



Brilliant Blunders



FROM DARWIN TO EINSTEIN

Colossal Mistakes *by* Great Scientists That Changed
Our Understanding *of* Life *and the* Universe

MARIO LIVIO



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BRILLIANT BLUNDERS

*From Darwin to Einstein—
Colossal Mistakes by Great Scientists
That Changed Our Understanding of
Life and the Universe*

Mario Livio

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PREFACE

Throughout the entire period that I have been working on this book, every few weeks someone would ask me what my book was about. I developed a standard answer: “It is about blunders, and it is *not* an autobiography!” This would get a few laughs and the occasional approbation “What an interesting idea.” My objective was simple: to correct the impression that scientific breakthroughs are purely success stories. In fact, nothing could be further from the truth. Not only is the road to triumph paved with blunders, but the bigger the prize, the bigger the potential blunder.

Immanuel Kant, the great German philosopher, wrote famously, “Two things fill the mind with ever new and increasing admiration and awe, the more often and steadily we reflect upon them: the *starry heavens above me and the moral law within me.*” In the time that has passed since the publication of his *The Critique of Practical Reason* (1788), we have made impressive progress in understanding the former; considerably less so, in my humble opinion, in elucidating the latter. It is apparently much more difficult to make life or mind comprehensible to itself. Nevertheless, the life sciences in general—and the research into the operation of the human brain in particular—are truly picking up speed. So it may not be altogether inconceivable after all that one day we will even fully understand why evolution has concocted a sentient species.

While this book is about some of the remarkable endeavors to figure out life and the cosmos, it is more concerned with the journey than with the destination. I tried to concentrate on the thought process and the obstacles on the way to discovery rather than on the achievements themselves.

Many people have helped me along the way, some maybe even unknowingly. I am grateful to Steve Mojzsis and Reika Yokochi for discussions on topics related to geology. I thank Jack Dunitz, Horace Freeland Judson, Matt Meselson, Evangelos Moudrianakis, Alex Rich, Jack Szostak, and Jim Watson for conversations on chemistry, biology, and specifically on Linus Pauling’s work. I am indebted to Peter Eggleton, John Faulkner, Geoffrey Hoyle, Jayant Narlikar, and Lord Martin Rees for helpful discussions on astrophysics and cosmology, and on Fred Hoyle’s work.

I would also like to express my gratitude to all the people who provided me with invaluable materials for this book, and in particular to: Adam Perkins and the staff of the Cambridge University Library, for materials on Darwin and on Lord Kelvin; Mark Hurn of the Institute of Astronomy, Cambridge, for materials on Lord Kelvin and on Fred Hoyle; Amanda Smith of the Institute of Astronomy, Cambridge, for materials on Fred Hoyle and for processing photos related to Watson and Crick; Clifford Meade and Chris Petersen of the Special Collections Department of Oregon State University, for materials on Linus Pauling; Loma Karklins of the Caltech Archives, for material on Linus Pauling; Sarah Brooks from the Nature Publishing Group, for material on

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Finally, I thank my agent, Susan Rabiner, for her relentless encouragement; my editor, Bob Bender, for his thoughtful comments; Loretta Denner, for her assistance during copyediting; and Johanna Li, for her dedication during the entire production of this book.

CHAPTER 1

MISTAKES AND BLUNDERS

Great blunders are often made, like large ropes, of a multitude of fibres. Take the cable thread by thread, take separately all the little determining motives, you break them one after another, and you say: that is all. Wind them and twist them together they become an enormity.

—VICTOR HUGO, *LES MISÉRABLES*

When the mercurial Bobby Fischer, perhaps the most famous chess player in the history of the game, finally showed up in Reykjavik, Iceland, in the summer of 1972 for his world championship match against Boris Spassky, the anticipation in the chess world was so thick you could cut it with a chain saw. Even people who had never shown any interest in chess before were holding their breath for what had been dubbed “the Match of the Century.” Yet in the twenty-ninth move of the very first game, in a position that appeared to be leading to a dead draw, Fischer chose a move that even amateur chess players would have rejected instinctively as a mistake. This may have been a typical manifestation of what is known as “chess blindness”—an error that in the chess literature is denoted by “??”—and would have disgraced a five-year-old in a local chess club. Particularly astonishing was the fact that the mistake was committed by a man who’d smashed his way to the match with the Russian Spassky after an extraordinary sequence of twenty successive wins against the world’s top players. (In most world-class competitions, there are easily as many draws as outright victories.) Is this type of “blindness” something that happens only in chess? Or are other intellectual enterprises also prone to similarly surprising mistakes?

Oscar Wilde once wrote, “Experience is the name everyone gives to their mistakes.” Indeed, we all make numerous mistakes in our everyday lives. We lock our keys inside the car, we invest in the wrong stock (or sometimes in the right stock, but at the wrong time), we grossly overestimate our ability to multitask, and we often blame the absolutely wrong causes for our misfortunes. This misattribution, by the way, is one of the reasons that we rarely actually learn from our mistakes. In all cases, of course, we realize that these were mistakes only after we have made them—hence, Wilde’s definition of “experience.” Moreover, we are much better at judging other people than at analyzing ourselves. As psychologist and Nobel laureate in economics Daniel Kahneman has put it, “I am not very optimistic about people’s ability to change the way they think, but I am fairly optimistic about their ability to detect the mistakes of others.”

Even attentively and carefully constructed processes, such as those involved in the criminal justice system, fail occasionally—sometimes heartbreakingly so. Ray Krone of Phoenix, Arizona, for instance, spent more than ten years behind bars and faced the death penalty after having been convicted *twice* of a brutal murder he did not commit.

He was eventually fully exonerated (and the real killer implicated) by DNA evidence.

The focus of this book, however, is not on such mistakes, no matter how grave they may be: it is on major *scientific blunders*. By “scientific blunders,” I mean particularly serious conceptual errors that could potentially jeopardize entire theories and game plans, or could, in principle at least, hold back the progress of science.

Human history teems with stories of momentous blunders in a wide range of disciplines. Some of these consequential errors go all the way back to the Scriptures, or to Greek mythology. In the book of Genesis, for instance, the very first act of Eve—the biblical mother of all living humans—was to yield to the crafty serpent and to eat the forbidden fruit. This monumental lapse in judgment led to no less than the banishment of Adam and Eve from the Garden of Eden, and—at least according to the thirteenth-century theologian Thomas Aquinas—even to humans being eternally denied access to absolute truth. In the Greek mythology, Paris’s misguided elopement with the beautiful Helen, the wife of the king of Sparta, brought about the total destruction of the city of Troy. But these examples don’t even begin to scratch the surface. Throughout history, neither renowned military commanders nor famous philosophers or groundbreaking thinkers were immune to serious blunders. During World War II, the German field marshal Fedor von Bock foolishly repeated Napoléon’s ill-fated attack on Russia in 1812. Both officers failed to appreciate the insurmountable powers of “General Winter”—the long and harsh Russian winter for which they were woefully unprepared. The British historian A. J. P. Taylor once summarized Napoléon’s calamities this way: “Like most of those who study history, he [Napoléon] learned from the mistakes of the past how to make new ones.”

In the philosophical arena, the great Aristotle’s erroneous ideas on physics (such as his belief that all bodies move toward their “natural” place) fell just as wide off the mark as did Karl Marx’s awry predictions on the imminent collapse of capitalism. Similarly, many of Sigmund Freud’s psychoanalytic speculations, be it on the “death instinct”—a supposed impulse to return to a pre-life state of quietude—or on the role of an infantile Oedipus complex in the neuroses of women, have been found to be pathetically amiss, to put it mildly.

You may think, OK, people made mistakes, but surely, when it comes to some of the greatest *scientists* of the past two centuries—such as the twice Nobel laureate Linus Pauling or the formidable Albert Einstein—they were correct at least in those theories for which they are best known, right? After all, hasn’t the intellectual glory of modern times been precisely in the establishment of science as an empirical discipline, and of error-proof mathematics as the “language” of fundamental science? Were, then, the theories of these illustrious minds and of other comparable thinkers truly free of serious blunders? Absolutely not!

The purpose of this book is to present in detail some of the surprising blunders of a few genuinely towering scientists, and to follow the unexpected consequences of those blunders. At the same time, my goal is also to attempt to analyze the possible causes for these blunders and, to the extent possible, to uncover the fascinating relations between those blunders and features or limitations of the human mind. Ultimately, however, I hope to demonstrate that the road to discovery and innovation can be constructed even through the unlikely path of blunders.

As we shall see, the delicate threads of evolution interweave all the particular

blunders that I have selected to explore in detail in this book. That is, these are serious blunders related to the theories of the evolution of life on Earth, the evolution of the Earth itself, and the evolution of our universe as a whole.

Blunders of Evolution and Evolution of Blunders

One of the definitions of the word “evolution” in the *Oxford English Dictionary* reads: “The development or growth, according to its inherent tendencies, of anything that may be compared to a living organism . . . Also, the rise or origination of anything by natural development, as distinguished from its production by a specific act.” This was not the original meaning of the word. In Latin, *evolutio* referred to the unrolling and reading of a book that existed in the form of a scroll. Even when the word started to gain popularity in biology, it was used initially only to describe the growth of an embryo. The first utilization of the word “evolution” in the context of the genesis of species can be found in the writings of the eighteenth-century Swiss naturalist Charles Bonnet, who argued that God had pre-organized the birth of new species in the germs of the very first life-forms he created.

In the course of the twentieth century, the word “evolution” has become so intimately associated with Darwin’s name that you may find it hard to believe that in the first, 1859 edition of his masterwork, *On the Origin of Species*, Darwin does not mention the word “evolution” as such even once! Still, the very last word of *The Origin* is “evolved.”

In the time that has passed since the publication of *The Origin*, evolution has assumed the broader meaning of the definition above, and today we may speak of the evolution of such diverse things as the English language, fashion, music, and opinions, as well as of sociocultural evolution, software evolution, and so on. (Check out how many web pages are devoted just to “the evolution of the hipster.”) President Woodrow Wilson emphasized once that the correct way to understand the Constitution of the United States was through evolution: “Government is not a machine, but a living thing . . . It is accountable to Darwin, not to Newton.”

My focus on the evolution of life, of the Earth, and of the universe should not be taken to mean that these are the only scientific arenas in which blunders have been committed. Rather, I have chosen these particular topics for two main reasons. First, I wanted to critically review the blunders made by some of the scholars that appear on almost everybody’s short list of great minds. The blunders of such luminaries, even if of a past century, are extremely relevant to questions scientists (and, indeed, people in general) face today. As I hope to show, the analysis of these blunders forms a living body of knowledge that is not only captivating in its own right but also can be used to guide actions in domains ranging from scientific practices to ethical behavior. The second reason is simple: The topics of the evolution of life, of the Earth, and of the universe have intrigued humans—not just scientists—since the dawn of civilization, and have inspired tireless quests to uncover our origins and our past. The human intellectual curiosity about these subjects has been at least partially at the root of religious beliefs, of the mythical stories of creation, and of philosophical inquiries. At

the same time, the more empirical, evidence-based side of this curiosity has ultimately given birth to science. The progress that humankind has made toward deciphering some of the complex processes involved in the evolution of life, the Earth, and the cosmos is nothing short of miraculous. Hard to believe, but we think that we can trace cosmic evolution back to when our universe was only a fraction of a second old. Even so, many questions remain unanswered, and the topic of evolution continues to be a hot-button issue even today.

It took me quite a while to decide which major scientists to include in this journey through deep intellectual and practical waters, but I eventually converged on the blunders of five individuals. My list of surprising “blunderers” includes the celebrated naturalist Charles Darwin; the physicist Lord Kelvin (after whom a temperature scale is named); Linus Pauling, one of the most influential chemists in history; the famous English astrophysicist and cosmologist Fred Hoyle; and Albert Einstein, who needs no introduction. In each case, I will address the central theme from two rather different—but complementary—perspectives. On one hand, this will be a book about some of the theories of these great savants and the fascinating relations among those theories, viewed in part from the unusual vantage point of their weaknesses and sometimes even failures. On the other, I will scrutinize briefly the various types of blunders and attempt to identify their psychological (or, if possible, neuroscientific) causes. As we shall see, blunders are not born equal, and the blunders of the five scientists on my list are rather different in nature. Darwin’s blunder was in not realizing the full implications of a particular hypothesis. Kelvin blundered by ignoring unforeseen possibilities. Pauling’s blunder was the result of overconfidence bred by previous success. Hoyle erred in his obstinate advocacy of dissent from mainstream science. Einstein failed because of a misguided sense of what constitutes aesthetic simplicity. The main point, however, is that along the way, we shall discover that blunders are not only inevitable but also an essential part of progress in science. The development of science is not a direct march to the truth. If not for false starts and blind alleys, scientists would be traveling for too long down too many wrong paths. The blunders described in this book have all, in one way or another, acted as catalysts for impressive breakthroughs—hence, their description as “brilliant blunders.” They served as the agents that lifted the fog through which science was progressing, in its usual succession of small steps occasionally punctuated by quantum leaps.

I have organized the book in such a way that for each scientist, I first present the *essence* of some of the theories for which this individual is best known. These are very concise summaries intended to provide an introduction to the ideas of these masters and an appropriate context for the blunders, rather than to represent comprehensive descriptions of the respective theories. I have also chosen to concentrate only on *one* major blunder in each case instead of reviewing a laundry list of every possible mistake that these pundits may have committed during their long careers. I shall start with the man about whom the *New York Times* correctly wrote in its obituary notice (published on April 21, 1882) that he “has been read much, but talked about more.”

CHAPTER 2

THE ORIGIN

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.

—CHARLES DARWIN

The most striking thing about life on Earth is its prodigious diversity. Take a casual stroll on a spring afternoon; you are likely to encounter several kinds of birds, many insects, perhaps a squirrel, a few people (some may be walking their dogs), and a large variety of plants. Even just in terms of the properties that are the easiest to discern, organisms on Earth differ in size, color, shape, habitat, food, and capabilities. On one hand, there are bacteria that are less than one hundred thousandth of an inch in length, and on the other, there are blue whales more than 100 feet long. Among the thousands of known species of the marine mollusks known as nudibranchs, there are many that are plain looking, while others have some of the most sumptuous colors exhibited by any creature on Earth. Birds can fly at astonishing heights in the atmosphere: On November 29, 1975, a large vulture was sucked into a jet engine at a height of 37,900 feet above the Ivory Coast in West Africa. Other birds, such as the migrating bar-headed geese and the whooper swans, regularly fly higher than 25,000 feet. Not to be outdone, ocean creatures achieve similar records in depth. On January 23, 1960, the record-setting explorer Jacques Piccard and Lieutenant Don Walsh of the US Navy descended slowly in a special probe called a bathyscaphe to the deepest point at the bottom of the Pacific Ocean—the Mariana Trench—south of Guam. When they finally touched down at the record depth of about 35,800 feet, they were amazed to discover around them a new type of bottom-dwelling shrimp that did not seem to be bothered by the ambient pressure of some 17,000 pounds per square inch. On March 26, 2012, film director James Cameron reached the deepest point in the Mariana Trench in a specially designed submersible. He described it as a gelatinous landscape as desolate as the Moon. But he also reported seeing tiny shrimp-like critters no bigger than an inch in length.

Nobody knows for sure how many species are currently living on Earth. A recent catalogue, published in September 2009, formally describes and gives official names to about 1.9 million species. However, since most living species are microorganisms or very tiny invertebrates, many of which are very difficult to access, most estimates of the total number of species are little more than educated guesses. Generally, estimates range from 5 million to about 100 million different species, although a figure of 5 to 10 million is considered probable. (The most recent study predicts about 8.7

million.) This large uncertainty is not at all surprising once we realize that just one tablespoon of dirt beneath our feet could harbor many thousands of bacterial species.

The second amazing thing characterizing life on Earth, besides its diversity, is the incredible degree of *adaptation* that both plants and animals exhibit. From the anteater's tubelike snout, or the chameleon's long and fast-moving tongue (capable of hitting its prey in about 30 thousandths of a second!), to the woodpecker's powerful, characteristically shaped beak, and the lens of the eye of a fish, living organisms appear to be perfectly fashioned for the requirements that life imposes on them. Not only are bees constructed so that they can comfortably fit into the flowering plants from which they extract nectar, but the plants themselves exploit the visits of these bees for their own propagation by polluting the bees' bodies and legs with pollen, which is then transported to other flowers.

There are many different biological species that live in an astonishing "scratch my back and I will scratch yours" interaction, or *symbiosis*. The ocellaris clown fish, for instance, dwells among the stinging tentacles of the Ritteri sea anemone. The tentacles protect the clown fish from its predators, and the fish returns the favor by shielding the anemone from other fish that feed on anemones. The special mucus on the clown fish's body safeguards it from the poisonous tentacles of its host, further perfecting this harmonious adaptation. Partnerships have even developed between bacteria and animals. For example, at seafloor hydrothermal vents, mussels bathed in hydrogen-rich fluids were found to thrive by both supporting and harvesting an internal population of hydrogen-consuming bacteria. Similarly, a bacterium from the genus *Rickettsia* was found to ensure survival advantages for the sweet potato whiteflies—and thereby for itself.

Parenthetically, one quite popular example of an astonishing symbiotic relationship is probably no more than a myth. Many texts describe the reciprocation between the Nile crocodile and a small bird known as the Egyptian plover. According to Greek philosopher Aristotle, when the crocodile yawns, the little bird "flies into its mouth and cleans his teeth"—with the plover thereby getting its food—while the crocodile "gets ease and comfort." A similar description appears also in the influential *Natural History* by the first-century natural philosopher Pliny the Elder. However, there are absolutely no accounts of this symbiosis in the modern scientific literature, nor is there any photographic record that documents such a behavior. Maybe we shouldn't be too surprised, given the rather questionable record of Pliny the Elder: Many of his scientific claims turned out to be false!

The prolific diversity, coupled with the intricate fitting together and adaptation of a wondrous wealth of life-forms, convinced many natural theologians, from Thomas Aquinas in the thirteenth century to William Paley in the eighteenth, that life on Earth required the crafting hand of a supreme architect. Such ideas appeared even as early as the first century BCE. The famous Roman orator Marcus Tullius Cicero argued that the natural world had to stem from some divine "reason":

If all the parts of the universe have been so appointed that they could neither be better adapted for use nor be made more beautiful in appearance . . . If, then, nature's attainments transcend those achieved by human design, and if human skill achieves nothing without the application of reason, we must grant that nature

too is not devoid of reason.

Cicero was also the first to invoke the clock-maker metaphor that later became the touchstone argument in favor of an “intelligent designer.” In Cicero’s words:

It can surely not be right to acknowledge as a work of art a statue or a painted picture, or to be convinced from distant observations of a ship’s course that its progress is controlled by reason and human skills or upon examination of the design of a sundial or a water-clock to appreciate that calculation of the time of day is made by skill and not by chance, yet none the less to consider that the universe is devoid of purpose and reason, though it embraces those very skills, and the craftsmen who wield them, and all else beside.

This was precisely the line of reasoning adopted by William Paley almost two millennia later: A contrivance implies a contriver, just as a design implies a designer. An intricate watch, Paley contended, attests to the existence of a watchmaker. Therefore, shouldn’t we conclude the same about something as exquisite as life? After all, “Every indication of contrivance, every manifestation of design, which existed in the watch, exists in the works of nature; with the difference, on the side of nature, of being greater and more, and that in a degree which exceeds all computation.” This fervent pleading for the imperative need for a “designer” (since the only possible but unacceptable alternative was considered to be fortuitousness or chance) convinced many natural philosophers until roughly the beginning of the nineteenth century.

Implicit in the design argument was yet another dogma: Species were believed to be absolutely *immutable*. The idea of eternal existence had its roots in a long chain of convictions about other entities that were considered enduring and unchanging. In the Aristotelian tradition, for instance, the sphere of the fixed stars was assumed to be totally inviolable. Only in Galileo’s time was this particular notion completely shattered with the discovery of “new” stars (which were actually *supernovae*—exploding old stars). The impressive advances in physics and chemistry during the seventeenth and eighteenth centuries did point out, however, that some essences were indeed more basic and more permanent than others, and that a few were almost timeless for many practical purposes. For example, it was realized that chemical elements such as oxygen and carbon were constant (at least throughout human history) in their basic properties—the oxygen breathed by Julius Caesar was identical to that exhaled by Isaac Newton. Similarly, the laws of motion and of gravity formulated by Newton applied everywhere, from falling apples to the orbits of planets, and appeared to be positively unchangeable. However, in the absence of any clear guidelines as to how to determine which natural quantities or concepts were genuinely fundamental and which were not (in spite of some valiant efforts by empiricist philosophers such as John Locke, George Berkeley, and David Hume), many of the eighteenth-century naturalists opted to simply adopt the ancient Greek view of ideal, unchanged species.

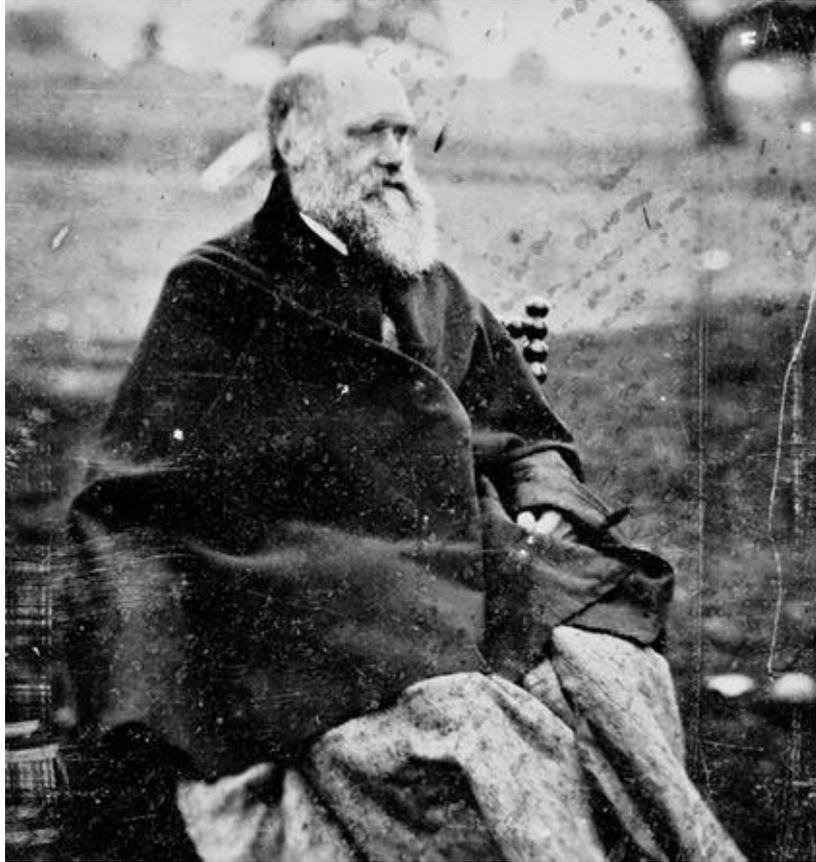


Figure 1

These were the prevailing tides and currents of thought about life, until one man had the chutzpah, the vision, and the deep insights to weave together a huge set of separate clues into one magnificent tapestry. This man was Charles Darwin ([figure 1](#) shows him late in life), and his grand unified conception has become humankind's most inspiring nonmathematical theory. Darwin has literally transformed the ideas on life on Earth from a myth into a science.

Revolution

The first edition of Darwin's book *On the Origin of Species* was published on November 24, 1859, in London, and biology was changed forever on that day. (Figure 2 shows the title page of the first edition; Darwin referred to it as "my child" upon publication.) Before we examine the central arguments of *The Origin*, however, it is important to understand what is *not* discussed in that book. Darwin does not say even one word either about the actual *origin* of life or about the *evolution* of the universe as a whole. Furthermore, contrary to some popular beliefs, he also does not discuss at all the evolution of humans, except in one prophetic, optimistic paragraph near the end of the book, where he says, "In the distant future I see open fields for more important researches. Psychology will be based on a new foundation, that of the necessary acquirement of each mental power and capacity by graduation. Light will be thrown on the origin of man and his history." Only in a later book, *The Descent of Man and*

Selection in Relation to Sex, which was published about a dozen years after *The Origin*, did Darwin decide to make it clear that he believed that his ideas on evolution should also apply to humans. He was actually much more specific than that, concluding that humans were the natural descendants of apelike creatures that probably lived in trees in the “Old World” (Africa):

We thus learn that man is descended from a hairy, tailed quadruped, probably arboreal in its habits and an inhabitant of the Old World. This creature, if its whole structure had been examined by a naturalist, would have been classed among the Quadrumana [primates with four hands, such as apes], as surely as the still more ancient progenitor of the Old and New World monkeys.

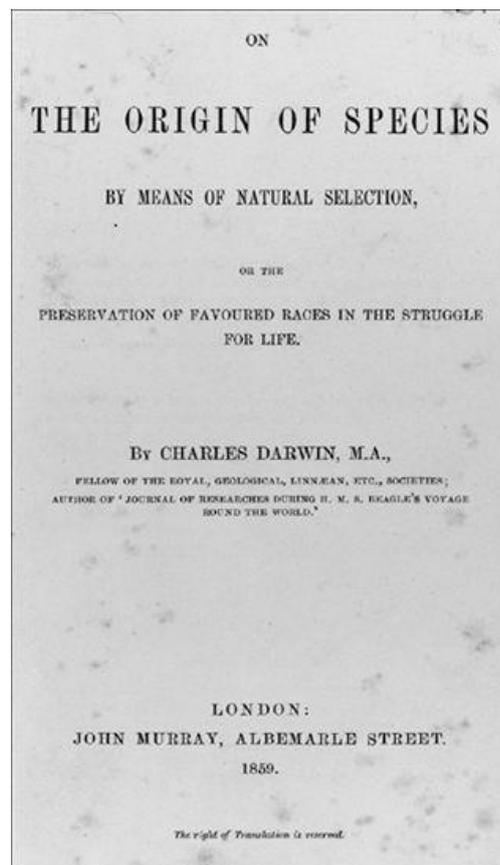


Figure 2

Most of the intellectual heavy lifting on evolution, however, had already been achieved in *The Origin*. In one blow, Darwin disposed of the notion of design, dispelled the idea that species are eternal and immutable, and proposed a mechanism by which adaptation and diversity could be accomplished.

In simple terms, Darwin's theory consists of four main pillars that are supported by one remarkable mechanism. The pillars are: *evolution*, *gradualism*, *common descent*, and *speciation*. The crucial mechanism that drives it all and glues the different elements into cooperation is *natural selection*, which, we know today, is supplemented to some degree by a few other vehicles of evolutionary change, some of which could not have been known to Darwin.

Here is a very succinct account of these distinct components of Darwin's theory.

The description will mostly trace Darwin's own ideas rather than updated, modernized versions of these concepts. Still, in a few places, it will be essentially impossible to avoid the delineation of evidence that has accumulated since Darwin's time. As we shall discover in the next chapter, however, Darwin did make one serious error that could have negated entirely his most important insight: that of natural selection. The root of the error was not Darwin's fault—nobody in the nineteenth century understood genetics—but Darwin did not realize that the theory of genetics with which he was operating was lethal for the concept of natural selection.

The first essence in the theory was that of evolution itself. Even though some of Darwin's ideas on evolution had an older pedigree, the French and English naturalists that preceded him (among whom, figures such as Pierre-Louis Moreau de Maupertuis, Jean-Baptiste Lamarck, Robert Chambers, and Darwin's own grandfather, Erasmus Darwin, stood out) failed to provide a convincing mechanism for evolution to take place. Here is how Darwin himself described evolution: "The view which most naturalists entertain, and which I formerly entertained—namely, that each species has been independently created—is erroneous. I am fully convinced that species are not immutable; but that those belonging to what are called the same genera are lineal descendants of some other and generally extinct species." In other words, the species that we encounter today did not always exist. Rather, these are the descendants of some earlier species that became extinct. Modern biologists tend to distinguish between *microevolution* and *macroevolution*. Microevolution encompasses small changes (such as those sometimes observed in bacteria) that are the results of the evolutionary process over relatively short periods of time, typically within local populations. Macroevolution refers to the results of evolution over long timescales, typically among species—and which could also involve mass extinction episodes, such as the one that snuffed out the dinosaurs. In the years since the publication of *The Origin*, the idea of evolution has become so much the guiding principle of all the research in the life sciences that in 1973 Theodosius Dobzhansky, one of the twentieth century's most eminent evolutionary biologists, published an essay entitled "Nothing in Biology Makes Sense Except in the Light of Evolution." At the end of this article, Dobzhansky noted that the twentieth-century French philosopher and Jesuit priest Pierre Teilhard de Chardin "was a creationist, but one who understood that the Creation is realized in this world by means of evolution."

Darwin borrowed the idea embodied in his second pillar, that of gradualism, mainly from the works of two geologists. One was the eighteenth-century geologist James Hutton, and the other was Darwin's contemporary and later close friend Charles Lyell. The geological record showed horizontal banding patterns covering large geographical areas. This, coupled with the uncovering of different fossils within these bands, suggested a progression of incremental change. Hutton and Lyell were largely responsible for the formulation of the modern theory of *uniformitarianism*: the notion that the rates at which processes such as erosion and sedimentation occur at present are similar to the rates in the past. (We shall return to this concept in chapter 4, when we'll discuss Lord Kelvin.) Darwin argued that just as geological action shapes the Earth gradually but surely, evolutionary changes are the result of transformations that span hundreds of thousands of generations. One should not, therefore, expect to see significant alterations in less than tens of thousands of years, except perhaps in