

On the Origins of Modern Science: Copernicus and Darwin

Francisco J. Ayala

University of California, Irvine, USA

Abstract

Copernicus, Galileo, Newton and other physical scientists ushered in a conception of the universe as matter in motion governed by natural laws. Their discoveries brought about a fundamental revolution, namely a commitment to the postulate that the universe obeys immanent laws that can account for natural phenomena. The workings of the universe were brought into the realm of science: explanation through natural laws.

Darwin completed the Copernican revolution by extending it to the living world. Darwin accumulated evidence demonstrating that organisms evolve over eons of time and diversify as they adapt to environments that are enormously diverse. Most important, however, is that he discovered natural selection, the process that accounts for the evolution of organisms and for their adaptive features; that is, their “design.”

Darwin’s theory of evolution accounts for the design and diversity of organisms as the result of the gradual accumulation of spontaneous mutations sorted out by natural selection. Mutation and selection have jointly driven the marvelous process that, starting from microscopic organisms, has yielded orchids, birds, and humans. The theory of evolution conveys chance and necessity, randomness and determinism, jointly enmeshed in the stuff of life. Darwin’s fundamental discovery is that there is a natural process that is creative although not conscious.

Introduction

There is a version of the history of the ideas that sees a parallel between the Copernican and the Darwinian revolutions. In this view, the Copernican Revolution consisted in displacing the Earth from its previously accepted locus as the center of the universe, moving it to a subordinate place as just one more planet revolving around the sun. In congruous manner, the Darwinian Revolution is viewed as consisting of the displacement of humans from their exalted position as the center of life on earth, with all other species created for the service of humankind.

According to this version of intellectual history, Copernicus had accomplished his revolution with the heliocentric theory of the solar system. Darwin’s achievement emerged from his theory of organic evolution.

Sigmund Freud refers to these two revolutions as “outrages” inflicted upon humankind’s self-image and adds a third one, his own: “Humanity in the course of time had to endure from the hands of science two great outrages upon its naïve self-love. The first was when it realized that our earth was not

the centre of the universe, but only a tiny speck in a world-system of a magnitude hardly conceivable; this is associated in our minds with the name of Copernicus, although Alexandrian doctrines taught something very similar. The second was when biological research robbed man of his peculiar privilege of having been specially created, and relegated him to a descent from the animal world, implying an ineradicable animal nature in him: this transvaluation has been accomplished in our own time upon the instigation of Charles Darwin, Wallace, and their predecessors, and not without the most violent opposition from their contemporaries. The third and most bitter blow upon man's craving for grandiosity" was meted out in the twentieth century by psychoanalysis, revealing that man's *ego* "is not even master in his own house."

What the standard version of the Copernican and Darwinian revolutions says is correct but inadequate, because it misses what is most important about these two intellectual revolutions, namely that they ushered in the beginning of science in the modern sense of the word. These two revolutions may jointly be seen as the one Scientific Revolution, with two stages, the Copernican and the Darwinian.

The Copernican Revolution

The Copernican Revolution was launched with the publication in 1543, the year of Nicolaus Copernicus' death, of his *De revolutionibus orbium celestium* (On the Revolutions of the Celestial Spheres), and bloomed with the publication in 1687 of Isaac Newton's *Philosophiæ naturalis principia mathematica* (The Mathematical Principles of Natural Philosophy).

The discoveries by Copernicus, Kepler, Galileo, Newton, and others, in the sixteenth and seventeenth centuries, gradually ushered in a conception of the universe as matter in motion governed by natural laws. It was shown that Earth is not the center of the universe, but a small planet rotating around an average star; that the universe is immense in space and in time; and that the motions of the planets around the sun can be explained by the same simple laws that account for the motion of physical objects on our planet. Laws such as $f = m \times a$ (force = mass x acceleration); or the inverse-square law of attraction, $f = g(m_1 m_2) / r^2$ (the force of attraction between two bodies is directly proportional to their masses, but inversely related to the square of the distance between them).

These and other discoveries greatly expanded human knowledge. The conceptual revolution they brought about was more fundamental yet: a commitment to the postulate that the universe obeys immanent laws that account for natural phenomena. The workings of the universe were brought into the realm of science: explanation through natural laws. All physical phenomena could be accounted for as long as the causes were adequately known.

The Darwinian Revolution

The advances of physical science brought about by the Copernican Revolution had, however, driven mankind's conception of the universe to a split-personality state of affairs, which persisted well into the mid-nineteenth century. Scientific explanations, derived from natural laws, dominated the world of nonliving matter, on the Earth as well as in the heavens. However, supernatural explanations, which depended on the unfathomable deeds of the Creator, were accepted as explanations of the origin and configuration of living creatures.

Authors, such as William Paley (1743-1805), argued that the complex design of organisms could not have come about by chance, or by the mechanical laws of physics, chemistry, and astronomy, but was rather accomplished by an Omniscient and Omnipotent Deity, just as the complexity of a watch, designed to tell time, was accomplished by an intelligent watchmaker.

It was Darwin's genius to resolve this conceptual quagmire. Darwin completed the Copernican Revolution by drawing out for biology the notion of nature as a lawful system of matter in motion that human reason can explain without recourse to supernatural agencies.

The conundrum faced by Darwin can hardly be overestimated. The strength of the argument from design to demonstrate the role of the Creator had been forcefully set forth by Paley, as well as by other philosophers and theologians. Wherever there is function or design, we look for its author. It was Darwin's greatest accomplishment to show that the complex organization and functionality of living beings can be explained as the result of a natural process—natural selection—without any need to resort to a Creator or other external agent. The origin and adaptations of organisms in their profusion and wondrous variations were thus brought into the realm of science.

Darwin's Theory

Darwin considered natural selection, rather than his demonstration of evolution, his most important discovery, and designated it as “my theory,” a designation he never used when referring to the evolution of organisms. The discovery of natural selection, Darwin's awareness that it was a greatly significant discovery because it was science's answer to Paley's argument from design, and Darwin's designation of natural selection as “my theory” can be traced in Darwin's “Red Notebook” and “Transmutation Notebooks B to E,” which he started in March 1837, not long after returning (on October 2, 1836) from his five-year voyage on the *Beagle*, and completed in late 1839.

Early in the Notebooks, Darwin registers his discovery of natural selection and repeatedly refers to it as “my theory.” From then until his death in 1882, Darwin's life would be dedicated to substantiating natural selection and its companion postulates, mainly the pervasiveness of hereditary variation and the enormous fertility of organisms, which much surpassed the capacity of available resources. He relentlessly pursued observations and performed experiments in order to test the theory and resolve presumptive objections.

The evolution of organisms was commonly accepted by naturalists in the middle decades of the nineteenth century. The distribution of exotic species in South America, in the Galápagos Islands, and elsewhere, and the discovery of fossil remains of long-extinguished animals, confirmed the reality of evolution in Darwin's mind. The intellectual challenge was to explain the origin of distinct species of organisms, how new ones adapted to their environments, that “mystery of mysteries,” as it had been labeled by Darwin's older contemporary, the prominent scientist and philosopher Sir John Herschel (1792–1871).

In his *Autobiography*, Darwin wrote, “The old argument of design in nature, as given by Paley, which formerly seemed to me so conclusive, falls, now that the law of natural selection has been discovered. We can no longer argue that, for instance, the beautiful hinge of a bivalve shell must have been made by an intelligent being, like the hinge of a door by a man.”

Wherever there is function or design, we look for its author. Whenever we see a watch, we know that there is a watchmaker. Similarly, the structures, organs and behaviors of living beings are directly organized to serve certain purposes or functions. The functional design of organisms and their features would therefore seem to argue for the existence of a Designer. Darwin's great accomplishment was to show that the diversity and adaptations of living beings can be explained as the result of natural selection.

Darwin accepted that organisms are “designed” for certain purposes, that is, they are functionally organized. Organisms are adapted to certain ways of life and their parts are adapted to perform certain functions. Fish are adapted to live in water, kidneys are designed to regulate the composition of blood, the human hand is made for grasping. But Darwin went on to provide a natural explanation of the design.

The seemingly purposeful aspects of living beings could now be explained, like the phenomena of the inanimate world, by the methods of science, as the result of natural laws manifested in natural processes.

Darwin's Explanation of Design

Darwin is deservedly given credit for the theory of evolution. The evolution of organisms was commonly accepted by naturalists in the middle decades of the 19th century. In *The Origin of Species*, Darwin accumulated overwhelming evidence demonstrating the evolution of organisms. However, Darwin accomplished something much more important for intellectual history than demonstrating evolution. Indeed, accumulating evidence for common descent with diversification may very well have been a subsidiary objective of Darwin's masterpiece. Darwin's *The Origin of Species* is, first and foremost, a sustained argument to solve the problem of how to account scientifically for the design of organisms. Darwin brings about the evidence for evolution because evolution is a necessary consequence of his theory of design. Darwin's most revolutionary achievement is that he extended the Copernican revolution to the world of living things.

Alfred Russel Wallace

Alfred Russel Wallace (1823–1913) is famously given credit for discovering, independently of Darwin, natural selection as the process accounting for the evolution of species. On June 18, 1858, Darwin wrote to Charles Lyell that he had received by mail a short essay from Wallace such that “if Wallace had my [manuscript] sketch written in [1844] he could not have made a better abstract.” Darwin was thunderstruck.

Wallace's independent discovery of natural selection is remarkable. Wallace, however, was not interested in explaining design, but rather in accounting for the evolution of species, which he saw as a sustained and progressive process, as indicated in his paper's title: “On the Tendency of Varieties to Depart Indefinitely from the Original Type.” Wallace thought that evolution proceeds indefinitely and is progressive. Darwin, on the contrary, did not accept that evolution would necessarily represent progress or advancement, nor did he believe that evolution would always result in morphological change over time; rather, he knew of the existence of “living fossils,” organisms that had remained unchanged for millions of years. For example, “some of the most ancient Silurian animals, as the Nautilus, Lingula, etc., do not differ much from living species.” (We now know that the Silurian geological period lasted from 444 to 416 million years ago.)

In 1858, Darwin was at work on a multivolume treatise, intended to be titled “On Natural Selection.” Wallace's paper stimulated Darwin to write *The Origin of Species*, which would be published the following year. Darwin intended this as an abbreviated version of the much longer book he had intended to write. As I have noted earlier, Darwin's focus, in *The Origin of Species* as elsewhere, was the explanation of design, with evolution playing the subsidiary role of supporting evidence.

Darwin's Origin

The Origin of Species is usually characterized as the most important book ever published about the theory of evolution. This is correct, but not so much because of the numerous observations and facts magisterially gathered by Darwin demonstrating the evolution of organisms, but rather because with his theory of natural selection he advanced an explanation that accounted not only for the evolution of organisms, but also for their adaptations. The Introduction and Chapters I through VIII of *The Origin of Species* explain how natural selection accounts for the adaptations and behaviors of organisms, their “design.” The extended argument starts in Chapter I, where Darwin describes the successful selection of

domestic plants and animals and, with considerable detail, the success of pigeon fanciers seeking exotic “sports.” The success of plant and animal breeders manifests how much selection can accomplish by taking advantage of spontaneous hereditary variations that occur in organisms but happen to fit the breeders’ objectives. A sport (mutation) that first appears in an individual can be multiplied by selective breeding, so that after a few generations that sport becomes fixed in a breed, or “race.” The familiar breeds of dogs, cattle, chickens, and food plants have been obtained by this process of selection practiced by people with particular objectives.

The ensuing chapters (II–VIII) of *The Origin of Species* extend the argument to variations propagated by natural selection for the benefit of the organisms themselves, rather than by artificial selection of traits desired by humans. As a consequence of natural selection, organisms exhibit design, that is, exhibit adaptive organs and functions. The design of organisms as they exist in nature, however, is not “intelligent design,” imposed by God as a Supreme Engineer or by humans; rather, it is the result of a natural process of selection, promoting the adaptation of organisms to their environments. This is how natural selection works: Individuals that have beneficial variations, that is, variations that improve their probability of survival and reproduction, leave more descendants than individuals of the same species that have less beneficial variations. The beneficial variations will consequently increase in frequency over the generations; less beneficial or harmful variations will be eliminated from the species. Eventually, all individuals of the species will have the beneficial features; new features will arise over eons of time.

Organisms exhibit complex design, but this design does not exhibit, in current language, “irreducible complexity,” emerging all of a sudden in full bloom. Rather, according to Darwin’s theory of natural selection, the design has arisen gradually and cumulatively, step by step, promoted by the reproductive success of individuals with incrementally more adaptive elaborations.

It follows from Darwin’s explanation of adaptation that evolution must necessarily occur as a consequence of organisms becoming adapted to different environments in different localities, and to the ever-changing conditions of the environment over time; and as hereditary variations become available at a particular time that improve, in that place and at that time, the organisms’ chances of survival and reproduction. *The Origin of Species*’ evidence for biological evolution is central to Darwin’s explanation of design, because this explanation implies that biological evolution occurs, which Darwin therefore seeks to demonstrate in most of the remainder of the book (chapters IX–XIII. In the sixth edition of *The Origin of Species*, these are chapters X–XIV, because Darwin had added a new chapter VII: “Miscellaneous objections to the theory of natural selection.”).

In the concluding Chapter XIV of *Origin*, Darwin returns to the dominant theme of adaptation and design. In an eloquent final paragraph, Darwin asserts the “grandeur” of his vision: “It is interesting to contemplate an entangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these *elaborately constructed* forms, *so different* from each other, and dependent on each other *in so complex a manner*, have all been produced by laws acting around us.... Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved” (emphasis added).

Adaptation and Evolution

Darwin’s *The Origin of Species* addresses the issue of how to account for the adaptive configuration of organisms and their parts, which are so obviously designed to fulfill certain functions. Darwin argues that hereditary adaptive variations (“variations useful in some way to each being”)

occasionally appear, and that these are likely to increase the reproductive chances of their carriers. The success of pigeon fanciers and animal breeders clearly shows the occasional occurrence of useful hereditary variations. In nature, over the generations, Darwin's argument continues, favorable variations will be preserved, multiplied, and conjoined; injurious ones will be eliminated. Evolution affects all aspects of an organism's life—morphology (form and structure), physiology (function), behavior, and ecology (interaction with the environment). Underlying these changes are changes in the hereditary materials. Hence, in genetic terms, evolution consists of changes in the organisms' hereditary makeup. Darwin formulated natural selection primarily as differential survival. The modern understanding of the principle of natural selection is formulated in genetic and statistical terms as differential reproduction. Natural selection simply implies that some genes and genetic combinations are transmitted to the following generations more frequently than their alternates. Favored genes will become more common in every subsequent generation, and their alternates less common. Natural selection is a statistical bias in the relative rate of reproduction of alternative genes.

Evolution can be seen as a two-step process. First, hereditary variation arises by mutation; second, selection occurs by which useful variations increase in frequency and those that are less useful or injurious are eliminated over the generations. "Useful" and "injurious" are terms used by Darwin in his definition of natural selection. The significant point is that individuals having useful variations "would have the best chance of surviving and procreating their kind." As a consequence, useful variations increase in frequency over the generations, at the expense of those that are less useful or injurious.

Natural selection is much more than a "purifying" process, for it is able to generate novelty by increasing the probability of otherwise extremely improbable genetic combinations. Natural selection in combination with mutation becomes, in this respect, a creative process. Moreover, it is a process that has been occurring for many millions of years, in many different evolutionary lineages and a multitude of species, each consisting of a large number of individuals. Evolution by mutation and natural selection has produced the enormous diversity of the living world with its wondrous adaptations. Several hundred million generations separate modern animals from the early animals of the Cambrian geological period (542 million years ago). The number of mutations that can be tested, and those eventually selected, in millions of individual animals over millions of generations is difficult for a human mind to fathom, but we can readily understand that the accumulation of millions of small, functionally advantageous changes could yield remarkably complex and adaptive organs, such as the eye.

Natural selection does not operate as a sieve that retains the rarely arising useful genes and lets go the more frequently arising harmful mutants; at least, not only. Natural selection acts in the filtering way of a sieve, but it is much more than a purely negative process, for it is able to generate novelty by increasing the probability of otherwise extremely improbable genetic combinations. Natural selection is thus a creative process. It does not "create" the entities (mutations) upon which it operates, but it produces adaptive (functional) genetic combinations that could not have existed otherwise.

Darwin's Critics

Critics have sometimes alleged as evidence against Darwin's theory of evolution examples showing that random processes cannot yield meaningful, organized outcomes. It is thus pointed out that a series of monkeys randomly striking letters on a typewriter would never write *The Origin of Species*, even if we allow for millions of years and many generations of monkeys pounding at typewriters. This criticism would be valid if evolution would depend only on random processes. But natural selection is a non-random process that promotes adaptation by selecting combinations that "make sense," i.e., that are useful to the organisms. The analogy of the monkeys would be more appropriate if a process existed by which, first, meaningful words would be chosen every time they appeared on the typewriter; and then there would also be typewriters with previously selected words rather than just letters in the keys, and again there would be a process to select meaningful sentences every time they appeared in this second typewriter. If every time words such as "the,"

“origin,” “species,” and so on, appeared in the first kind of typewriter, they each became a key in the second kind of typewriter, meaningful sentences would occasionally be produced in this second typewriter. If such sentences became incorporated into keys of a third type of typewriter, in which meaningful paragraphs were selected whenever they appeared, it is clear that pages and even chapters “making sense” would eventually be produced. The end product would be an “irreducibly complex” text.

We need not carry the analogy too far, since the analogy is not fully satisfactory, but the point is clear. Evolution is not the outcome of purely random processes, but rather there is a “selecting” process, which picks up adaptive combinations because these reproduce more effectively and thus become established in populations. These adaptive combinations constitute, in turn, new levels of organization upon which the mutation (random) plus selection (non-random or directional) process again operates. The complexity of organization of animals and plants is “irreducible” to simpler components in one or very few steps, but not through the millions and millions of generations and the multiplicity of steps and levels made possible by eons of time.

A critical point is that evolution by natural selection is an incremental process, operating over eons of time and yielding organisms better able to survive and reproduce than others, which typically differ from one another at any one time only in small ways; for example, the difference between producing more or fewer progeny or between having or lacking an enzyme able to catalyze the synthesis of one particular amino acid. Notice also that increased complexity is not a necessary outcome of natural selection, although complexity increases from time to time in some lineages of descent, so that, although rare, these lineages are very conspicuous over time’s eons. That is, increased complexity is not a necessary consequence of evolution by natural selection, but rather emerges occasionally. The longest living organisms on Earth are the microscopic bacteria, which have continuously existed on our planet for three and a half billion years and yet exhibit no greater complexity than their old time ancestors. More complex organisms came about much later, without the elimination of their simpler relatives. For example, the primates appeared on earth some fifty million years ago and our species, *Homo sapiens*, came about two hundred thousand years ago.

Step-by-Step

Individuals of a given species differ from one another at any one time only in small ways; for example, the difference between bacteria that have or lack an enzyme able to synthesize the sugar lactose or between moths that have light or dark wings. These differences typically involve one or only a few genes, but they can make the difference between survival or death, as in the evolution of resistance to DDT in disease-transmitting mosquitoes or to antibiotics in people. Consider a different sort of example. Some pocket mice (*Chaetodipus intermedius*) live in rocky outcrops in Arizona. Light, sandy-colored mice are found in light-colored habitats, whereas dark (melanic) mice prevail in dark rocks formed from ancient flows of basaltic lava. The match between background and fur color protects the mice from a vian and mammal predators that hunt guided largely by vision. Mutations in one single gene (coding for the melanocortin-1-receptor, represented as *MC1R*) account for the difference between light and dark pelage (Nachman et al., 2003).

Adaptations that involve complex structures, functions, or behaviors involve numerous genes. Many familiar mammals, but not marsupials, have a placenta. Marsupials include the familiar kangaroo and other mammals native primarily to Australia and South America. Dogs, cats, mice, donkeys, and primates are placental. The placenta makes it possible to extend the time the developing embryo is kept inside the mother and thus make the newborn better prepared for independent survival. However, the placenta requires complex adaptations, such as the suppression of harmful immune interactions between mother and embryo, delivery of suitable nutrients and oxygen to the embryo, and the disposal of embryonic wastes. The mammalian placenta evolved more than 100 million years ago and proved a

successful adaptation, contributing to the explosive diversification of placental mammals in the Old World and North America.

The placenta also has evolved in some fish groups, such as *Poeciliopsis*. Some *Poeciliopsis* species hatch eggs. The females supply the yolk in the egg, which furnishes nutrients to the developing embryo (as in chicken). Other *Poeciliopsis* species, however, have evolved a placenta through which the mother provides nutrients to the developing embryo. Molecular biology has made possible the reconstruction of the evolutionary history of *Poeciliopsis* species. A surprising result is that the placenta evolved independently three times in this fish group. The required complex adaptations accumulated in each case in less than 750,000 years (Reznick et al., 2002; Avise, 2006).

Natural selection produces combinations of genes that would seem highly improbable because natural selection proceeds stepwise over long periods of time. Consider the evolution of the eye in humans and other vertebrates. Perception of light, and later vision, were important for the survival and reproductive success of their ancestors, because sunlight is a predominant feature of the environment. Accordingly, natural selection favored genes and gene combinations that increased the functional efficiency of the eye. Such mutations gradually accumulated, eventually leading to the highly complex and efficient vertebrate eye (Ayala, 2007).

Chance and Necessity

Engineers have a preconception of what the design of a contrivance of structure is supposed to achieve, and will select suitable materials and arrange them in a preconceived manner so that it fulfills the intended function. On the contrary, natural selection has no foresight, nor does it operate according to some preconceived plan. Rather it is a purely natural process resulting from the interacting properties of physicochemical and biological entities. Natural selection is simply a consequence of the differential multiplication of living beings, as pointed out. It has some appearance of purposefulness because it is conditioned by the environment: which organisms reproduce more effectively depends on what variations they possess that are useful in the place and at the time where the organisms live. But natural selection does not anticipate the environments of the future; drastic environmental changes may be insuperable to organisms that were previously thriving. Species extinction is the common outcome of the evolutionary process. The species existing today represent the balance between the origin of new species and their eventual extinction. More than 99 percent of all species that ever lived on Earth have become extinct without issue. These may have been more than one billion species; the available inventory of living species has identified and described less than two million out of some ten million estimated to be now in existence.

The team of typing monkeys is a bad analogy of evolution by natural selection, because it assumes that there is “somebody” who selects letter combinations and word combinations that make sense. In evolution there is no one selecting adaptive combinations. These select themselves because they multiply more effectively than less adaptive ones.

The process of natural selection can explain the adaptive organization of organisms, as well as their diversity and evolution, as a consequence of their adaptation to the multifarious and ever changing conditions of life. The fossil record shows that life has evolved in a haphazard fashion. The radiations, expansions, relays of one form by another, occasional but irregular trends, and the ever-present extinctions, are best explained by natural selection of organisms subject to the vagaries of genetic mutation and environmental challenge. The scientific account of these events does not necessitate recourse to a preordained plan, whether imprinted from without by an omniscient and all-powerful Designer, or resulting from some immanent force driving the process towards definite outcomes. Biological evolution differs from a painting or an artifact in that it is not the outcome of preconceived design.

Natural selection accounts for the “design” of organisms, because adaptive variations tend to increase the probability of survival and reproduction of their carriers at the expense of maladaptive, or less

adaptive, variations. The arguments of Paley against the incredible improbability of chance accounts of the adaptations of organisms are well taken as far as they go. But neither Paley nor any other author before Darwin was able to discern that there is a natural process (namely, natural selection) that is not random, but rather is oriented and able to generate order or “create.” The traits that organisms acquire in their evolutionary histories are not fortuitous but determined by their functional utility to the organisms, “designed” as it were to serve their life needs.

Chance is, nevertheless, an integral part of the evolutionary process. The mutations that yield the hereditary variations available to natural selection arise at random, independently of whether they are beneficial or harmful to their carriers. But this random process (as well as others that come to play in the great theatre of life) is counteracted by natural selection, which preserves and multiplies what is useful and eliminates the harmful. Without hereditary mutation, evolution could not happen because there would be no variations that could be differentially conveyed from one to another generation. But without natural selection, the mutation process would yield disorganization and extinction because most mutations are disadvantageous. Mutation and selection have jointly driven the marvelous process that starting from microscopic organisms has yielded orchids, birds, and humans.

The theory of evolution conveys chance and necessity jointly intricately in the stuff of life; randomness and determinism interlocked in a natural process that has spurred the most complex, diverse, and beautiful entities in the universe: the organisms that populate the earth, including humans who think and love, endowed with free will and creative powers, and able to analyze the process of evolution itself that brought them into existence. This is Darwin's fundamental discovery, that there is a process that is creative though not conscious, a process that creates design without necessitating a designer.

Coda

Darwin completed the Copernican Revolution. The most important significance in the history of ideas of the Copernican and the Darwinian revolutions is that they jointly brought in the emergence of science, as a way of explaining all phenomena of the natural world. Science had, thus, come of age and, with science, modern technology, which overwhelmingly is the dominant feature of the world in which we live.

References

- Avise, J. C. (2006) *Evolutionary Pathways in Nature. A Phylogenetic Approach* (Cambridge University Press, Cambridge, UK).
- Ayala, F. J. (2007) Darwin's greatest discovery: Design without designer. *Proc. Natl. Acad. Sci. USA* **104**, 8567-8573.
- Nachman, M. W., Hoekstra, H. E., & D'Agostino, S. L. (2003) The genetic basis of adaptive melanism in pocket mice. *Proc. Natl. Acad. Sci. USA* **100**, 5268–5273.
- Reznick, D. N., Mateos, M., & Springer, M. S. (2002) Independent Origins and Rapid Evolution of the Placenta in the Fish Genus *Poeciliopsis*. *Science* **298**, 1018–1020.