# The Rise and Fall of the Orthogenesis Non-Darwinian Theory of Evolution

**Jerry Bergman***

## Abstract

Orthogenesis is the theory that evolution occurs in a straight line, not branching, and is internally goal-directed. The theory was an attempt to explain the source of new genetic information in biological evolution. Although the theory boasted a number of prominent supporters, it did not survive scientific scrutiny and is now effectively moribund. The main problem with orthogenesis was that no plausible mechanism to drive straight-line evolution was ever demonstrated, and all of the examples used to support orthogenesis could be explained by other theories. Today the most widely accepted theory concerning the source of new genetic information is gene mutations. But mutation is regarded by some prominent biologists as an inadequate source of genetic novelty. It is important to study the doctrine of orthogenetic evolution because it prepares us to understand what may very well happen to the mutation-based evolutionary theory in the future.

## Introduction

Starting with a living cell, evolution must scientifically theorize how one-celled organisms evolved into all of the many life-forms existing today, including multicellular humans. A fundamental problem that evolutionists face is identifying the source of new biological information required for all of this biological change. Every theory that has been advanced in the past to explain the origin of new biological information was eventually discarded as biological knowledge increased. Science historian Peter Bowler (1979, p. 70) wrote that the "rise and fall of orthogenesis represents an important component of the debate over the validity of Darwin's theory, which raged around the turn of the century."

It is now widely believed that several mechanisms are involved in creating new biological information, but orthogenesis is not one of them. Historically it was one of several major theories proposed to counter the numerous objections that were raised against Darwin's theory of evolution by natural selection. One objection to his theory was that random variations, acted on by natural selection, are not a sufficient mechanism by which evolution might produce the life-forms existing today.

> Darwin assumed that the variations of individuals occurred more or less at random, hence selection for advantageous characters was the main directing agent. But if variations were *not* random—if they tended to occur more readily in some directions than others—then the direction of variation might itself control the course of evolution, with selection

* Jerry Bergman, Biology Department, Northwest State College, Archbold, OH, jbergman@northweststte.edu

Accepted for publication November 21, 2009

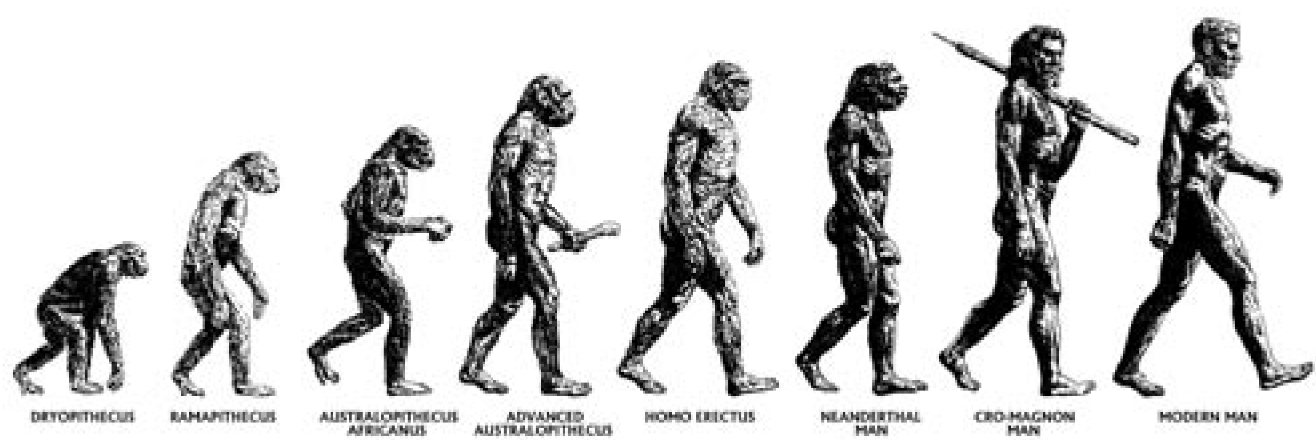



**Figure 1. An example of straight-line evolution is the famous human evolution progression series which S. J. Gould (1989, p. 30) concluded is a gross distortion of the fossil evidence. (Illustrated by Richard Geer.)**

> playing only the negative role of eliminating those directions that were harmful. 'Orthogenesis' was the name coined by Wilhelm Haacke … to designate the process of evolution by 'definitely directed variation' (Bowler, 1979, p. 40).

Specifically, a major criticism of Darwinism was the

> impossibility of explaining the beginnings of advantageous modification and the beginning of new organs, by the selection of fluctuating individual variation … and the admitted cases of forthright development along fixed lines not apparently advantageous (Kellogg, 1907, p. 274).

De Vries (1909, 1910) proposed mutations as the source of new biological information. This theory was initially greeted with skepticism by many biologists because other theories were considered more plausible to account for what appeared to be evolutionary progress. The extensive debate over orthogenesis and its implications was important because the theory initially "appeared to provide experimental disproof of Darwin's theory" of evolution (Bowler, 1979, pp. 40–41).

Classical Darwinism taught that natural selection is the major force imparting direction to evolution by eliminating the less well adapted organisms (Latham, 2005, p. 143). Conversely most orthogenesis theorists argued that natural selection does not significantly alter the predetermined orthogenesis path because they believed that evolution generally does not result from external factors as taught by Lamark or Darwin (Gould, 1977, pp. 79–90). A major reason for opposition to orthogenesis was that many evolutionists wanted "to leave as much as possible of the original structure of Darwinism intact" (Bowler, 1979, p. 41).

## Orthogenesis: Description and Evidence

Orthogenesis, also called autogenesis, was popular for several decades among biologists as an explanation for providing new biological information (Milner, 1990, p. 345). The theory postulated an inherent tendency (bias, driving force, or potential) for organisms to "vary in certain directions, as ancestors vicariate or break apart into descendants" (Grehan and Ainsworth, 1985, p. 174). Called straight-line, "goal-directed" evolution, the theory concluded that the influence of internal "organismic forces" guiding genetic variation in specified directions was a critical factor driving evolution (for the most famous example, see Figure 1). The "internal drive" idea in orthogenesis was similar to vitalism, except that many of its advocates believed the mechanism driving evolution was a biological force, not an ethereal one as was proposed in vitalism.

This endogenous perfecting drive, or "law of growth," was believed to move organisms toward a specific or ultimate end goal, just as an embryo is driven to develop into an adult life-form by internal forces. Nägeli described the drive to perfection as resulting from "something inherent in the organic world which makes each organism in itself a force or factor making [progress] … towards progressive evolution" (Kellogg, 1907, pp. 277–278). Orthogenesists did not deny the influence of external factors but rather stressed that there must exist a combination of the two influences: external factors and an inherent driving force (Bowler, 1979, p. 50). Actually, there existed "two or three theories of orthogenesis which have been developed to the degree where they are boldly offered as substitutes for natural selection" (Kellogg, 1907, p. 277).

The term "orthogenesis" was popularized by Theodor Eimer, professor of zoology and comparative anatomy at Germany's Tübingen University, but the idea was much older. While a student and colleague of August Weismann, Eimer "grew increasingly dissatisfied with Darwin's selection theory, turning to both Lamarckism and orthogenesis as alternatives" (Bowler, 1979, p. 42). Eimer's principle line of evidence for orthogenesis came from his extensive study of butterflies, which he reviewed in a 513-page monograph (1897). In this work he "attributes evolution almost exclusively to development along definitely determined lines" (Dennert, 1904, p. 71). Eimer's book (Eimer, 1890) became a leading text in the orthogenesis movement. Some called his explanation of evolution an "endogenous perfecting principle" or force (Blomberg and Garland, 2002, p. 899).

Another early supporter of orthogenesis was the entomologist Vernon Kellogg. Kellogg had some reservations about Darwinism and

> was quite prepared to consider those alternatives that seemed to be supported by sound evidence. In particular he accepted the existence of some nonadaptive characters and the need to invoke a mechanism to explain them. He discussed Eimer's work at some length, emphasizing that (unlike Nägeli's theory) orthogenesis was scientifically respectable because it depended on external forces to elicit the variation (Bowler, 1979, p. 61).

Other well-known popularizers of orthogenesis included eminent botanist Carl Nägeli, German biologist Wilhelm Haeckel, biologists Leo Berg and Alpheus Hyatt, paleontologist Edward Drinker Cope, and the "giant of paleontology" Henry Fairfield Osborn (Colbert, 1994, p. 64). Additional advocates of orthogenesis included C. O. Whitman, the famous naturalist William Beebe, and renowned paleontologist O. C. Marsh (Larson, 2001). The concept also played a central role in the ideas of neo-Lamarkian philosopher and Nobel Laureate Henri Bergson, who accepted the elements of orthogenesis that supported his own theory, which he called "creative evolution" (1941, pp. 79–85). Ironically, even Darwin was impressed with some of the early orthogenesis concepts, calling them the "laws of growth" (Grehan and Ainsworth, 1985).

Osborn described evolution as an "explosion out from an ancestral form," such as adaptive radiation that spread into every conceivable ecological niche. He concluded that once a "perfect mechanism evolved, evolution stopped" and "adaptation to a different physical environment or habitual zone" was impossible (Ruse, 1996, p. 265). This conclusion explains why evolution seems to have stopped for many forms of life. Called "living fossils," they have not changed much since their initial appearance in the geologic record. Some of Osborn's major ideas go back to Edward Drinker Cope, a Lamarckian. Osborn saw evolution, not as a succession of distinct creatures, but rather as a continuous ascent of progress marked by increasing perfection of form, function, and beauty (Ruse, 1996, p. 268). One major attraction of orthogenesis was the fact that the "theory could infuse evolution with design, or at least purpose" (Larson, 2001, p. 101).

Orthogenesists argued that evolution in general progressed in a defined and restricted path from ancestors to descendants with only a few side branches (MacFadden, 1994). Its supporters concluded that evolution occurs as a result of the influence of internal forces that limit variation in specified directions. For this reason evolution follows a predetermined path that eventually leads to humans. Orthogenesists also asserted that evolution continues until a maximized structure evolves, at which point evolutionary change ceases and stasis prevails.

The evolution of organisms would be driven in one direction to a "state of perfection." The fossil record, which indicated a directional change toward common goals, seemed to support orthogenesis. The evolution of the horse was cited as one example. This is one reason why

> *orthogenesis* soon became popular, especially among the paleontologists. It is still associated largely with those trends observed in the fossil record that seem difficult to explain by natural selection (Bowler, 1979, p. 40).

Supporters of this once popular theory hypothesized that the many examples of life-forms that have gone extinct did so because in this straight-line, directional evolution certain characteristics evolved to excess or were unwieldy, causing extinction. Evidence of an orthogenic evolutionary mechanism includes the enormous Cretaceous reptiles that required prodigious amounts of food just to survive (Kellogg, 1907). The now-extinct Irish elk also was cited as prime support for the theory because the antlers evolved to become so large that they contributed to the animal's becoming extinct (Gould, 1977, pp. 84–85). Supporters of orthogenesis reasoned that the antlers would not have became so large if this trait was not predetermined, and natural selection could not have caused this trait to evolve because the large size of the antlers was clearly detrimental to survival (see Figure 2).

Another anomaly that orthogenesis was used to explain was the titanothere, a rhinoceros-like animal that was judged to have evolved well beyond its adaptive optimum. This example of orthogenesis was so important that Osborn wrote a whole monograph on it (1929) in which he argued that the titanothere had "nasal horns" that evolved to the extent that they seriously interfered with adaptation. He concluded that the horns first appeared in the fossil record only in adult titanotheres, but, as a result

**Figure 2. The Irish elk *(Megaloceros)*, showing the enormous size of its antlers, so large that it had difficulity walking. Photograph taken from a mounted specium. From J.G. Millais. 1897. *British Deer and their Horns.* Henry Southeran, London, England.**

of orthogenesis, they developed earlier and earlier until they appeared on the skull before birth, causing the animals' extinction (Ruse, 1996, p. 271).

D'arcy Thompson argued that evidence of orthogenesis exists in the progressive "gradual increase or decrease" in a trait such as size (1942, p. 807). He assembled scores of examples in his classic work, *On Growth and Form*, which has been reprinted numerous times, including an abridged edition edited by John Bonner (1966). Bonner concluded in the introduction to the abridged reprint that Thompson's book has had considerable influence in biology (1966, p. vii).

## Horse Evolution as Further Evidence for Orthogenesis

Horse evolution from *Eohippus* to the modern horse was both the most common and best-supported example supporting orthogenesis theory (Simpson, 1967, p. 131). Orthogenesis asserted that animals evolved along certain lines or paths toward a predetermined goal that natural "selection based on utility [is] unable to explain" (Kellogg, 1907, p. 275). Professor Marsh, a paleontologist, attempted to confirm Darwinism by working out the history of horse evolution from the fossil record (Milner, 1990). Marsh collected a magnificent set of fossil horses and then attempted to trace its evolution

> from a small three-toed animal "the size of a fox" through larger animals with progressively larger hooves, developed from the middle toe. Darwin thought Marsh's sequence from little *Eohippus* ("Dawn horse") to modern *Equus* was the best evolutionary demonstration anyone had produced in the 15 years since the *Origin of Species* (1859) was published (Milner, 1990, p. 220).

Marsh arranged his fossil collection in such a way that it would

> "lead up" to the one surviving species, blithely ignoring many inconsistencies and any contradictory evidence. Ironically, his famous reconstruction of horse evolution was copied by anthropologists. They, too, thought they saw a straight-line lineage "leading up" to the sole surviving species of a once-varied group: *Homo sapiens* (Milner, 1990, p. 220).

British biologist Thomas Henry Huxley was greatly impressed with Marsh's progressive series of fossil horses when he visited Marsh's lab. Marsh's classic orthogenic, unilinear horse evolution soon became

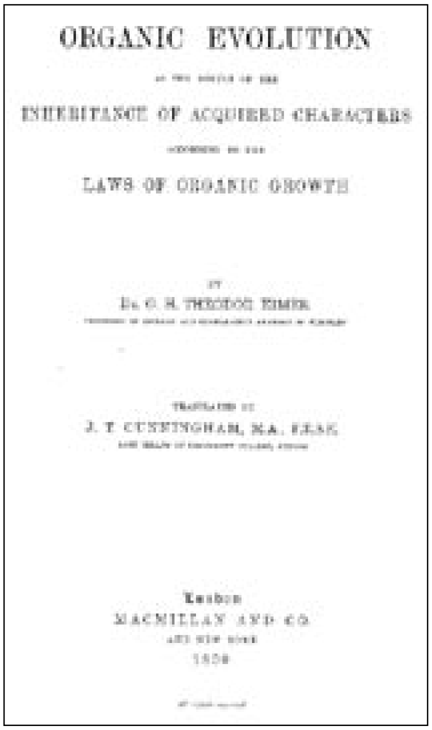
> enshrined in every biology textbook and in a famous exhibit at the American Museum of Natural History. It showed a sequence of mounted skeletons, each one larger and with a more well-developed hoof than the last. (The exhibit is now hidden from public view as an outdated embarrassment.) (Milner, 1990, p. 220)

## Convergent Evolution Was Used as Evidence

One variant related to orthogesis included a theory that was developed by leading evolutionist H. Osborn, a theory called "aristogenesis" (Witham, 2002, p. 30). Osborn argued that the common observation called evolutionary parallelism—today called convergent evolution—was persuasive evidence for orthogenesis. Convergent evolution is when animal structures evolve along discrete, but similar, lines to yield very similar structures (Colbert, 1994, p. 64). Thus, wings are believed to have evolved separately at least three times (in birds, bats, and pterodactyls), forming remarkably similar structures. To Osborn these examples proved the existence of the orthogenetic inward drive. How else could so many animals evolve in totally separated and very different environments into animals that were so very similar that the same common name is used for both, such as placental mole and the marsupial mole?

Howe (1965, 1972, 1999, and 2000) has summarized and evaluated the evidence for convergent evolution. He

**Figure 3. Henry Fairfield Osborn, the head of the American Museum of Natural History. (From the author's collection.)**


ORGANIC EVOLUTION

INHERITANCE OF ACQUIRED CHARACTERS

LAWS OF ORGANIC GROWTH

MACMILLAN AND CO

**Figure 4. One of the most important books of the orthogenesis movement, Eimer's (1890) *Organic Evolution as the Result of the Inheritance of Acquired Characters according to the Laws of Organic Growth.***

attributed it instead to the Creator's versatility by producing wings, echolocation, or similar structures in animals that are taxonomically widely separated. Howe asserted such parallelism supports creation, not evolution.

Examples of convergent evolution of entire organisms include many placentals, such as the wolf, ocelot, anteater, flying squirrel, groundhog, and mouse, all which have remarkably similar marsupial counterparts in animals that must have had totally different evolutionary lineages. See Table I for the corresponding placental and Australian marsupials. This table shows the extent of which ecological counterparts are found in two very distinct zoologies groups. This parallelism is such a degree that it could not have arisen by any kind of evolutionary process.

**Table I. Corresponding placental and Australian marsupials.**

| Placental Mammals | Marsupial Mammals |
|---|---|
| Wolf (*Canis*) | Tasmanian Wolf (*Thylacinus*) |
| Ocelot (*Felis*) | Native Cat (*Dasyurus*) |
| Anteater (*Myrmecophaga*) | Anteater (*Myrmecobis*) |
| Flying Squirrel (*Glaucomys*) | Flying Phalanger (*Petourus*) |
| Groundhog (*Marmota*) | Wombat (*Phasolmys*) |
| Mouse (*Mus*) | Mouse (*Dasycercus*) |
| Placental Mole | Marsupial Mole |
| Lemer | Spotted Cuscus |
| Saber-toothed placental (*Similodontidae*) | Saber-toothed marsupial (*Thylacosmilidae*) |

Orthogenesis and convergence are often assumed to be the same because both were used by anti-Darwinians. However, orthogenesis postulates parallel evolution driven by nonadaptive trends in related species; in contrast, convergence is a theoretical process by which unrelated organisms independently adapted to similar habitats or lifestyles. Lamarkians believed their theory of use-inheritance could better explain "convergent evolution," and they postulated that much more convergence existed than the Darwinians postulated. Bergson (1941) concluded that only orthogenetic evolution can

> account for the building up of identical complex organs on independent lines of development. For it is quite conceivable that the same effort to turn the same circumstances to good account might have the same result, especially if the problem put by the circumstances is such as to admit of only one solution (p. 86).

## Teilhard and Orthogenesis

Orthogenesis was further popularized by Jesuit paleontologist Teilhard de Chardin. He argued for an orthogenetic evolution that would eventually reach a state of perfection, which he called the "Omega Point." De Chardin wrote that without orthogenesis life would only have merely spread out, but with it the ascent of life became "inevitable" (1959, p. 109).

## Opposition to Orthogenesis by Simpson and Others

Close to a century after Marsh's horse exhibit first appeared in the American Museum of Natural History, the paleontologist George Gaylord Simpson reexamined horse evolution and "concluded that generations of students had been misled" (Milner, 1990, p. 220). Simpson (1951, pp. 163–171) effectively documented that no simple, gradual, unilinear evolution of horses had occurred in history. He argued that horse evolution was not gradual but rather very "jerky," displaying clear evidence for punctuated equilibrium. Teeth, toes, and even body size "varied in different lineages, independently of each other" (Milner, 1990, p. 220). The pattern documented by the fossil evidence, Simpson concluded, is better explained by opportunism and the tendency for natural selection to favor larger animal sizes (Simpson, 1967, p. 131). He concluded that orthogenesis did not provide an adequate explanation of horse evolution (Simpson, 1953).

Another orthogenesis critic was August Weismann, who recognized "that the traditional Darwinian theory was inadequate," and developed his own theory, called the *germ plasma* theory (Bowler, 1979, p. 56). Ironically, Weismann accepted orthogenesis as a "minor addition to natural selection" but concluded that its influence was limited to particular developments by individual species (Bowler, 1979, p. 53). Weismann argued that most of the variation driving evolution was caused by random genetic changes and natural selection.

Ultimately, orthogenesis fails to explain the source of the "unknown inner forces inherent in organisms" that moved the organism "toward some ideal goal," which many saw as a "mystic essentially teleologic force" (Kellogg, 1907, p. 278). Simpson was opposed to orthogenesis because he concluded it required "some mysterious inner force" that cannot be explained by science (Simpson, 1953, p. 125).

## The Theory's End

The orthogenesis theory has now largely been abandoned because no plausible physical mechanism for the postulated internal drive that caused life to evolve in a specific direction was ever found (Ruse, 1996; Simpson, 1967). Another major problem was that the fossil record does not support "straight-line" evolution, a fact that was called the "paradox of stasis" by Hendry.

> The most obvious manifestation of this paradox is that neo-Darwinian theory, with its emphasis on the power of selection, predicts the potential for rapid adaptation, whereas most lineages of organisms instead show long-term stasis: that is, very little cumulative change over long periods of time (Hendry, 2007, p. 147).

A further reason for the rejection of orthogenesis was that the examples used to support it have all been shown to have many exceptions and irregularities or are just plain wrong. Observations that orthogenesis purported to explain were better explained by other theories or remain unexplained.

Simpson was the most influential critic of orthogenesis. He asserted that evolution in general does not proceed in straight lines but rather "only a tendency" to do so existed "with so many exceptions as hardly to constitute a rule" (1967, p. 133). One of the most fundamental objections to orthogenesis was that it was advocated by "vitalists and finalists," while Darwinism was supported by a large number of persons who vehemently rejected the conclusion that "direction" exists in evolution (Simpson, 1967, p. 132).

In spite of a lack of evidence, the orthogenesis idea persisted for decades and is still ingrained in both "modern scientific thought and in everyday society in general" (MacFadden, 1994, p. 27). It was recently resurrected by Calvin College physics professor Howard Van Till. His theory concluded that a "complete initial creation" and an inbuilt "robust foundational formational economy" are responsible for the creation of all things, living and nonliving (1990, pp. 112–115). According to Van Till the innate properties necessary to bring about "all of the diverse physical structures and life-forms that have appeared in the course of time" without outside intervention were built into the nonliving building blocks of the universe (Van Till, 1990, p. 85). This form of vitalism credits God with constructing the seeds of life very early in the universe, and for this reason life contains the drive to perfect itself. This view is simply another form of theistic evolution and orthogenesis.

## Summary

Darwin described his theory of evolution as merely "a provisional hypothesis or speculation," but he believed it was the best extant theory that could explain the origin of the species, and that "until a better one [can] be advanced, it will serve to bring together a multitude of facts which are at present left disconnected by any efficient cause" (Darwin, 1896, p. 350). In the decades around 1900, a number of non- and neo-Darwinian theories were developed, including orthogenesis, in an attempt to explain the origin of new biological information. Most of these theories have now been discarded (Bowler, 1983). The lethal problem with orthogenesis was that there was no known mechanism to account for an endogenous perfecting force.

No post-Darwinian theory has yet achieved the popularity of neo-Darwinism. Some biologists have tried to resurrect a form of orthogenesis called "phylogenetic inertia," which is the idea that once an organism begins to evolve in a specific direction, it tends to keep evolving in that way (Blomberg and Garland, 2002).

Clearly, "evolutionary theory is a tumultuous field where many differing views are now competing for dominance" (Esensten, 2003, p. 2). The history of the rise and fall of orthogenesis supports the idea that evolutionism has always been a "tumultuous field" and will continue to be such. Meanwhile, the collapse of each new philosophical attempt to explain the source of novelty in biology is additional support for the creation origins views. The neo-Darwinian concept of mutations and natural selection may well also be discarded when its limitations are more fully understood.

**Acknowledgments:** I wish to thank Ted Siek, PhD, Clifford Lillo, MA, John UpChurch, Jody Allen, RN, George Howe, PhD, and two anonymous reviewers for their reviews on an earlier copy of this paper.

## References

Bergson, H. 1941. *Creative Evolution*. Modern Library, New York, NY.

Blomberg, S.P., and T. Garland, Jr. 2002.

Tempo and mode in evolution: phylogenetic inertia, adaptation and comparative methods. *Journal of Evolutionary Biology* 15:299–910.

Bowler, P.J. 1979. Theodor Eimer and orthogenesis: evolution by "definitely directed variations." *Journal of the History of Medicine* 34(1):40–73.

Bowler, P.J. 1983. *The Eclipse of Darwinism: Anti-Darwinism Theories in the Decades around 1900.* Johns Hopkins University Press, Baltimore, MD.

Colbert, Edwin H. 1994. Four giants of paleontology. *Natural History* 5:62–67.

Darwin, Charles. 1896. *Animals and Plants Under Domestication.* Vol. II. D. Appleton, New York, NY.

De Chardin, P.T. 1959. *The Phenomenon of Man.* With an Introduction by Julian Huxley. Harper, New York, NY.

Dennert, E. 1904. *At the Deathbed of Darwinism.* German Literary Board, Burlington, IA.

De Vries, H. 1909. *The Mutation Theory.* Vol. I. Open Court, Chicago, IL.

De Vries, H. 1910. *The Mutation Theory.* Vol. II. Open Court, Chicago, IL.

Eimer, T. 1890. *Organic Evolution as the Result of the Inheritance of Acquired Characters according to the Laws of Organic Growth.* Macmillan, New York, NY.

Eimer, T. 1897. *Orthogenesis der Schmetterlinge.* Wilhelm Engelmann, Leipzig, Germany.

Eldredge, N. 1985. *Time Frames: The Rethinking of Darwinian Evolution and the Theory of Punctuated Equilibria.* Simon and Schuster, New York, NY.

Esensten, J.H. 2003. Death to intelligent design. *The Harvard Crimson Online Edition,* March 3, 2003.

Gould, S.J. 1977. *Ever Since Darwin.* Norton, New York, NY.

Gould, S.J. 1982. Introduction. In Goldschmidt, R., *The Material Basis of Evolution.* Yale University, New Haven, CT.

Gould, S.J. 1989.*Wonderful Life: The Burgess Shale and the Nature of life*. Norton: New York, NY.

Grehan, J.R., and R. Ainsworth. 1985. Orthogenesis and evolution. *Systematic Zoology* 34(2):174–192.

Hendry, A. 2007. The Elvis paradox. *Nature* 446:147–150.

Howe, G.F. 1965. Homology, analogy, and creative components in plants. *Creation Research Society Quarterly* 2:11–21.

Howe, G.F. 1972. Homology, analogy, and innovative teaching." Unpublished manuscript. georgefhowe@sbcglobal.net.

Howe, G.F. 1999. Homology and origins. *Creation Matters* 4:1–5.

Howe, G.F. 2000. The origin of flowering plants. *Creation Research Society Quarterly* 37:66–67.

Kellogg, V. 1907. *Darwinism To-Day*. Henry Holt, New York, NY.

Larson, E.J. 2001. *Evolution's Workshop: God and Science on the Galapagos Islands.* Basic Books, New York, NY.

Latham, A. 2005. *The Naked Emperor: Darwinism Exposed.* Janus Publishing Company, London, UK.

MacFadden, B.J. 1994. *Fossil Horses: Systematics, Paleobiology and Evolution of the Family Eaquidae.* Cambridge University Press, New York, NY.

Milner, Richard. 1990. *The Encyclopedia of Evolution: Humanity's Search for Its Origins.* Facts on File, New York, NY.

Osborn, H. 1929. *The Titanotheres of Ancient Wyoming, Dakota, and Nebraska.* U.S. Geological Survey Monograph No. 55, Washington, DC.

Ruse, M. 1996. *Monad to Man: The Concept of Progress in Evolutionary Biology.* Harvard University Press, Cambridge, MA.

Simpson, George Gaylord. 1951. *Horses: The Story of the Horse Family in the Modern World and Through Sixty Million Years of History.* Oxford University Press, New York, NY.

Simpson, George Gaylord. 1953. *Life of the Past.* Yale University Press, New Haven, CT.

Simpson, George Gaylord. 1967. *The Meaning of Evolution.* Yale University Press, New Haven, CT.

Steele, Edward J., Robyn A. Lindley, and Robert V. Blanden. 1998. *Lamarck's Signature: How Retrogens are Changing Darwin's Natural Selection Paradigm.* Perseus Books, Reading, MA.

Thompson, D'arcy Wentworth. 1942. *On Growth and Form.* Macmillan, New York, NY.

Thompson, D'arcy Wentworth. 1966. *On Growth and Form: An Abridged Edition.* Edited by John Tyler Bonner. Cambridge University Press, Cambridge MA.

Van Till, Howard J. 1990. The scientific investigation of cosmic history." In Van Till, Howard J., Robert E. Snow, John H. Stek, and Davis A. Young (editors), *Portraits of Creation: Biblical and Scientific Perspectives on the World's Formation,* pp. 82–125. Eerdmans, Grand Rapids, MI.

Witham, Larry A. 2002. *Where Darwin Meets the Bible.* Oxford University Press, New York, NY.