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Acquiring Knowledge on Species-Specific Biorealities: The Applied Evolutionary Epistemological Approach

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> Reflection on what it is like to be a bat seems to lead us, therefore, to the conclusion that there are facts that do not consist in the truth of propositions expressible in a human language. We can be compelled to recognize the existence of such facts without being able to state or comprehend them. (Nagel 1974)

INTRODUCTION

Evolutionary epistemology is an inter- and transdisciplinary research area that associates both with philosophy of biology and with the evolutionary sciences. It understands knowledge as an evolved phenomenon displayed by *all* biological species (Campbell 1974; Wuketits 1989; Bradie 1986; Gontier 2006a). Evolutionary epistemologists investigate how species acquire and transmit information and knowledge about the world, how and to what extent the evolved systems of knowledge of biological species in turn inform us of the ontological state of the universe, and how knowledge itself evolves over the course of evolutionary time.

In this chapter, we outline how, by making use of the evolutionary sciences, evolutionary epistemology differs from traditional epistemological fields, and we demonstrate how evolutionary epistemology fits into the broader field of philosophy of biology. Besides by means of natural selection, evolution can occur by a myriad of evolutionary mechanisms and we briefly outline how this plurality results in various evolutionary epistemologies. While early evolutionary epistemologists favored a hypothetical realist position, today scholars favor constructivist approaches to knowledge. This means that scholars no longer adhere to the view that organisms re-present an outer world through the process of adaptation, but that organisms actively participate in constructing the world, by building species-specific biorealities. Rather than present an encompassing evolutionary epistemology, in this chapter we provide a research program on how to study these biorealities.

KNOWLEDGE IS AN EVOLVED PHENOMENON DISPLAYED BY ALL BIOLOGICAL ORGANISMS

From the ancient Greeks onwards, philosophers have assumed that only humans can obtain true knowledge ("*episteme*") of the world as it is in itself. True knowledge was understood to involve a relation between an individual human knower and the outer world (Pinxten 1997), a relation that was thought to be expressed exclusively in linguistic propositions (Figure 10.1).

At the dawn of the 20th century, however, the early Wittgenstein (1922) demonstrated that we cannot prove by making use of logic that our linguistic propositions relate to the world. The later Wittgenstein (1953) understood language not as an epistemic tool whereby we represent the world, but as a system that results from sociocultural interactions.

Subsequently, two new schools developed concerning how we are to understand knowledge, one proclaiming that knowledge is a sociological phenomenon, the other that it is an evolved phenomenon. Following Wittgenstein, scholars understood "paradigms" (Kuhn 1962) and "epistemic fields" (Foucault 1969) as "regimes of truth" (Foucault 1971) or "scientific research programs" (Lakatos 1978) that are defined by human actors who are part of sociocultural and political communities (Figure 10.2). From within such a Sociology of Knowledge, knowledge becomes redefined as a relation between different knowers (Munz 1993).

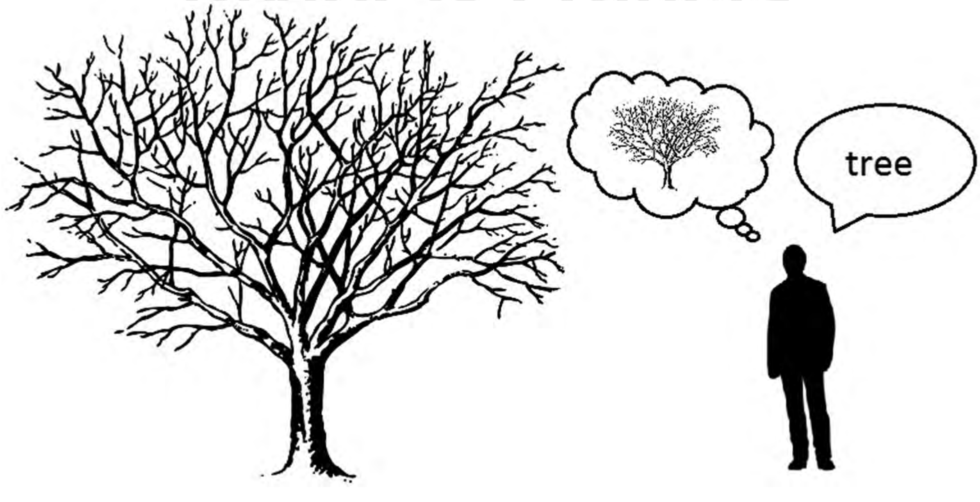

Figure 10.1 Classic view of knowledge

For classic philosophers, epistemology goes hand in hand with solving the reference problem, that is, the problem of how our language, that is considered an expression of our thoughts and empirical observations, corresponds to the matters of fact of the outer world. For empiricists, the world gives us impressions that we transform into language that we use to speak about the world. For rationalists, our mind possesses the right mental, linguistic categories to understand our senses and the objects they perceive in the world. Knowledge is therefore defined as a somewhat direct relation between humans and the world that becomes expressed in language.

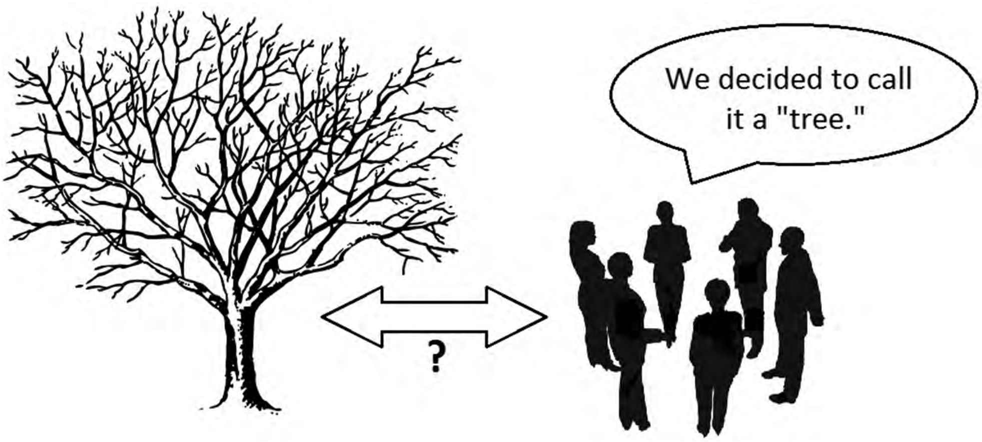

Figure 10.2 Sociology of Knowledge

Knowledge is understood as a consensus-based relation entertained between different humans. How our knowledge relates to the physical environment is secondary to understanding how power, hegemony, and sociocultural traditions are established and how they found worldviews.

By adopting an evolutionary stance, evolutionary epistemologists reject the idea that knowledge is *solely* the product of sociocultural traditions where humans develop consensus-views on what is true or false; and they reject the idea that knowledge is exclusively located in the human mind or the consequence of empirical observation. Instead, all organisms are recognized to have knowledge and knowledge is redefined as a relation between the evolved organism and the outer world (Wuketits 2006). The mind, our senses, language, culture, and society are recognized as evolved phenomena (Campbell 1959), and evolutionary epistemology therefore tries to provide an evolutionary foundation for the sociological and cultural phenomena that are associated with knowledge formation. The cognitive capacity to learn (Piaget 1971) and the sociocultural capacity to transmit learned knowledge across generations (Skinner 1986) are recognized as outcomes of evolutionary processes. Because knowledge is defined as a relation between all organisms and the world, for evolutionary epistemologists the question of how our evolved knowledge relates to the outer, physical world remains a valid research question (Figure 10.3).

Organisms have evolved anatomical adaptations to their environments, as well as cognitive schemes of reaction and behavioral patterns that allow them to survive and reproduce in the world. Evolutionary epistemologists (Lorenz 1941; Campbell 1959) understand the evolved anatomy, cognition, and behavior of organisms as systems of information that embody knowledge about the world. It is embodied because it neither comes in the form of language, nor do species need to be conscious about the knowledge they have—their bodies literally embody knowledge.

Many biological individuals also demonstrate knowledge that surpasses their individual anatomy, cognition, and behavior. Either the knowledge is somehow "carried" by the group instead of by each organism individually (which is something that happens especially in sociocultural systems), or the group-knowledge externalizes and often materializes (in termite mounds, for example, or colonies, or shared technological tool complexes that become part of the species' environment). Several primates and most hominids, for

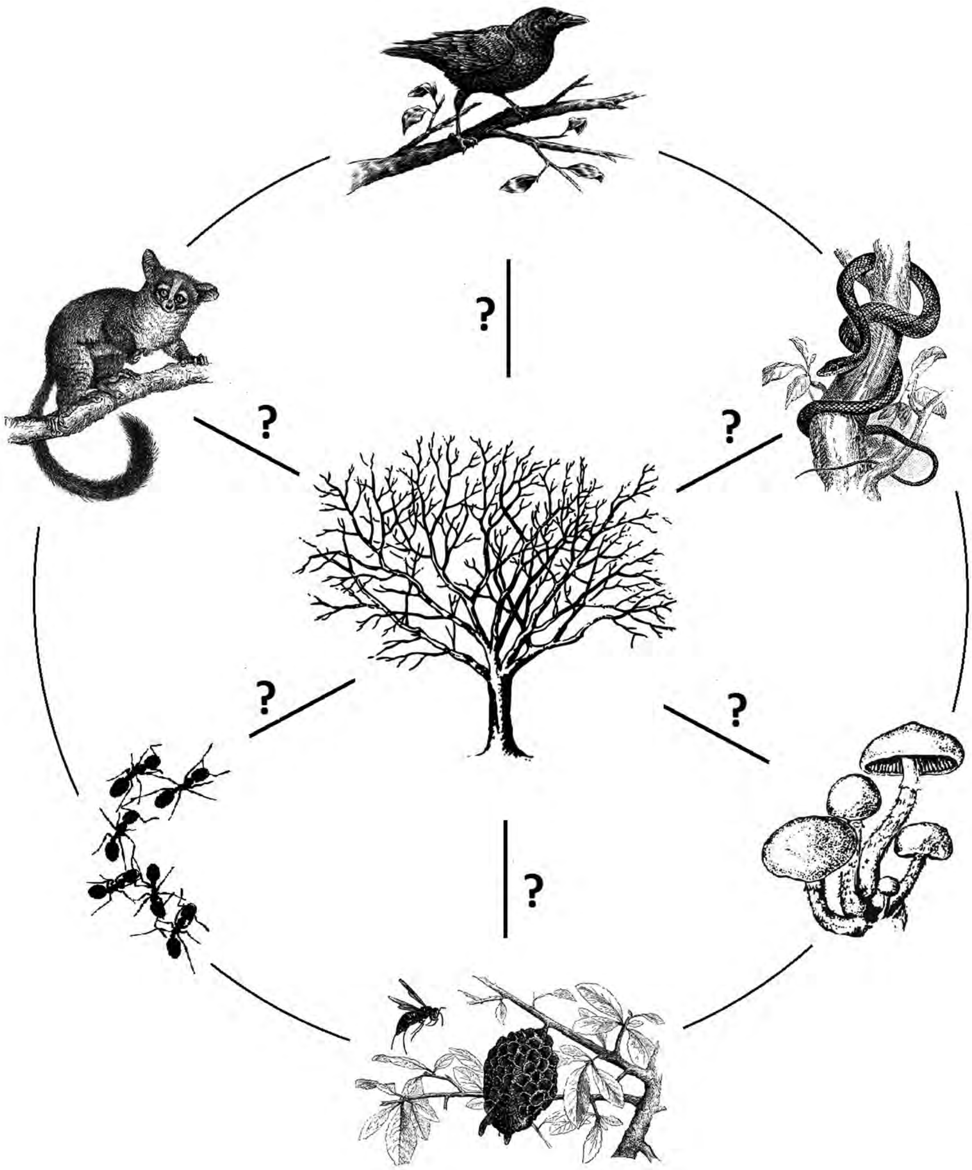

Figure 10.3 Evolutionary epistemology

Knowledge is understood as an evolved relation between the entire organism and its environment. Organisms have evolved anatomical features, cognitive capacities, and behavioral patterns that provide them with means to respond to and anticipate their biotic and abiotic environment, enabling them to survive and reproduce. These features are understood as informational systems that enable the acquisition of knowledge about the environment.

example, accumulate information on how to use and manufacture tools, knowledge that is culturally transmitted over generations through time. And humans have a biologically evolved capacity to learn language, but they learn the specific language they speak from their caregivers. Societies, cultures, or languages function as "extended minds" (Clark & Chalmers 1998; Clark 1999) that are studied from within a general evolutionary framework, as evolved traits.

DIFFERENT EVOLUTIONARY THEORIES RESULT IN DIFFERENT EVOLUTIONARY EPISTEMOLOGIES

It is a fascinating fact that the various life forms that exist today have evolved different means to survive and reproduce in this world. These different means represent evolved information, but the question remains if, how, and to what extent this information references the outer world. Bats and dolphins, for example, have evolved particular anatomical, cognitive, and behavioral traits that enable them to navigate in their specific environment. Bats are well suited to survive and reproduce in a terrestrial or aerial environment, but, unlike dolphins, they do not possess knowledge on how to survive within a marine environment. Each organism connects with certain but not other aspects of the living and non-living world, up to the point that one can argue that organisms live in species-specific biologically informed realities or "*biorealities*." We return to this concept later in the chapter. Here, we focus on how evolutionary epistemology tries to answer the questions of how organismal knowledge evolved, and how it lends insight into the outer world. The answer given is variable and dependent upon the evolutionary framework one adheres to.

Following Darwin, the founders of the field of evolutionary epistemology (Lorenz 1941; Campbell 1959, 1974; Piaget 1971; Skinner 1986) understood the evolved anatomical features, cognitive capacities, and behavioral patterns from within an adaptationist (Lamarck 1809) and selectionist (Darwin 1859) framework. Organisms are understood to adapt to the outer environment, which results in species-specific ways of surviving and reproducing; and natural and sexual selection occurs at the interface between an organism and its environment (which contains both biotic and abiotic components). If organisms display anatomical features, cognitive capacities, and behavioral patterns that enable them to survive long enough to reproduce, then in accordance with natural selection theory, it may be assumed that these traits are adapted to the outer world. If organisms and the various traits they display are not adaptive, then organisms are naturally weeded out.

Such an adaptationist and selectionist view enabled the early evolutionary epistemologists to maintain a hypothetical realist view (Campbell 1960). Organisms are considered to "fit" to the world when they are able to survive and reproduce, and adaptations are understood as evolved re-presentations of the outer world. Konrad Lorenz (1941), for example, famously wrote that "the hoof of the horse is already adapted to the ground of the steppe before the horse is born." Karl Popper (1963, 1972) saw a direct analogy with natural selection theory when he assumed organisms to be like evolved conjectures about the world that somewhat approximate reality or are "corroborated" by reality when they are adapted, and that are "refuted" or "falsified" by the external environment when they are maladaptive. Donald Campbell (1974) drew strong parallels between natural selection theory and Popper's theory of conjectures and refutations, as well as B.F. Skinner's (1986) theory of trial and error learning, and suggested that our bodies constantly test our hypothetical ideas about the outer world. And following Popper (1972: 145; 1984: 19–31) who defined "organs" as embodied "theories" and theories are exosomatic organs, Peter Munz (1993) called organisms "embodied theories" and theories (understood as both scientific thoughts and sociocultural ideas) were dubbed "disembodied organisms." One can, for example, state that a fish provides an as yet unfalsified theory of the water, and by studying the anatomy and behavior of a fish, one can acquire knowledge of the water. A scientific theory is a disembodied organism because it evolves through time, it develops new features, and unfit ideas are eliminated by the environment.

From the viewpoint of hypothetical realism, natural selection becomes nature's way to conjecture, test, falsify, or confirm evolved hypotheses or theories about the world, hypotheses that are embodied in the form of evolved organisms. Knowledge accumulates or grows over evolutionary time, and biological species can even be understood as instruments to acquire knowledge of the outer world (Munz 1993). We humans, for example, cannot see ultraviolet light, but we can point toward scorpions and butterflies that can. Besides the technical instruments that humans have developed over the course of history, life's biodiversity provides a further means to uncover the various layers of reality.

The hypothetical realism adhered to by these scholars (Campbell 1960; Hooker 1989) is nonetheless already tempered through the acknowledgment that there remains a discrepancy between the biological and the purely physical world. Organisms are not literal re-presentations of the outer world because (1) living organisms simply differ from the abiotic world even though they are made up of inorganic matter; (2) adaptive organisms differ from one another; and (3) successful survival and reproduction does not necessarily imply that organisms are adaptive, it merely means that they are not maladaptive. The fact that some organisms survive and reproduce might be due to an abundance of resources, and if a scarcity would arise, competing or predator species might cause the former to go extinct. Non-falsified organisms or theories are not immediately representative of the outer world, they might simply not have been put to the test yet.

Today, the early hypothetical realist views are treated more cautiously. Since the foundation of the Modern Synthesis, numerous fields have questioned several tenets of the core neo-Darwinian framework. New research avenues have opened up including, amongst others:

1. Evo-devo: a field that studies niche construction (Lewontin 1982, 2000; Odling-Smee 1988), phenotypic plasticity (West-Eberhard 2003), developmental systems (Griffiths & Grey 1994; Oyama 2000), and epigenetic mechanisms (Jablonka & Lamb 1989, 2006).
2. Ecology (Van Valen 1973; Odum 1994; Lewontin 2000): a field that divides "the environment" into a biotic and abiotic component and investigates the various interactions amongst them.
3. Macroevolution (Serrelli & Gontier 2015): a research endeavor that studies evolution at the grand scale, beyond populations.
4. Reticulate evolution (Gontier 2015): a vernacular term for evolution as it occurs through hybridization (Arnold 1997), horizontal gene transfer, infectious heredity, symbiosis, and symbiogenesis (Margulis & Sagan 2000; Rosenberg et al. 2007; Gilbert et al. 2012).

These various schools have further specified the exact nature of the organism, the environment, and the relation that exists between these entities. The founders of the Modern

Synthesis treated the organism and the environment as somewhat homogenous entities, and the relation between them was considered unidirectional from the environment to the organism. An organism was either adapted to its external environment or it was not, and it was the environment that, through selection, molded which organisms survived and reproduced.

Today, we recognize that organisms are heterogeneous entities that besides displaying adaptive traits, often simultaneously display maladaptive traits, or neutral traits (Kimura 1968), and existing traits can become exapted for other functions (Gould & Lewontin 1979). Our laryngeal tract, for example, enables a rich vocal palate that allows for differentiated speech, but it also facilitates choking.

Ecological and macroevolutionary perspectives have further diversified "the environment." For one, the environment where the hypothesized struggle for existence occurs is by and large made up of other organisms (Van Valen 1973). Second, these different organisms group together into complexes that form populations, communities, ecosystems, and ultimately the biosphere (see Figure 10.4). And third, the abiotic environment also consists of a multilayered nested hierarchy, where abiotic processes can influence the further course of evolution (Salthe 1985; Tëmkin & Eldredge 2015).

Constructivist approaches necessitate rethinking the classic relation between organisms and the environment and provide more reciprocal and dynamic views. There does not merely exist a struggle for existence over scare resources, and organisms are not merely passive vehicles that adapt to their environment due to outer selection processes. They actively construct their environment (Gould & Lewontin 1979; Lewontin 1982) in such a way that even inhospitable environments become inhabitable. Numerous organisms anticipate winter and store food. On an ecological level, many species not merely compete, but also interact in such a way that new metabolic cycles, tissues, or biological individuals are formed (Margulis & Sagan 2000). Anaerobic bacteria, for example, that get poisoned by oxygen, symbiotically populate the oxygen-low gut environment of many mammals where they contribute to the good digestion of their host; and lichens are symbiotic organisms made up of distinct species—algae that partner up with cyanobacteria and/or fungi.

Rather than demonstrate adaptation toward an external environment, niche construction and symbiosis demonstrate adaptability (Warburton 1956), or an organism's ability to actively modify and build the environment in such a way that it becomes adapted to it. Such traits do not necessarily result in a one-to-one correspondence with the physical world that exists outside the organism; rather, organisms are less representative or referential of an "independent outer world." Species form an active part in building the biosphere, an influence that extends well into the abiotic world. The earth's atmosphere, for example, is oxygen-rich, and 90 percent of that oxygen was created as a waste-product by early cyanobacteria (Margulis & Sagan 2002).

Constructivist approaches (Vollmer 1984; Riedl 1987; Hooker 1989), and even non-adaptationist views (Wuketits 2006) have been put forward to explain how organisms and the species they group into embody knowledge, not merely by "re-presenting" the "outer" world, but by actively constructing it. While hypothetical realism assumes a fit between the organism and the environment, within constructivist views it is recognized that over evolutionary time distinct biorealities have emerged. As such, there is no constant "outer world," but an ever-changing sequential series of emerging biorealities.

ORGANISMS CONSTRUCT SPECIES-SPECIFIC BIOREALITIES

Ancient philosophers investigated how human knowledge (epistemology) provides insight into the nature of the earth and the larger cosmos (ontology), but they thought the cosmos and its components were stable entities and any change that occurred was assumed to be repeated in a cycle of coming and becoming. Ancient philosophers therefore merely sought to find the right order of the cosmic hierarchy, a hierarchy and order they assumed to be eternal. Today, we know that the universe originated approximately 13.7 billion years ago, and life originated on earth somewhat 4 billion years ago. Every abiotic and biotic entity must therefore have come into being, and what exists as "real" is variable over time. With the origin of the universe, various types of matter and energy originated, and with the origin of living beings, various forms of knowledge evolved. The knowledge that species embody and materialize is diverse, and results from organism-environmental interactions. The relation between the biotic and abiotic world is dynamic in kind, and the knowledge that accumulates from this interaction is variable in time and space. Consequently, there is no essential and given knowledge system, nor does there exist a fixed or invariant truth that is waiting to be discovered by these various knowledge systems.

Whether and how the various knowledges that the living world acquired are in one-to-one correspondence with an "outer world," understood as a stable and purely physical world, are the wrong questions to ask. Rather, over time, multiple species-specific and species-bounded biological realities, or biorealities have evolved, realities that are also bounded by physical and chemical laws. What counts as "real" or "true" for one species might not count as "real" for another. We humans, for example, have especially adapted to a mesocosm (Vollmer 1984), a world of middle-sized objects. We cannot observe the bacteria that occupy our skin or gut, or the molecules that form a table~~, and we cannot observe the entire universe~~. Bacteria, on the other hand, even without possessing vision or brains, can easily overcome these biophysical boundaries and establish a biochemical communication with our skin, or penetrate deep inside table wood.

Because biological realities are species-specific and because species evolve, the various biorealities that are formed over time are not stable. There is not one homogenous outer world "out there." Rather, over evolutionary time multiple and varying biorealities emerged. When species go extinct their specific bioreality often ceases to exist while new biorealities become constructed when new species evolve. Biorealities expand and contract in time, in congruence with the species that build them, but boundaries are fuzzy. Though species-specific, different biorealities often overlap, especially when different species occupy the same niche where they are dependent upon the same resources; or when species share common descent, and therefore share common traits that enable them to modify and construct their environment in similar ways. A purely solipsistic view, for example, extrapolated toward organisms or species, is impossible just because we can prove that at least all eukaryotic organisms are related to one another by common descent.

In sum, constructivist approaches necessitate a more dynamic and emergent view of the world. In so far as there existed an "outer world" before life originated, earth has significantly altered in association and perhaps even in correspondence with the life forms that have evolved over time. There does not exist an external relation between the organism and the world, the world has changed inside out, because of the organisms that have evolved, and therefore the world itself becomes an emerging and changing entity. A valid question then becomes how these biorealities are ordered over time, that is, if and how these different biorealities match together into a nested hierarchy (or multiple nested hierarchies), and how they together form a reality (or multiple realities). On a higher level, and to some extent, the various species-specific "biorealities" give ~~prove~~ of the existence of such larger hierarchically structured and nested entities.

APPLIED EVOLUTIONARY EPISTEMOLOGY AND THE WIDER FIELD OF PHILOSOPHY OF BIOLOGY

In this part we present a research program for how to study emerging biorealities. Applied evolutionary epistemology covers the following five research areas:

1. What aspects or traits of biological individuals count as information or knowledge?
2. How can evolutionary theories explain the origin and evolution of these information and knowledge systems?
3. Where do these knowledge systems evolve?
4. How do the evolved knowledge systems underlie the construction of various biorealities and how can the latter in turn lend insight into the ontological layers of the world?
5. Can evolutionary mechanisms themselves be regarded as knowledge-acquiring systems?

The first research endeavor roughly coincides with research on the units of evolution (what evolves, Table 10.1), the second with research on the various evolutionary mechanisms that explain how these units evolve (Table 10.2); and the third coincides with research on the levels of evolution (where in "reality" or "the environment" these units evolve according to certain mechanisms, Figure 10. 4). These three research endeavors are tightly related to one another, because identifying units of evolution always coincides with identifying the locus or level where this unit evolves as well as with the mechanism whereby the unit evolves at a certain level (Gontier 2010).

Darwin identified the organism (what we today designate as the phenotype) as the unit of evolution, and he argued that the organism evolves at the level of the environment by means of natural selection. Following Darwin, philosophers (Brandon 1982) and evolutionary

Table 10.1 Examples of units of selection

Unit	Characterization
Replicator	any entity able to "create copies of itself" (Dawkins 1976: 15) something that demonstrates "fecundity, longevity, and copying-fidelity" (Dawkins 1976: 18)
Meme	"a unit of imitation" (Dawkins 1976: 192) "brain structures whose 'phenotypic' manifestation as behavior or artifact is the basis of their selection" (Dawkins 1982: 164)
Interactor	"an entity that directly interacts as a cohesive whole with its environment in such a way that replication is differential" (Hull 1980: 318)
Culturgene	"that which generates culture" (Lumsden & Wilson 1981: 26) "a relatively homogeneous set of artifacts, behaviors, or mentifacts (mental constructs having little or no direct correspondence with reality) that either share without exception one or more attribute states selected for their functional importance, or at least share a consistently recurrent range of such attribute states within a given polythetic set" (Lumsden & Wilson 1981: 27)

biologists (Williams 1966; Dawkins 1976, 1982; Lewontin 1970) originally focused exclusively on identifying the units and levels of natural selection, by attempting to "universalize" the theory in approaches that became known as "universal Darwinism" (Dawkins 1982, 1983) or "universal selectionism" (Cziko 1995). Besides anatomical, phenotypic form, these scholars also understand cognition or individual and even group behavior to be units that evolve by means of natural selection. And from within evolutionary epistemology, any and all biologically evolved traits can be understood as systems of information.

Universalization implies the following. When it is argued that science (Toulmin 1972; Hull 1988) or culture (Cavalli-Sforz & Feldman 1981; Lumsden & Wilson 1981; Boyd and Richerson 1985; Laland et al. 1995; Mesoudi 2015) evolve by means of natural selection, it needs to be demonstrated how Darwin's theory of natural selection can be extrapolated toward sociocultural phenomena such as scientific or cultural knowledge, and also the units of sociocultural selection (e.g., ideas, rituals, or practices), as well as the levels where these entities evolve, need to be specified. In this regard, Michael Bradie (1986) distinguished between the evolution of epistemological mechanisms (EEM) and the evolutionary epistemology of theories (EET) program: the former investigates the evolution of the biological organs and systems employed in the acquisition of knowledge, while the latter investigates the evolution of the knowledge corpuses that are constructed by knowers.

To explain how natural selection theory can be applied to the sociocultural domain, pioneering evolutionary epistemologists and evolutionary biologists (Table 10.2) have developed several "heuristics" (Campbell 1959, 1960), "Darwinian principles" (Lewontin 1970), or "universal selection formulas" (Hull 1980; Plotkin 1994).

Theorizing on the levels of selection (Figure 10.4) used to be associated with theorizing on how the "superorganic" (Hutton 1788; Spencer 1876; Sapir 1917) relates to the inorganic and organic layers of reality. Today, it is associated more with multilevel selection theory (Okasha 2005) as well as with ecologically and macroevolutionary-oriented fields where scholars actively build hierarchies of the biotic and abiotic world. We return to this when we discuss the fourth point.

First, it is important to emphasize that the classic units and levels of selection debate is currently more accurately defined as the units and levels of evolution debate (Gontier 2010, 2012). Scholars nowadays recognize the existence of a myriad of units that evolve at various levels (Table 10.3), by a multitude of evolutionary mechanisms beyond natural

Table 10.2 Examples of universal selection formulas

Blind variation and selective survival (Campbell 1959)
Blind variation and selective retention (Campbell 1960)
Phenotypic variation, differential fitness (because of different environments), and heritability of that fitness (Lewontin 1970)
Conjectures and refutations (Popper 1963, 1972)
"A process in which the differential extinction and proliferation of interactors cause the differential perpetuation of the replicators that produced them" (Hull 1980: 381)
Replication, variation, and environmental interaction
(Replicator, interactor, lineage) (Hull 1980; Hull et al. 2001)
Blind trial and error learning (Skinner 1986)
Generate, test, regenerate schema (Plotkin 1994)

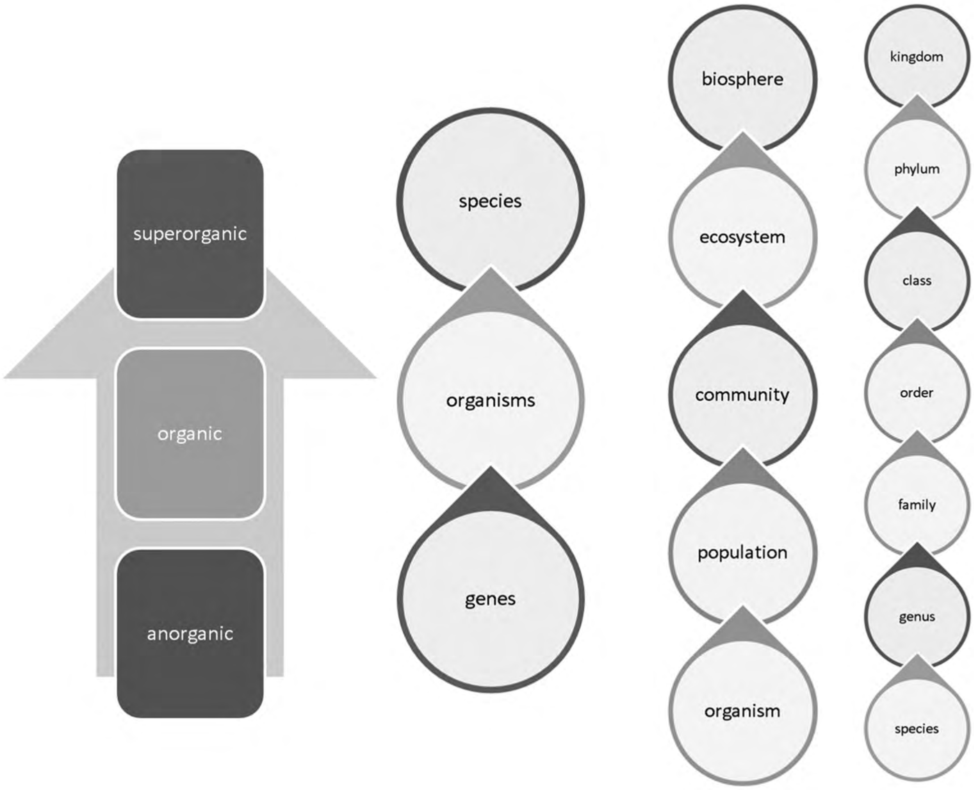

Figure 10.4 Examples of hierarchies of the biotic and abiotic world

From left to right, Hutton's geological and Spencer' sociocultural distinction between the anorganic or non-living, organic or living and superorganic or sociocultural world; the biological hierarchy of what are considered real entities; the ecological hierarchy; and the theoretical genealogical hierarchy.

Table 10.3 Units of non-selectionist mechanisms

Unit	Characterization
Developmental systems theory	
Reproducer	"The pieces of development that are passed on in progeneration [that] confer the capacity to develop on the offspring" (Griesemer 2000: 361)
	"Special or developmental progeneration is multiplication with material overlap of mechanisms conferring the capacity to develop. Development is acquisition of the capacity to reproduce. Reproduction, therefore, is progeneration of entities that develop." (Griesemer 2000: 361)
Symbiosis and Symbiogenesis theory	
Holobiont	"The symbiotic complex" consisting of an individual biont and its (multiple) symbionts (Margulis 1991: 2–4)
Hologenome	"Host genome + microbiome, including viriome" (Rosenberg & Zilber-Rosenberg 2014: 111)

selection. Evolution can be reticulate, or it can occur by means of genetic and ecological drift, niche construction, epigenetic mechanisms, and so on.

However, much work remains to be done in these new fields. The mechanisms that underlie reticulate evolution or the evolutionary emergence of (epigenetic) developmental systems are still not fully understood, and scholars still need to "universalize" the units whereupon and the levels whereat such evolution occurs. Eco-evo-devo fields (Griffiths & Gray 1994; Hahlweg 1989; Jablonka & Lamb 1989, 2006; Oyama 2000) are currently investigating how organismal knowledge is often not reducible to genes. Internal structures such as bodily organs, hormonal and vascular systems, or complex biochemical gene-protein interactions are complex adaptive systems (Hooker 1989) that possess "information" that can become transmitted across generations. And reticulate evolution (Margulis & Sagan 2000, 2002; Gontier 2015) can occur by means of symbiosis, symbiogenesis, infectious heredity, hybridization, and lateral gene transfer. Sometimes, such reticulate evolution requires the horizontal transmission of genetic material, sometimes it requires genetic exchange through sex, and sometimes it involves the merging of different bodies into one another, such as bacteria that infect an organism's airways.

Non-genetic and epigenetic information is also horizontally exchanged and shared between individuals at a sociocultural level. Strong parallels can be drawn between language and culture borrowing and symbiogenesis, for example (Gontier 2006b, 2007), but the mechanisms whereby reticulate evolution occurs are yet to be universalized.

Turning to the fourth point, the recognition that numerous units, levels, and mechanisms of evolution exist necessitates us to investigate how these units and levels interact as well as how the various mechanisms interact to bring forth evolution (Gontier 2010). Units and levels form hierarchically nested realities (Salthe 1985; Tëmkin & Eldredge 2015; Pievani 2015), and the nested ontological layers increase in complexity in what concerns their organization. Studying this increasing complexity relates to theorizing on the major transitions ~~that life~~ (Table 10.4) has gone through since its evolutionary emergence, transitions that are often defined in terms of new means to store and pass on information (Maynard Smith & Száthzmary 1995; Calcott & Sterenly 2011).

Table 10.4 Maynard Smith & Száthmary's (1995) Major transitions in evolution

Major Transitions in Evolution
Replicating molecules to populations of molecules
Independent replicators to chromosomes
RNA to DNA
Prokaryotes to Eukaryotes
Asexual clones to sexual populations
Protists to animals, plants and fungi
Solitary individuals to colonies
Primate societies to human societies

These ideas also find their roots in the works of early evolutionary epistemologists, who shared the aim to build a hierarchy or "taxonomy of behavior" (Lorenz 1941, 1958; Tinbergen 1963) that would map onto the tree of life and portray the evolution of knowledge. Campbell (1959, 1974), for example, distinguished between ten and twelve stages of "inductively achieved knowledge," and his stages provided an evolutionary line-up of the various informational systems that evolved.

Such theorizing therefore connects with the theorizing on how evolutionary mechanisms themselves are knowledge-acquiring devices, which brings us to the fifth point of the program. Lorenz (1941), the founder of ethology, Jean Piaget (1971), the founder of developmental psychology, Skinner (1986), one of the founders of behaviorism and operant conditioning, were all also evolutionary epistemologists; and Campbell (1959) had a background in comparative psychology. These scholars commenced the investigation of cognition and knowledge as an organismal trait that establishes itself during development (ontogeny), through trial and error, observational and other kinds of learning, and this development in turn is driven both by our evolved anatomical and neurocognitive constitution and by our equally evolved sociocultural environment, over the course of phylogeny. Skinner (1986) investigated operant conditioning in various animals, and he developed a theory of language learning that was based upon such operant conditioning. Behaviorist schools became accompanied with cognitive schools of thought (Piaget 1971) that attempted to enter the "black box" that had been the mind up until then.

Lorenz (1941) wrote what has become a classic paper in the field wherein he reevaluated Kant's synthetic a priori claims from within an evolutionary perspective. Most eukaryotic organisms are born with "instincts" or "fixed action patterns" that can be understood as inborn knowledge because they comprise a set of biological expectations about and responses to a specific environment. Newborn ducks, for example, instinctively follow the first thing they see once they hatch. Under normal circumstances, they first see their mother, and it is adaptive to follow her around because she provides food and protection. The newborn ducks do not see the mother as a "mother," "caregiver," or "protector," but they evolved to instinctively follow the first thing they see. Under experimental conditions, Lorenz was able to demonstrate that they would also follow him, or even mobile toys such as trains. Such behavior is called "imprinting," and it demonstrates a specific type of inborn knowledge about the environment. Before the duck was able to learn through experience what his mother can do for it, it "knows" to follow her around. Similarly, animal courtship and mating or fighting are highly ritualized behaviors, called "fixed action patterns," that enable organisms to respond adequately to certain environmental cues. Experiments show that many organisms know how to behave sexually or violently before having observed or learned the behavior or having acted accordingly.

Such behavior is "known" from birth onward (and thus a priori given), but the reason organisms possess this inborn knowledge is that it evolved over the course of evolution. As such, Lorenz (1941), and later also Campbell (1959, 1974), reinterpreted Kant's synthetic a priori (innate) knowledge as knowledge that was obtained synthetically (inductively or a posteriori), by our ancestors over the course of phylogeny. The justification for such claims was found in the theory of natural selection. Such a view furthermore implies that knowledge accumulates over time, and early ethologists assumed that over the course of evolution, learned habits turned into inborn instincts, and thus somehow became conserved and transmitted through generations over time. This was a somewhat neo-Lamarckian claim, and current eco-evo-devo schools are studying the possibility of such inheritance of acquired characteristics, within and beyond the genome.

CONCLUDING REMARKS

Evolutionary epistemology is a field particularly concerned with solving the problem of the development and transmission of information and knowledge through time, across all domains of life. Knowledge is thereby broadly conceived, and includes anatomical, cognitive, behavioral, and sociocultural traits displayed by organisms. As such, it has identified a fundamental question that remained unanswered by the founders of the Modern Synthesis—namely, the question of how new information becomes introduced, stored, and transmitted over generations through time.

Natural selection *strictu sensu* is a theory that explains how existing information is selected over time and how maladaptive information is deleted. To explain how novel information becomes introduced, Darwin made use of Lamarckian inheritance theory, but the founders of the Modern Synthesis conjectured that new traits resulted solely from small random genetic mutations. Today, we know that much more counts as information than what is stored in genes, and this non-genetic and epigenetic information can become stored and transmitted through epigenetic mechanisms, drift, and mechanisms that underlie reticulate evolution.

Philosophy is most successful when it launches new research fields or even entire new scientific disciplines. Many of the founding fathers of evolutionary epistemology were also founding fathers of fields such as ethology, comparative psychology, behaviorism, and cognitive psychology. These fields have now evolved into the new evolutionary sciences that include evolutionary psychology, evolutionary linguistics, evolutionary anthropology, evolutionary sociology, and so on. Nonetheless, many of the questions first raised by evolutionary epistemologists have not been answered satisfactorily by the new evolutionary sciences. And because the research program has to some degree been incorporated into other disciplines, the major philosophical issues raised by the early evolutionary epistemologists have unfortunately been somewhat abandoned by philosophers. The problem of inductively acquired knowledge, or how ontogenetically acquired traits become players in phylogeny remains crucial for both philosophers and evolutionary scholars. The above outlined applied evolutionary epistemological research program provides a means whereby these different fields can interact to find answers.

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REFERENCES

Arnold, M. 1997. *Natural Hybridization and Evolution* (Oxford University Press).

Boyd, R. & Richerson, P. 1985. *Culture and the Evolutionary Process* (~~Chicago~~ University Press).

Bradie, M. 1986. "Assessing evolutionary epistemology." *Biology & Philosophy* 1: 401–459.

Brandon, R. 1982. "The levels of selection." Proceedings of the Philosophy of Science Association 1: 315–323.

Calcott, B. & Sterelny, K. (eds.). 2011. *The Major Transitions in Evolution Revisited* (MIT Press).

Campbell, D. 1959. "Methodological suggestions from a comparative psychology of knowledge processes." *Inquiry* 2: 152–183.

Campbell, D. 1960. "Blind variation and selective retention in creative thought as in other knowledge processes." *Psychological Review* 67: 380–400.

Campbell, D. 1974. "Evolutionary epistemology." In P. Schilpp (ed.), *The Philosophy of Karl Popper Vol. 1* (La Salle) 413–459.

Cavalli-Sforza, L. & Feldman, M. 1981. *Cultural Transmission and Evolution* (Princeton University Press).

Clark, A. 1999. "An embodied cognitive science?" *Trends in Cognitive Sciences* 3: 345–351.

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

Cziko, G. 1995. *Without Miracles* (MIT Press).

Darwin, C. 1859. *The Origin of Species* (Murray).

Dawkins, R. 1976. *The Selfish Gene* (Oxford University Press).

Dawkins, R. 1982. "Replicators and vehicles," In King's College Sociobiology Group (ed.), Current Problems in Sociobiology (Cambridge University Press) 45–64.

Dawkins, R. 1983. "Universal Darwinism." In D. Hull & M. Ruse (eds.), *The Philosophy of Biology* (Oxford University Press) 15–35.

Foucault, M. 1969. *L'Archéologie du Savoir* (Gallimard).

Foucault, M. 1971. *L'Ordre du Discours* (Gallimard).

Gilbert, S., Sapp, J., & Tauber, A. 2012. "A symbiotic view of life: We have never been individuals." *Quarterly Review of Biology* 87: 325–341.

Gontier, N. 2006a. "Introduction to evolutionary epistemology, language and culture." In N. Gontier, J. van Bendegem, & D. Aerts (eds.), *Evolutionary Epistemology, Language and Culture* (Springer) 1–26.

Gontier, N. 2006b. "Evolutionary epistemology and the origin of language: Taking symbiogenesis seriously." In N. Gontier, J. van Bendegem, & D. Aerts (eds.), *Evolutionary Epistemology, Language and Culture* (Springer) 195–226.

Gontier, N. 2007. "Universal symbiogenesis: An alternative to universal selectionist accounts of evolution." *Symbiosis* 44: 167–181.

Gontier, N. 2010. "Evolutionary epistemology as a scientific method: A new look upon the units and levels of evolution debate." *Theory in Biosciences* 129: 167–182.

Gontier, N. 2012. "Applied evolutionary epistemology: A new methodology to enhance interdisciplinary research between the human and natural sciences." *Kairos* 4: 7–49.

Gontier, N. 2015. "Reticulate evolution everywhere." In N. Gontier (ed.), *Reticulate Evolution* (Springer) 1–40.

Gould, S. J. & Lewontin, R. 1979. "The spandrels of San Marco and the panglossian paradigm: A critique of the adaptationist programme." *Proceedings of the Royal Society London, Series B: Biological Sciences* 205: 581–598.

Griesemer, J. 2000. "Development, culture and the units of inheritance." *Philosophy of Science* 67: S348–S368.

Griffiths, P. & Gray, R. 1994. "Developmental systems and evolutionary explanation." *Journal of Philosophy* 91: 277–304.

Hahlweg, K. 1989. "A systems view of evolution and evolutionary epistemology." In K. Hahlweg & C. Hooker (eds.), *Issues in Evolutionary Epistemology* (State University of New York Press) 45–78.

Hooker, C. 1989. "Evolutionary epistemology and natural realism," In K. Hahlweg & C. Hooker (eds.), *Issues in Evolutionary Epistemology* (State University of New York Press) 101–150.

Hull, D. 1980. "Individuality and selection." *Annual Review of Ecology and Systematics* 11: 311–332.

Hull, D. 1988. *Science as a Process* (University of Chicago Press).

Hull, D., Langman, R., & Glenn, S. 2001. "A general account of selection: Biology, immunology, and behavior." *Behavioral and Brain Sciences* 24: 511–573.

Hutton, J. 1788. "Theory of the Earth." *Transactions of the Royal Society of Edinburgh* 1: 209–304.

Jablonka, E. & Lamb, M. 1989. "The inheritance of acquired epigenetic variations." *Journal of Theoretical Biology* 139: 69–83.

Jablonka, E. & Lamb, M. 2006. *Evolution in Four Dimensions* (MIT Press).

Kimura, M. 1968. "Evolutionary rate at the molecular level." *Nature* 217: 624–626.

Kuhn, T. 1962. *The Structure of Scientific Revolutions* (~~Chicago~~ University Press).

Lakatos, I. 1978. *The Methodology of Scientific Research Programmes* (Cambridge University Press).

Laland, K., Kumm, J., & Feldman, M. 1995. "Gene-culture co-evolutionary theory." *Current Anthropology* 36: 131–146.

Lamarck, J. 1809. *Philosophie Zoologique* (Dentu Libraire, Museum d'Histoire Naturelle).

Lewontin, R. 1970. "The levels of selection." *Annual Review of Ecological Systems* 1: 1–18.

Lewontin, R. 1982. "Organism and environment." In H. Plotkin (ed.), *Learning, Development and Culture* (Wiley) 151–170.

Lewontin, R. 2000. *The Triple Helix* (Harvard University Press).

Lorenz, K. 1941. "Kant's lehre vom apriorischen im lichte gegenwärtiger biologie." *Blätter für Deutsche Philosophie* 15: 94–125.

Lorenz, K. 1958. "The evolution of behavior." *Scientific American* 199: 67–78.

Lumsden, C. & Wilson, E. (1981) *Genes, Mind, and Culture* (World Scientific Publishing).

Margulis, L. 1991. "Symbiogenesis and symbionticism." In L. Margulis & R. Fester (eds.), *Symbiosis as a Source of Evolutionary Innovation* (MIT Press) 1–14.

Margulis, L. & Sagan, D. 2000. *What is Life?* (University of California Press).

Margulis, L. & Sagan, D. 2002. *Acquiring Genomes* (Basic Books).

Maynard Smith, J. & Szathmáry, E. 1995. *The Major Transitions in Evolution* (Oxford University Press).

Mesoudi, A. 2015. "Cultural evolution: A review of theory, findings and controversies." *Evolutionary Biology*. doi:10.1007/s11692-015-9320-0.

Munz, P. 1993. *Philosophical Darwinism* (Routledge).

Nagel, T. 1974. "What is it like to be a bat?" *Philosophical Review* 83: 435–450.

Odling-Smee, F. 1988. "Niche constructing phenotypes." In H. Plotkin (ed.), *The Role of Behavior in Evolution* (MIT Press) 73–132.

Odum, H. 1994. *Ecological and General Systems* (Colorado University Press).

Okasha, S. 2005. "Multilevel selection and the major transitions in evolution." *Philosophical Biology* 72: 1013–1025.

Oyama, S. 2000. *The Ontogeny of Information* (Duke University Press).

Piaget, J. 1971. *Genetic Epistemology* (W. W. Norton).

Pievani, T. 2015. "How to rethink evolutionary theory: A plurality of evolutionary patterns." *Evolutionary Biology*. doi:10.1007/s11692-015-9338-3.

Pinxten, R. 1997. *When the Day Breaks* (Peter Lang).

Plotkin, H. 1994. *Darwin Machines and the Nature of Knowledge* (Penguin Books).

Popper, K. 1963. *Conjectures and Refutations* (Routledge & Kegan Paul).

Popper, K. 1972. *Objective Knowledge* (Clarendon Press).

Popper, K. 1984. "Critical Remarks on the Knowledge of Lower and Higher Organisms, the So-Called Motor Systems." In O. Creutzfeldt, R. Schmidt, & W. Willis (eds.), *Sensory Motor Integration in the Nervous System* (Springer-Verlag) 19–31.

Riedl, R. 1987. *Begriff und Welt* (Parey).

Rosenberg, E. & Zilber-Rosenberg, I. 2014. *The Hologenome Concept* (Springer).

Rosenberg, E., Koren, O., Reshef, L., Efrony, R., & Zilber-Rosenberg, I. 2007. "The role of microorganisms in coral health, disease and evolution." *Nature Reviews Microbiology* 5: 355–362.

Salthe, S. 1985. *Evolving Hierarchical Systems* (Columbia University Press).

Sapir, E. 1917. "Do we need a 'superorganic'?" *American Anthropologist* 19: 441–447.

Serrelli, E. & Gontier, N. (eds.). 2015 *Macroevolution* (Springer).

Skinner, B. F. 1986. "The evolution of verbal behavior." *Journal of the Experimental Analysis of Behaviour* 45: 115–122.

Spencer, H. 1876. *The Principles of Sociology, Vol. 1* (Williams and Norgate).

Tëmkin, I. & Eldredge, N. 2015. "Networks and hierarchies: Approaching complexity in evolutionary theory." In N. Gontier & E. Serrelli. (eds.), *Macroevolution* (Springer) 227–275.

Tinbergen, N. 1963. "On aims and methods of ethology." *Zeitschrift für Tierpsychologie* 20: 410–433.

Toulmin, S. 1972. *Human Understanding* (Princeton University Press).
Van Valen, L. 1973. "A new evolutionary law." *Evolutionary Theory* 1: 1–30.
Vollmer, G. 1984. "Mesocosm and objective knowledge: On problems solved by evolutionary epistemology." In F. Wuketits (ed.), *Concepts and Approaches in Evolutionary Epistemology* (D. Reidel) 69–121.
Warburton, F. 1956. "Genetic assimilation: Adaptation versus adaptability." *Evolution* 10: 337–339.
West-Eberhard, M. 2003. *Developmental Plasticity and Evolution* (Oxford University Press).
Williams, G. 1966. *Adaptation and Natural Selection* (Princeton University Press).
Wittgenstein, L. 1922. "*Tractatus Logico-Philosophicus* (trans. C. Ogden) (Kegan Paul).
Wittgenstein, L. 1953. *Philosophical Investigations* (trans. G. E. M. Anscombe & R. Rhees) (Blackwell).
Wuketits, F. 1989. "Cognition: A non-adaptationist view." *La Nuova Critica* 9–10: 5–15.
Wuketits, F. 2006. "Evolutionary epistemology: The non-adaptationist approach." In N. Gontier, J. van Bendegem, & D. Aerts (eds.), *Evolutionary Epistemology, Language and Culture* (Springer) 33–46.