolithic technological change, however, is a matter of ongoing debate and it might not be as direct as Washburn (1978) has supposed. Tennie and colleagues' (2017) study of the tool-making abilities of the relatively small-brained *Homo floresiensis* is a case in point. But the mere facts about the above case cannot completely overthrow Washburn's (1978) conjecture of a roughly parallel occurrence between the two most striking trends in hominin evolution, namely, the growing sophistication of stone-tools over hundreds of thousands of years and the nearly three-fold increase in hominin brain size accompanied by a possible upsurge of neural resources.[8] Considering the dominant view of the brain as the primary source of conscious-cognitive capacities, and drawing upon the experimental-archaeological evidence of increasing brain-size as well as neural complexity, some connection between the gradual development of prehistoric flaked-stone tools and the evolution of early hominin conscious-cognitive faculties becomes conceivable.

What is more, the possible (evolutionary) connection between hominin tool-production and hominin conscious-cognitive abilities may plausibly be explained

[8]Increasing neural complexity indicates not an increase in the absolute numbers of neurons but novel neural connections among existing neurons.

using Popper's (non-dualist) interactionist hypothesis. Early hominin conscious-cognitive traits might be interpreted, following Popper, as not merely emerging from specific hominin brain-features (most likely involved in stone tool-related activities) but also causally acting on these generating sources.

Most of the grounding philosophical assumptions on the evolution of minds or consciousness (world 2) are generally discussed in the absence of the world of culture (world 3). In sharp contrast, Popper (1982) has taken world 3 as an indispensable part of the evolution of consciousness or minds (world 2). Hominin minds did not just produce such stone tools but had also been affected and transformed by those tools—by their own creations. We are creatures of our own making, since world 2 not only creates world 3, but evolves together and in interaction with the objective, extra-somatic, world 3 products (Popper and Eccles 1977, 442). This insightful observation of Popper enables us to see why the archaeological data of prehistoric stone tools—possibly the earliest creative (world 3) products of the (now extinct) hominin conscious-cognitive faculties—are of great significance for any critical-philosophical account of the origin and evolution of (hominin) minds or consciousness (world 2).

References

Arhem, P., Liljenstrom, H.: On the coevolution of consciousness and cognition. J. Theor. Biol. **187**, 601–612 (1997)

Averill, E., Keating, B.F.: Does interactionism violate a law of classical physics? Mind **90**(357), 102–107 (1981)

De Beaune, S.A.: The invention of technology: prehistory and cognition. Curr. Anthropol. **45**(2), 139–162 (2004)

Bondi, H.: The philosopher for science. Nature **358**, 363 (1992)

Campbell, D.T.: Downward causation in hierarchically organized biological systems. In: Ayala, F.J., Dobzhansky, T. (eds.) Studies in the Philosophy of Biology, pp. 179–186. Macmillan, London (1974)

Churchland, P.: Matter and consciousness: a contemporary introduction to the philosophy of mind. MIT Press, Cambridge MA (1984)

Clark, A., Chalmers, D.: The extended mind. Analysis **58**, 7–19 (1998)

Cornman, J.W.: A nonreductive identity thesis about mind and body. In: Feinberg, J. (ed.) Reason and Responsibility: Readings in Some Basic Problems of Philosophy. Dickenson Publishing Co., Encino (1978)

Davies, P.C.W.: The physics of downward causation. In.: Clayton, P., Davies, P. (eds.) The Re-Emergence of Emergence, pp. 35–51. Oxford University Press, Oxford (2006a)

Davies, P.C.W.: Preface. In.: Clayton, P., Davies, P. (eds.) The Re-Emergence of Emergence, pp. ix–xiv. Oxford University Press, Oxford (2006b)

Dennett, D.C.: Current issues in the philosophy of mind. Am. Philos. Q. **15**(4), 249–261 (1978)

Dennett, D.C.: Review of the self and its brain: an argument for interactionism. J. Philosophy. **76**(2), 91–97 (1979)

Dennett, D.C.: Granny versus mother nature—no contest. Mind Lang. **11**(3), 263–269 (1996)

Ellis, G. F. R.: On the nature of emergent reality. In.: Clayton, P., Davies, P. (eds.) The Re-Emergence of Emergence, pp. 79–107. Oxford University Press, Oxford (2006)

Fodor, J.: Deconstructing dennett's Darwin. Mind Lang. **11**(3), 246–262 (1996)

Greene, B.: The elegant universe. W.W. Norton & Company, New York (1999)

Heil, J.: Philosophy of mind: a contemporary introduction. Routledge, New York (1998)
Heil, J.: Philosophy of mind: a guide and anthology. Oxford University Press, Oxford (2004)
Hihara, S., et al.: Extension of corticocortical afferents into the anterior bank of the intraparietal sulcus by tool-use training in adult monkeys. Neuropsychol. **44**, 2636–2646 (2006)
James, W.: Are we automata? Mind **4**, 1–22 (1979)
Jeffares, B.: The co-evolution of tools and minds: cognition and material culture in the hominin lineage. Phenomenol. Cogn. Sci. **09**, 503–520 (2010)
Jones, M.W.: Electromagnetic-field theories of mind. J. Conscious. Stud. **20**(11–12), 1–26 (2013)
Jones, M.W.: How to make mind-brain relations clear. J. Conscious. Stud. **17**(5–6), 135–160 (2010)
Kim, J.: Being realistic about emergence. In. Clayton, P., Davies, P. (eds.) The Re-Emergence of Emergence, pp. 189–202. Oxford University Press, Oxford (2006a)
Kim, J.: Emergence: core ideas and issues. Synthese. **151**(3), 547-559 (2006b)
Libet, B.: A testable field theory of mind—brain interaction. J. Conscious. Stud. **1**(1), 119–126 (1994)
Libet, B.: Conscious mind as a field. J. Theor. Biol. **178**, 223–224 (1996)
Lindhal, B.I.B.: Estimating Popper's impact. Nature **360**, 204 (1992)
Lindhal, B.I.B.: Consciousness and biological evolution. J. Theor. Biol. **187**, 613–687 (1997)
Lindhal, B.I.B., Arhem, P.: Mind as a force field: comments on a new interactionistic hypothesis. J. Theor. Biol. **171**, 111–122 (1994)
Lindhal, B.I.B., Arhem, P.: Consciousness and neural force fields. J. Conscious. Stud. **23**(7–8), 228–253 (2016)
Lowe, E.J.: An introduction to the philosophy of mind. Cambridge University Press, Cambridge (2000a)
Lowe, E.J.: Causal closure principles and emergentism. Philosophy. **75**(294), 571–585 (2000b)
Malafouris, L.: The Brain-Artefact Interface (BAI): a challenge for archaeology and cultural neuroscience. Soc. Cogn. Affect. Neurosci. **5**, 264–273 (2010)
Malafouris, L.: How things shape the mind: a theory of material engagement. The MIT Press, Cambridge, MA (2013)
Malafouris, L.: Neuroarchaeology: exploring the links between neural and cultural plasticity. In: Chiao, J.Y. (ed.) Cultural Neuroscience: Cultural Influences on Brain Function, pp. 253–261. Elsevier, Amsterdam (2009)
Malafouris, L.: Metaplasticity and the primacy of material engagement. Time and Mind **8**(4), 351–371 (2015)
Mithen, S. (ed.): Creativity in human evolution and prehistory. Routledge, London (1998)
Mithen, S., Parsons, L.: The brain as a cultural artefact. Camb. Archaeol. J. **18**(5), 415–422 (2008)
Moore, M.W., Perston, Y.: Experimental insights into the cognitive significance of early stone tools. Plos One **11**(7), (2016). https://doi.org/10.1371/journal.pone.0150341
Nagel, T.: What it is like to be a Bat? Philos. Rev. **83**, 435–450 (1974)
Nowell, A., Davidson, I. (eds.): Stone tools and the evolution of human cognition. University Press of Colorado, Boulder (2010)
Orban, G.A., Caruana, F.: The neural basis of human tool use. Front. Psychol. **5**, 3–10 (2014)
Popper, K.R.: Natural selection and the emergence of the mind. Dialectica **32**(3–4), 339–355 (1978)
Popper, K.R.: Three worlds. Mich. Q. Rev. **18**(1), 1–23 (1979a)
Popper, K.R.: Objective knowledge: an evolutionary approach. Oxford University Press, Oxford (1979b)
Popper, K.R.: The open universe: an argument for indeterminism. Routledge, London (1988)
Popper, K.R.: Knowledge and the body-mind problem. Routledge, London (1994)
Popper, K.R., Eccles, J.C.: The self and its brain. Springer Verlag, Berlin (1977)
Popper, K.R.: Scientific reduction and the essential incompleteness of all science. In: Ayala, F. J., Dobzhansky, T. (eds.) Studies in the Philosophy of Biology, pp. 259–284. Macmillan, London (1974)
Popper, K.R.: The place of mind in nature. In: Elvee, R.Q. (ed.) Mind in Nature, pp. 31–59. Harper & Row, Cambridge (1982)

Popper, K.R.: Critical remarks on the knowledge of lower and higher organisms, the so-called sensory motor systems. In.: Creutzfeldt, O., Schmidt, R.F., Willis, W.D. (eds.) Sensory-Motor Integration in the Nervous System, pp. 19–31. Springer Verlag, Berlin (1984a)
Popper, K.R.: Evolutionary epistemology. In.: Pollard, J.W. (ed.) Evolutionary Theory: Paths into the Future, pp. 239–255. John Wiley & Sons, New York (1984b)
Popper, K.R., Lindhal, B.I.B., Arhem, P.: A discussion of the mind-brain problem. Theor. Med. **14**, 167–180 (1993)
Ronan, C.A.: The Cambridge illustrated history of the world's science. Cambridge University Press, Cambridge (1983)
Rooijen, J.V.: Interaction and evolution: a critique of Popper. Br. J. Philos. Sci. **38**(1), 87–92 (1987)
Rupert, R.D.: Challenges to the hypothesis of extended cognition. J. Philosophy. **101**(8), 389–428 (2004)
Settle, T.: Van Rooijen and Mayr versus Popper: is the Universe causally closed? Br. J. Philos. Sci. **40**(3), 389–403 (1989)
Skoyles, J.R.: Popper: Success or failure? Nature **359**, 100 (1992)
Stout, D., Chaminade, T.: The evolutionary neuroscience of tool making. Neuropsychol. **45**, 1091–1100 (2007)
Stout, D., Chaminade, T.: Making tools and making sense: complex, intentional behaviour in human evolution. Camb. Archaeol. Journal. **19**(1), 85–96 (2009)
Stout, D., Toth, N., Schick, K., Chaminade, T.: Neural correlates of early stone age tool making: technology, language and cognition in human evolution. Philos. Trans. R. Soc. B **363**, 1939–1949 (2008)
Stout, D.: Possible relations between language and technology in human evolution. In.: Nowell, A., Davidson, I. (eds.) Stone Tools and the Evolution of Human Cognition, pp. 159–184. University Press of Colorado, Boulder (2010)
Stout, D.: Stone tool making and the evolution of human culture and cognition. Philosophical Transactions of the Royal Society of London. Series B 366, 1050–1059 (2011)
Stout, D., Chaminade, T.: Stone tools, language and the brain in human evolution. Philosophical Transactions of the Royal Society of London. Series B, 367, 75–87 (2012)
Taylor, E.: An explication of emergence. Philos. Stud. **172**(3), 653–669 (2015)
Tennie, C. et. al.: Early stone tools and cultural transmission: resetting the null hypothesis. Curr. Anthropol. **58**(5), 652–672 (2017)
De la Torre, I.: The origins of stone tool technology in africa: a historical perspective. Philos. Trans. R. Soc. Lond. B: Biol. Sciences. **366**(1567), 1028–1037 (2011)
Toth, N.: The first technology. Sci. Am. **1**, 112–121 (1987)
Toth, N., Schick, K.D.: The Oldowan: the tool making of early hominins and chimpanzees compared. Ann. Rev. Anthropol. **38**, 289–305 (2009)
Van Gulick, Robert.: Reduction, emergence and other recent options on the mind-body problem: a philosophic overview. J. Conscious. Stud. **8**(9–10), 1–34 (2001)
Washburn, S.L.: The evolution of man. Sci. Am. **239**(3), 194–211 (1978)
Weinberg, S.: Dreams of a final theory. Vintage Books (1994)
Wynn, T.: Hafted spears and the archaeology of mind. Proc. Natl. Acad. Sci. **106**(24), 9544–9545 (2009)
Wynn, T.G., et al.: An ape's view of the Oldowan revisited. Evol. Anthropol. **20**(5), 181–197 (2011)
Wynn, T., Coolidge, F.L.: Archaeological insights into hominin cognitive evolution. Evol. Anthropol.: Issues, News, Reviews. **25**(4), 200–213 (2016)
Wynn, T.G., Coolidge, F.L. (eds.): Cognitive models in palaeolithic archaeology. Oxford University Press, Oxford (2017)

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