

# Dual Causality and the Autonomy of Biology

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**Abstract** Ernst Mayr's concept of dual causality in biology with the two forms of causes (proximate and ultimate) continues to provide an essential foundation for the philosophy of biology. They are equivalent to functional (=proximate) and evolutionary (=ultimate) causes with both required for full biological explanations. The natural sciences can be classified into nomological, historical nomological and historical dual causality, the last including only biology. Because evolutionary causality is unique to biology and must be included for all complete biological explanations, biology is autonomous from the physical sciences.

**Keywords** Dual causality · Proximate (functional) and ultimate (evolutionary) causes · Nomological-deductive and historical-narrative explanations · Nomological, historical nomological, and historical dual causality sciences · Autonomy of biology

## 1 Introduction

Ernst Mayr's long career can be divided into three broadly overlapping syntheses (Haffer 2007: 1–3), namely: (1) ornithology, systematics and zoogeography; (2) evolutionary biology; and (3) history and philosophy of biology with each being

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I would like to dedicate this paper to my colleague of 60 years, Professor Gerd von Wahlert (1925–2016), who always stressed the ecological aspects of evolutionary biology.

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built on the others (see also Bock 2005, 2006, 2014). Mayr's last synthesis was emphasized during his career at Harvard University beginning in 1953, and included an important, but largely misunderstood paper (Mayr 1961) on "Cause and effect in biology..." in which Mayr advocated the concept "dual causality" for biological explanations (see Beatty 1994 for an excellent treatment of Mayr's intellectual history leading to his publication of dual causality). Closely associated with dual causality, was his position that biology was autonomous from the physical sciences (Mayr 1982: 8–23, 1996, 2004a, b), the last two publications appearing shortly before his death on 3 February 2005 at the age of 100 years. In spite of the central importance of dual causality in biology, this idea has been little appreciated and continues to be misunderstood, possibly because of Mayr's choice of words and his original example of avian migration used to illustrate dual causality. Unfortunately Mayr never published a detailed paper on dual causality with additional examples.

Herein, I would like to present a re-analysis of Mayr's dual causality and to inquire into several related topics, which are:

- What are the different forms of explanations in science?;
- What are forms of explanations in the diverse fields of science?; and,
- Is biology autonomous from the physical sciences?

## 1.1 Dual causality in biology

When Darwin (1859) published his "On the Origin of Species" attention was quite naturally focused on the scientific questions of the descent of organisms from a common ancestor and on the mechanisms of organic evolution. At that time no one considered how biological evolution influenced ideas about causes and explanations in the philosophy of science, and whether biology was autonomous from the physical sciences. According to Mayr (1982: 70–71) and Haeckel (1878, 2015) was the first biologist to argue strongly that biology differed fundamentally from physics. In an almost forgotten paper published in *The Auk*, the *Journal of the American Ornithologists' Union*, with the curious title "Bird-watching and biological science", Julian Huxley (1916: 159–160; see Dewsbury 1992: 107) was the first to state that biological causes and explanations differed, in part, from those in the physical sciences. Huxley implied that a clear distinction exists between biological causes which were later designated as proximate and ultimate causality. However, the first use of the terms "proximate-ultimate causes" in biology was Baker (1938; see Mayr 1982: 68) which Mayr adopted in his 1961 paper on biological causality. Shortly thereafter, Tinbergen's (1963) published his very influential article for ethologists, again little known outside of that field, dealing with biological explanations in a general way without using the dichotomy of proximate-ultimate causality (Dewsbury 1992, 1994, 1999; Alcock and Sherman 1994; Beatty 1994; Cummins and Remsen 1992; Sherman 1998; Drickamer and Gillie 1998; these papers provide an excellent entry to the earlier literature).

A half century ago, Mayr (1961, 1962b, see also 1982: 67–71, 1993, 1976, 1988) inquired into the causes responsible for understanding all aspects aspects of the

observed phenotypical traits of organisms—that is, a full explanation. He formalized these ideas with his concept of “dual causality” as a distinctive aspect of biological explanation and as the foundation for biology being autonomous from the physical sciences (Mayr 1996, 2004a, b). He took these terms from Baker (1938: 162; see Mayr 1982: 68, 1997: 115–119; Beatty 1994; Cummins and Reimsen 1992), pointing out that earlier authors did not use a definite dichotomy of proximate-ultimate causality when discussing the causes of phenotypic attributes. Dual causality is a dichotomy of proximate versus ultimate causes in contrast to the larger series of causes of other authors (Tinbergen 1963).

Proximate causes include all aspects of the environment interacting with the “instructions” the organism’s genotype, etc. (=ultimate cause) to generate its phenotype and are equivalent to the causes used in the standard covering model in the physical sciences (Hempel 2001). The phenotype including all functioning (actions) of the organism during its entire life. All aspects of the environment includes those acting during ontogenetic development to produce “the phenotype” as well as those acting during the life of the organism resulting in any continuing modifications of the phenotype. An individual organism does not have a fixed, non-changing phenotype during its lifetime, but a constantly changing one depending on modifications in the environment; these include all age related alterations.

Ultimate causes are all inherited information of the organism, DNA, RNA, learned, template, etc, serving as instructions, in conjunction with the environment, to produce “the phenotype” as well as all further modifications in the phenotype during the life of the organism.

Unfortunately most biologists consider the statement that the genotype determines the phenotype of the organism to mean that an individual organism has a fixed phenotype during its life—not so! The phenotype of an individual organism changes continuously during its life so that the consequences of selective demands on that organism depend on the interaction of the existing phenotypic attributes with the particular selective demands operating at that time.

As an example of a phenotypic feature to explain the idea of dual causation, Mayr used the onset of the autumnal migration of an individual bird, a parulid warbler, breeding at his summer home in southern New Hampshire. Beatty (1994) provided an excellent analysis of Mayr’s early interest in avian migration as the basis for choosing this example. Mayr’s example of the onset of autumnal migration may have been a difficult choice because most biologists and philosophers do not understand the complexity of factors initiating the onset of autumnal migration of northern hemisphere birds.

The distinction between proximate and ultimate causes exists because of the evolutionary history of living organisms which includes two different types of modifications affecting the phenotypes of organisms.

Evolution is a general term with the broad meaning of change and has been applied to modifications in all entities from elementary particles to organisms with some authors considering that the same basic processes apply to all evolution. However organic evolution does have fundamental differences from the evolution (change) of individual entities, including those during the life of individual organisms. To clarify this distinction, Lewontin (1983: 65) introduced the adjective

“variational” for the evolution of living organisms which are the modifications observed between successive organisms over a time period of more than one generation. Lewontin’s variational evolution is equivalent to Mayr’s (1988: 262) populational evolution, but has the advantage because not all organisms reproduce sexually and the term population in biology is generally restricted to populations of sexually breeding organisms.

In distinction to variational evolution, Lewontin (1983: 66; see Bock 2010: 67) proposed transformational evolution which denotes change in the same object over time. Darwinian evolution is variational and applies to changes observed between successive generations of organisms, while transformational evolution is change seen in the modification of a single object over time. Changes of the earth, the solar system or of an individual organism are transformational. Individual humans undergo transformational change, but the human species undergoes variational (=populational) evolution. The four chambered heart, pulmonary circulation and single descending aorta in birds and mammals were variational evolutionary changes associated with homeothermy in these two vertebrate classes. The differences in the details of these features in birds and mammals result from ultimate causes stemming from the different variational evolution of birds (from the Archosauria) and of mammals (from the Synapsida) from their separate ancestral reptilian groups. Modifications in an individual bird or mammal in the heart, blood vessels and in the pulmonary and systematic circulations from the embryonic to the adult conditions are transformational changes.

All organisms have an evolutionary history; hence full explanations of every phenotypic attribute must include a unique ultimate cause in addition to the proximate causes; this is the central thrust of Mayr’s argument of dual causation.

Perhaps it was the words, the arguments and the example used, or perhaps it was a lack of specifying the foundation of the two causes, or perhaps most scholars still accept the notion that all natural sciences has a single form of causation/explanation, but relatively few workers have mentioned dual causality (Francis 1990; Ariew 2003; Ruse 2007) in spite of the claim by Laland et al. (2011, 2013a, b) of its fundamental importance in biology. There has not been a broad discussion of dual causality by philosophers of science and even by most biologists. I find little to no mention or discussion of Mayr’s dual causality in the general books on the philosophy of biology over the past several decades (Achinstein 1983; Allhoff 2001; Ayala and Arp 2010; Ayala and Dobzhansky 1974; Garvey 2007; Godfrey-Smith 2014; Grene and Depew 2004; Hull 1974, 2001; Hull and Ruse 1998; Rosenberg 1985; Rosenberg and McShea 2008; Ruse 1988, 1998; Salmon 1998; Sober 1993). Furthermore, little mention of dual causality exists by biologists aside from those cited above and to my recollection, no mention of dual causality exists in any general treatment or textbook on evolutionary theory since the introduction of this idea in 1961, including Mayr’s treatise (1982) on the history of biology and his evolution book (2001) for the general reader. Mayr (1997: 66–67, 2004b: 30–31) included only an overly brief, inadequate treatment of dual causality in his general summaries on biology.

In a their papers on dual causation Laland et al. (2011, 2013a) argue that dual causality hindered inquiry into evolutionary mechanisms and should be abandoned

because it lost its usefulness. This second paper (Laland et al. 2013a) gave rise to a series of further papers (Calcott 2013; Dickins and Barton 2013; Gardner 2013; Haig 2013; Scholl and Pigliucci 2015; Watt 2013; with further comments by Laland et al. 2013b); clearly the original manuscript was circulated to other workers as all 2013 papers appeared in the same journal issue. The papers by Laland et al. (2011, 2013a, b) call attention to the idea of dual causality, but I cannot agree with the major conclusions in these papers or in the several papers presented in connection with Laland et al. (2013a) for the following reasons.

First, a major difficulty in understanding Mayr's idea of dual causality may have stemmed from his choice of the terms proximate versus ultimate causes; some workers may have interpreted Mayr's "ultimate cause" with Plato's "final cause" (Francis 1990; Mayr 1993); however, this should not have been a major problem.

Second, Mayr dealt with full explanations of phenotypic attributes of organisms which may not have been made sufficiently clear in his original 1961 paper and his answer to criticisms, but were clear in his later books (Mayr 1997: 66–69, 112–120, 2001). His interest was in showing that dual causality exists in biology and is essential when providing full explanations of any phenotypic trait. He treated this two-parted explanation in terms of dual causality to emphasize its restriction to biology. His use of dual causality is reasonable because other historical sciences have dual nomological and historical explanations without the dual causality of biology.

It should also be emphasized that nowhere in his analysis did Mayr specify or restrict evolutionary mechanisms or stated the mechanisms by which the organism's phenotype developed from its genotype. Neither did he limit the series of factors involved in either his ultimate or proximate causality. Quite clearly and purposely, Mayr did not mention any evolutionary mechanisms in his analysis of dual causality; hence there is absolutely no foundation that dual causality restricts any further investigation about additional evolutionary mechanisms as claimed by Laland et al. (2011, 2013a), and in the following papers in that journal.

Assumed difficulties in the use of dual causality were claimed by Laland et al. (2013a: 721) "We also take issue with Mayr's corollary to the proximate-ultimate dichotomy, which infers from it that ultimate hypotheses cannot invoke developmental processes." Mechanisms of ontogenetic development are proximate causes, not ultimate, as also claimed incorrectly by Scholl and Pigliucci (2015: 657–658). Mayr's concept of dual causality clearly lies in the realm of the philosophy of science, not in the analysis of mechanisms of evolutionary change. My impression is that objections to Mayr's dual causality arose from an erroneous belief that it restricted the development of additional mechanisms of evolutionary change. Nothing could be further from the truth.

Third, Mayr's ultimate cause clearly relates to the inherited (genotype) and other information (learned, template) of the individual organism which produce the phenotype in association with the environment (the proximate cause). The concept of proximate versus ultimate causes applies to the analysis of the observed phenotypes, not to the genotypes or to the mechanisms modifying the genotype. Clearly the generation after generation modifications are the result of all evolutionary mechanisms acting in a particular lineage, but these mechanisms are

independent of the distinction between the proximate versus ultimate causes in the explanation of a particular observed phenotype.

Organic evolution is unique in that the evolutionary mechanisms act on the phenotype of individual organisms resulting in changes observed in the individual organisms during their life span; these are transformational, not variational modifications. Variational modifications result by reproduction of the organisms, generation by generation, producing changes in phenotypic attributes in successive populations because of alterations in their gene pools. Some complications may arise in cultural and template evolution (Bock 2010: 68–69) but these do not affect the current discussion.

Fourth, it is difficult to impossible to attribute explanation of the various attributes of a particular phenotype of an individual organism to proximate and ultimate causes when examining an organism in isolation; comparisons are needed. Mayr did not include any methods or suggestions on how to achieve this analysis. In his thought example of a phenotype, he used the onset of migration of an individual New World parulid warbler. He actually included an silent comparison to the life cycle of other avian species, namely the non-migratory screech owl, also resident in the woods of his New Hampshire “Farm.” I would argue that an understanding of the ultimate versus the proximate causes of an actual phenotype of any organism is possible only on the basis of a comparative study (see examples below).

Fifth, most philosophers and non-ornithologists may have had difficulties understanding the example Mayr used to illustrate his two sets of causes; the onset of autumnal avian migration was perhaps not the best example to illustrate the concept of dual causality. He cited the multitude factors inducing the onset of southward migration of an individual wood warbler (unspecified species, Parulidae: Passeriformes) in late summer from his “Farm” in southern New Hampshire. It is not at all certain that most philosophers of science or biologists appreciate the multiple factors causing the onset of autumnal migration of birds, especially since most species of northern hemisphere birds begin their southward flight well before their food supply and the weather conditions become adverse. Some avian species begin their southward migration in mid-summer immediately following breeding, well prior to the onset of inclement weather conditions. In addition to the immediate proximate factors mentioned by Mayr, there are a number of other proximate factors in the bird’s annual cycle affecting the onset of autumn migration, such as completing the annual molt, accumulating body fat and the onset of “Zugunruhe” (i e., nocturnal migratory unrest).

Sixth, most philosophers of science still accept the position that all sciences deal with universal statements using a single system of explanations. Considerable opposition exists to the ideas that all biology cannot be reduced completely to the physical sciences (Keller 2010) and that all explanations in science are non-historical (Beatty 1990; Dupré 2010). Almost all philosophers of science (e.g., Popper 1959, 1961, 1974), reject historical scientific explanations largely because historical laws do not exist. Nevertheless, rejection of historical laws does not preclude the need for historical explanations in science (Bock 1978, 1991, 2000, 2010). Further most philosophers of science focus on formulating theoretical statements covering universals. There has been little to no interest in

providing historical scientific explanations of singular or unique events and in discussing the significance of partial versus full explanations of these individual events.

## 1.2 Examples of Dual Causation

Clarification of the possible dual causality in the interpretation of any feature is not always easy and attempting to do so for individual unique traits may prove impossible in many cases; I have found such analyses of causality best done on the basis of comparative study. These comparisons frequently demonstrate multiple pathways of evolution (Bock 1959) illustrating the paradox of accident versus design (Mayr 1962a) and concept of paradaptation versus adaptation in evolution (Bock 1967, 2010: 71). Dual causality is shown in the following examples.

### 1.2.1 *The Single Dorsal Aorta in Mammals and in Birds*

The division of the heart ventricle into right and left portions in mammals and in birds differ; hence when a single aorta became advantageous in both groups of homoiothermic vertebrates compared to the dual dorsal aorta of their reptilian ancestors, only the right aorta could be retained in birds and the left in mammals. Hence the proximate explanation for the single dorsal aorta in birds and mammals would be a functional analysis of blood flow in these warm-blooded tetrapods—the proximate half of dual causality. Explanation of which aorta was retained is an evolutionary explanation—the ultimate half of dual causality—depend on the exact details of the subdivision of the ventricle in the different reptilian ancestors of birds (Archosauria) and of mammals (Synapsida). The genetic programs for the differing divisions of the ventricle in these two ancestral reptilian groups were inherited by their warm-blooded descendants and determined which half of the paired double dorsal aorta could be retained and which half lost.

### 1.2.2 *The Number of Digits in the Limbs of the Two Large Groups of Hoofed Mammals*

Specialization for locomotion in these two groups of running mammals resulted in the reduction of the digits from the original ancestral number of five, presumably for greater strength of fewer, thicker digits—a functional (proximate) explanation. Whether the digits are even or odd numbered is an evolutionary (ultimate) explanation depending on the position of central axis of the limbs in these two orders of mammals. In the even-toed Artiodactyla (cows and deer), this weight-bearing axis of the legs is between the third and fourth digits resulting in even digits (four or two). In the odd-toed Perissodactyla (horses and tapirs), this axis lies along the third digit resulting in odd digits (three or one). Again the proximate causes are reducible to the physical sciences, but ultimate causes are the genetic programs controlling the central axis of the limbs inherited by the different organisms which are not reducible to the physical sciences.

### 1.2.3 The Arrangement of Toes in Perching and Climbing Birds

This example of toe arrangement in perching and climbing birds is more complex, but fortunately involving simple morphology (toe arrangement) and simple functional-adaptive explanations (perching and climbing). The ancestral pattern of toes in living birds is three longer anterior toes (# 2, 3, and 4) and a shorter posterior hallux (# 1) found in the ancestor of the present-day orders of modern birds, going back to the Urvogel *Archaeopteryx*.

Functional-adaptive requirements for perching include any arrangement of strong opposing anterior and posterior toes allowing the bird to grasp firmly a tree branch. In the evolution of recent birds, several different toe arrangements appeared in diverse orders of primarily perching birds (Bock and de Witt Miller 1959: Fig. 7; Bock 1979: 38–39). The four known perching arrangements of toes are: (a) anisodactyl (hallux lengthened and strengthened); (b) syndactyl (hallux lengthened and strengthened and anterior toes largely bound together); (c) zygodactyl (fourth toe reversed to the rear); and (d) heterodactyl (second toe reversed to the rear). Climbing birds evolved from perching birds for which the functional requirement is having toes opposing the pull of gravity, hence favoring as many anterior toes as possible. Climbing arrangements of the toes depend on the toe arrangement in their perching ancestor and are: (a) anisodactyl; (b) syndactyl; (c) zygodactyl; (d) ectropodactyl (the zygodactyl toe is moved to a lateral position in woodpeckers); and (e) pamprodactyl (all toes anterior).

Earlier Steinbacher (1935) concluded that the *differences* between the several perching types and between the several climbing types of avian feet are nonadaptive; hence their evolution was nonadaptive. Neither conclusion is valid. Note that Steinbacher stated that the *differences* between these perching and climbing types are nonadaptive, not that *each type is* nonadaptive. Each perching and climbing foot type is adaptive (Bock and de Witt Miller 1959), a proximate (functional) cause. The differences between the four perching types and the five climbing types in birds have nothing to do with their adaptiveness, but depend upon which events which occurred in the history of each group, an evolutionary (ultimate) cause. The differences found between the several perching and the several climbing toe arrangements are paradaptive (nothing to do with adaptive: Bock 1967, 1979), yet each foot type is adaptive for perching and/or climbing; hence their evolution was adaptive resulting from the action of selective demands. Paradaptive attributes of biological features result from accidental genetic and other chance-based factors of evolutionary change – ultimate causality. Ultimate causality is also connected with Mayr's (1962a) concept of accident in evolution and the proximate cause with design in evolution. Use of the term “design” is inappropriate in evolution because it implies the existence of a designer; I suggested the substitution of the terms paradaptation for accident and adaptation for design (Bock 2009a).



### 1.2.4 *The Avian Secondary Jaw Articulation/Brace*

In addition to the usual quadrate jaw articulation, many birds have another (=secondary) jaw articulation serving as an additional brace for the lower jaw. This secondary articulation varies greatly in diverse groups of birds and may exist between the postero-medial process of the mandible and one of the two ventral processes of the basitemporal plate (posterior cranial base; Bock 1960; many groups of nonpasserine birds) or between the midpoint of the mandibular ramus and the ectethmoid plate immediately anterior to the eye (Bock and Morioka 1971; several genera of the Meliphagidae: Passeriformes). These secondary articulations serve as a additional brace for the lower jaw with the braincase. As in most vertebrates, birds possess cranial kinesis in which the upper jaw, as well as the lower jaw, rotates relative to the braincase. Akinetic mammals can open and close their mouth only by moving the lower jaw. Birds, possessing ceanial kinesis, can rotate both jaws (upper and lower) independently of each other. A secondary brace of the avian lower jaw may be needed depending on feeding habits and other uses of the bill which allows the upper jaw to move readily using minimum muscular force while bracing the mandible in a fixed position relative to the braincase (proximate cause: Bock 1964, 1999a, b: 30–31). A secondary brace can evolve only where a part of the lower jaw approaches and abuts against part of the brain case. This condition varies in different avian groups because of the previous evolutionary history of each group and results in quite dissimilar morphologies of the secondary jaw articulation/brace (ultimate cause).

### 1.2.5 *Division and Transplantation of Plant Clones*

An excellent botanical example is the extensive transplant investigations done in the 1930s and 1940s (Clausen 1951; Clausen et al. 1951) in which divided clones of plants (mainly of the *Achillea millefolium* group) were transplanted to controlled conditions in a phytotron greenhouse and to three experimental gardens at different altitudes in the California mountains. Remarkably different phenotypes resulted in each clone planted under diverse conditions of day and night temperatures and day length (Grant 1991: 173–174). In these experiments, the genotypes of the subdivided clones planted under different conditions were the same—ltimate (evolutionary) causality. What differed were the proximate (functional) causes (climatic conditions) acting on the genetically identical clones. Moreover, several clones, possessing different genotypes (ultimate causes), responded differently to the same climatic conditions. These transplant experiments clearly demonstrate diverse modifications in phenotypic features in organisms result from the differing combinations of dual proximate and ultimate causes.

The proximate (functional) explanations in these several examples are all reducible to explanations in the physical sciences. But the ultimate (evolutionary) explanations in biology cannot be reduced to the physical sciences. The ultimate cause depends on the inheritance (transfer, communication) of all type of information between organisms and includes not only genetic material passed from parents to their offspring, but also cultural (including learning), epigenetic and

template instructions (Bock 2010: 68–69) between different organisms usually but not limited, to conspecific individuals. The transfer of all forms of inherited information between organisms represent Mayr’s ultimate causality. Dual causality is essential for a full explanation of all attributes of biological organisms. These major points were, unfortunately, not made sufficiently clear in his original paper (Mayr 1961) or in his subsequent comments (Mayr 1962b), perhaps because he felt that they were sufficient clear.

The only article known to me discussing teaching dual causation is Cummins and Remsen (1992: 201) who state that: “Because distinguishing ultimate from proximate causes is so important in the history and philosophy of biology and because most students have so little appreciation of the ultimate causes that govern their bodies and the environment, we propose that varying levels of causation should be addressed explicitly in the classroom.” I knew Mayr’s paper on dual causality prior to teaching in 1961 and although I should have done so, I never covered this topic in any detail in my courses in vertebrate morphology and in evolutionary theory. I agree emphatically with Cummins and Remsen that dual causality is an important concept to be treated in courses in biology and the philosophy of biology, and must be included in appropriate courses if students are to obtain a complete explanatory foundation for biological features.

### 1.3 Validity of Dual Causation

I disagree strongly with the conclusions reached by Laland et al. (2011, 2013a) and the papers following Laland et al. (2013a) in *Biology and Philosophy* (2013, volume 28) about the validity of Mayr’s dual causality in biology. Dual causality remains an important contribution to the philosophy of biology for understanding the complete foundation of all biological features, but it is still poorly understood by most biologists and philosophers of science. Mayr’s brief introductory paper did not cover all of the roles and nuances of dual causation and considerably more analysis is needed before its full potential is realized; I have only been able to touch on some of these aspects herein.

## 2 Forms of Scientific Explanations

The accepted definition that empirical science is a system in which theoretical statements are subjected to test against objective, empirical observations (Hempel and Oppenheim 1948; Popper 1959, 1974; Shilpp 1974; Hempel 1965, 2001; Nagel 1961, 1965). Further, most scientists, philosophers and historian of science have generally considered that only one form of science exists—the standard covering model, based on the physical sciences using only Nomological-Deductive Explanations (N-D E) in which the objective, empirical tests of theoretical statements are strictly deductive. This is a reasonable approach because prior to the 1960s almost all philosophy of science was based on the physical sciences. Even after the rise of the philosophy of biology, many of the active philosophers of biology received their training from mentors steeped in the traditional ideas of the philosophy of science

based on physics. It is not surprising that Mayr's ideas of dual causality and of the autonomy of biology from the physical sciences were little understood and indeed fell largely on deaf ears with relatively few exceptions (Beatty 1994; Wuketits 2004).

Nomological-Deductive Explanations (N-D E: i.e., covering model: Hempel 1965, 2001; Hempel and Oppenheim 1948) are well treated elsewhere and need no further discussion, but Historical-Narrative Explanations (H-N E) need some additional description.

H-N Es provide an understanding of the existing attributes of a particular limited set of objects or phenomena at a specified time; these explanations depend on the past history of these objects and must depend on pertinent N-D Es (Bock 1978, 1991, 2007, 2010). Objects explained by H-N Es are singulars, not universals, and have definite spatial-temporal positions. H-N Es are stated on a non-deductive, probabilistic basis with the hope of reaching the most reasonable scientific analysis for the phenomenon studied. These explanations possess the following properties (Bock 2007: 98–99) with the first being the most important:

1. H-N Es are historical; hence earlier events affect later events.
2. H-N Es are not general, but singular in that a successful explanation for one phenomenon (mammalian homeothermy) need not hold for a similar phenomenon (avian homeothermy).
3. H-N Es must be based on pertinent N-D Es and these N-D Es, together with the pertinent empirical observations used to test them, form part of tests of the H-N Es.
4. H-N Es are theoretical statements and must be tested against objective empirical observations of all sorts. These tests may be inductive as well as deductive.
5. Generally the more precisely a H-N E is stated the more difficult it is to test and support. It is more difficult to test the H-N E that humans evolved from a chimpanzee-like ancestor than from an anthropoid ape ancestor or from a primate ancestor, etc.

Biological H-N Es include the evolution, phylogeny and classification of organisms and the evolutionary history of their attributes, i.e., anything related to the history of life. Being theoretical statements, H-N Es are also available to tests by falsification but such tests are often extremely difficult and can be inconclusive. Generally H-N Es are not tested by falsification but usually by confirmation with the addition of more and more corroborating support which is closely akin to induction. Objections cannot be raised to inductive testing of H-N Es because they are theoretical statements about a finite number of objects in contrast to N-D Es which cover an “unlimited” number of objects.

What makes H-N Es scientific is point 3 (above) that “H-N Es must be based on pertinent N-D Es and these N-D Es, together with the pertinent empirical observations used to test the N-D Es, form part of the H-N E test.” In the absence of this requirement, the H-N E is not scientific although many systematics still claim that systematic analyses should not be based on nomological evolutionary theory, but simply represent “existing natural order” whatever that notion may be. Within

evolutionary biology, descent with modification, Haeckelian phylogeny, Darwinian or evolutionary classification, Hennigian classification, historical biogeography and all analyses of the evolutionary history of any biological attribute or group (e.g., the evolution of pterosaurian flight, the evolution of mammals from synapsid reptiles) are H-N Es. In geology, the sequence of sedimentary rocks, the pattern of movement of tectonic plates and the pattern of movement of earth's magnetic poles are singular H-N Es although some difficulties still exist in establishing underlying N-D Es. A successful H-N E of the origin of avian flight is a singular event; this H-N E cannot serve as the explanation of the evolution of chiropteran flight or pterosaurian flight even though all three H-N Es are based on the same aerodynamical N-D Es.

### 3 Diversity of Science

Natural science includes only empirical science and exclude all other areas such as social science and computer science having science attached to their name. Empirical science is that area of analytic thought in which theoretical statements must be available for testing by objective empirical observations. Aside from this definition, empirical science is not monolithic as frequently assumed. Differences exist in the nature of possible causes and of possible forms of explanations which have been largely ignored by philosophers of science. At least three major subdivisions of empirical science can be recognized which are:

1. Non-historical nomological science, including physics and chemistry;
2. Historical nomological science, including geology, astronomy and non-comparative functional biology;
3. Historical dual causality science, including all aspects of comparative and evolutionary biology.

The division of biology into functional and evolutionary biology follows the thinking of many biologists (*e g.*, Mayr 1961, 1982, 1985, 1993, 1997, 2004a, b); although it is uncertain that a sharp separation can be made between these two biological areas; the pros and cons of this division are not essential to this analysis. Functional biology includes fields such as morphology, physiology, histology, embryology, ecology, ethology, cellular, molecular biology, medicine and agriculture. Evolutionary biology covers all aspects of comparative biology, phylogeny, systematics, historical biogeography, and the evolutionary history of biological features and taxonomic groups.

Non-historical nomological science is the field of study that most workers and most philosophers of science consider empirical science. (=covering law model). It is not surprising that this restriction of science to non-historical nomological science exists because most thinking about the philosophy of science was based on physics up to the mid-1960s and even thereafter. This restriction of the philosophy of science to physics was reasonable as the ideas of physics were (and perhaps still are) the best developed of all the empirical sciences. Whether correct or not, the physical sciences are non-historical because this limitation has been placed on these fields by

their practitioners. Historical events, such as the natural atomic pile found in Africa, can be argued by physicists as being properly geological in nature and therefore not a historical physical topic.

Historical nomological sciences contain not only nomological-deductive explanations but also possess a historical part; the major ones are geology and biology, but astronomy and cosmology should probably be included. Historical nomological sciences can be divided into nomological and historical segments with the nomological portion dealing with the mechanisms by which the included objects modify over time and the historical portion dealing with the actual changes of these objects; hence they are bipartite explanatory.

Clearly to be scientific, historical explanations in these sciences must be based firmly on underlying nomological explanations. Nevertheless, each historical explanation deals with a singular event which must be tested independently. Historical explanations of the origin of avian, chiropteran or pterosaurian flight are all independent explanations and each must be tested separately against different empirical observations even though each must be supported by nomological aerodynamics.

Historical dual causality science includes only biology which differs from other historical sciences in that a full explanation of any biological attribute must include both proximate (=functional) and ultimate (=evolutionary) causality. It is possible to have partial as well as full explanations in biology depending on whether one includes only functional causes or both functional and evolutionary causes; both types of explanations can make sense depending on the requirements of the inquiry (Bock 2007). The existence of dual causality in biology also determines teleological and teleonomic statements in biology (Mayr 1974, 1988: 38–66).

#### 4 Autonomy of Biology

Many workers have commented on whether biology is or is not reducible to the physical sciences. Most philosophers, based on the premise that all scientific explanations follow only the nomological-deductive approach, argue that biology is completely reducible to the physical sciences (Keller 2010). Fewer workers have argued that biology cannot be reduced completely to the physical sciences (Beatty 1990; Dupré 2010). Haeckel (1878, 2015) may have been the first biologist to state that biology is not reducible to the physical sciences (Mayr 1982: 70–71).

Mayr (1982: 32–36, 1985, 1988: 8–23, 1996, 1997, 2004a, b) took the strong position that biology is autonomous from the physical sciences because full explanations in biology must include evolutionary causality which cannot be reduced to explanations in the physical sciences. He agreed that functional biological explanations can be reduced to the physical sciences but these do not represent all biological explanation. Surprisingly Mayr did not use dual causality to support the autonomy of biology in most of his earlier papers. In papers published shortly before his death on 3 February 2005 Mayr (2004a: 31, b: 21) stated that dual causality “is the most diagnostic characteristic of biology” but unfortunately he also included some additional points which detract from the strength of his argument.

Biology is clearly autonomous from the physical sciences because the observed phenotype of all biological attributes is the result of the dual set of functional and evolutionary causality. The functional (proximate) causes and resulting explanations can, I believe, be reduced to the physical sciences in most, if not all, cases. But the evolutionary (ultimate) causes and resulting full explanation of the phenotype of all biological features are unique to biology. The instructions for phenotypic development depend on inherited DNA and RNA, and/or on cultural (including learning), epigenetic and template instructions from other organisms. These factors are not only inherited from the parent(s) of a particular organism but may also be acquired from other organisms as in the case of many behavioral attributes. Some oscine species (Passeriformes, e.g., Australian Superb Lyrebird: *Menura novaehollandiae*) mimic the song of other birds and of European human sounds heard in their environment and can pass the mimicked sounds to their offspring. The inherited/acquired ultimate causes are essential to the development of all phenotypic attributes of living organisms, and hence are necessary for full explanations of all phenotypic features of living organisms.

Additional support for the autonomy of biology from the physical sciences is unessential; dual causality is completely sufficient. Since a full explanation of all phenotypic attributes of all organisms depend on both functional and evolutionary causality and since the evolutionary causality is unique to biology, no further support for the autonomy of biology is needed.

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