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Introduction

Good old-fashioned Creationism was the doctrine that the Book of Genesis is a scientific text that provides a historical record of the origin of the Earth's biota. It claimed that the world is about 10,000 years old and that the fossil record has to be reinterpreted to accommodate this chronology. Good old-fashioned Creationism was bold and fun: if the reinterpretation of the fossil record requires a change in the laws of physics, Creationism said, so be it. Creationism accepted that the Flood happened as the Bible records it. Sloths would have had to migrate from West Asia to the neotropics in the allotted time, wombats to Australia. These sloths would have to move very, very fast, something that they are physiologically not prone to do. Old-fashioned Creationism could live with all of that. Biogeography places formidable challenges to Creationism – but those who are unconstrained by the laws of physics would presumably find it child's play to alter the facts of mere biogeography. Creationism can even live with the fact, first described by Andreas Vesalius in 1543, that, very strangely, men have the same number of ribs as women.[1]

But Creationism underwent a long-overdue Reformation in the 1990s in an attempt to make it more compatible with the findings of modern science. Unreformed Creationism lives on, in places such as the Creation Evidence Museum in Glen Rose, Texas. The museum sells books with titles such as *Crash Goes Darwin . . . and His Origin of Species*, *Dinosaurs by Design*, and *Noah's Ark: A Feasibility Study*;[2] fascinating books, but largely irrelevant as the Reformation has swept across all those institutions which urge the rejection of contemporary science and a return to an essentially fundamentalist religious view of the world. These institutions – for instance, the so-called Discovery Institute in Seattle – want to reform biological curricula in high schools in the United States and elsewhere to bring God back into science classrooms. But they do not want unreformed Creationism – at least that is the official story. They want Reformed Creationism.[3]

According to Reformed Creationism, we need no longer believe that the world is only about 10,000 years old, or that all extant animals are descended from those that jumped off Noah's Ark on Mount Ararat some 8,000 years ago. Darwin and evolution are no longer always equated with evil and blasphemy.[4] Instead, Reformed Creationism accepts parts of evolutionary biology, including some role for natural selection. It accepts that blind variation and natural selection – "Darwin's law of higgledy-piggledy" as the physicist John Herschel dismissively called it[5] – can explain phenomena such as the evolution of drug resistance in bacteria or pesticide resistance in insects. Most versions of Reformed Creationism even accept that natural selection may have modified traits such as the size and shape of bird beaks. For instance, they sometimes accept that natural selection molded the beaks of Darwin's finches in the Galápagos Islands where the size of available seeds selected for the form of beaks.[6] These versions of Reformed Creationism generally accept common descent: that all extant organisms are descended from a single ancestor in the recesses of deep time,[7] presumably the first cell.

Nevertheless, Reformed Creationism urges us to reject the view that evolutionary theory, coupled with our increasing knowledge of the physics and chemistry of living organisms, will eventually explain the emergence of all biological phenomena. Moreover, to get a full theory, it claims, we will have to embrace supernatural (or at least extra-natural) mechanisms. In particular, we will have to invoke the operation of a designing intelligence guiding the process of organic change. Reformed Creationism is called Intelligent Design (ID). Its intellectual stalwarts are Philip Johnson, William A. Dembski, and Michael J. Behe and much of this book will concern their arguments, though several lesser players will also enter the stage.[8]

The Central Argument

ID creationists' most fundamental biological claim is that complex adaptations could not have been produced by natural selection or any other natural process. Their emergence requires the intervention of an extra-natural designer. Bacterial flagella and the blood clotting cascade in mammals are their favorite examples though there are several others (see Chapter 6). This claim of impossibility is supposed to be bolstered by some alleged mathematical results from computer science and information theory – we will examine all these issues in this book.

One central argument underpins all of ID creationism. Briefly, that argument runs as follows: *first*, evolutionary theory is supposed to allow only: (i) the inheritance of traits; (ii) the occurrence of blind variation; and (iii) natural selection. (Chapter 2 will contain a detailed examination of these assumptions.) *Second*, according to this argument, evolutionary theory cannot at present explain many natural phenomena, in particular, the evolutionary emergence of biological complexity. *Third*, this failure is so blatant that it shows that evolutionary theory does not even have the conceptual resources to explain the emergence of complexity. (This "no conceptual resources" claim is critical to the success of the argument because, without it, evolutionary biologists have an obvious response: wait and see – as our science progresses, we will resolve the present difficulties.) *Fourth*, proponents of ID go on to claim, there is good reason to believe that the required resources must include intelligent mechanisms.

The aim of this book is to examine this argument – for ease of future reference, we will call it the "Central Argument" of Intelligent Design. Though the rejection of the Central Argument is the main conclusion defended in this book, what evolutionary biology actually says – and does not say – receives just as much critical attention as the Central Argument. This is also a book about biology, its philosophy, and its history – a feature of this book which makes it different from several very competent critiques of ID that have appeared recently.[9] However, Ken Miller's 1999 book, *Finding Darwin's God*, discusses a lot of the biology excellently.[10] Miller's book focuses on the ID creationists' major claims from the late 1990s. This book concentrates on the period since 2000 and, in that sense, complements Miller's treatment though there is some overlap (mainly in Chapter 6). Finally, this book is also a qualified defense of *naturalism*, the claim that the methods of science and their extensions are all we have to guide us through the enterprise of obtaining knowledge of the world. Here it parts company with Miller and his theological preoccupation of reclaiming God from the creationists – see Chapters 8 and 9. Naturalism, as we shall see later in the book (particularly in Chapter 9), is the real target of ID creationists and we will see how it fares under their criticisms.

Let us return to the "no conceptual resources" claim which, as we noted earlier, is critical to ID's Central Argument. There are two ways in which this claim can be fleshed out: (i) there is an abstract characterization of what is permitted by a theory, and a theorem or some such result that shows that some specific observed phenomenon is not permitted by the theory. This provides, essentially, a *reductio ad absurdum* argument against the theory; or, (ii) there is a body of phenomena that has proved recalcitrant to explanation over a sustained period of time, and these phenomena are better explained by some other fundamentally different theory even if that theory calls into question what was then the dominant scientific metaphysics. (Metaphysics, here, is taken to mean the most general assumptions about the world which all scientific theories must satisfy even when they disagree with each other.) ID creationists have tried both the options mentioned above. We will call the former the "inconsistency" option and the latter the "incompleteness" option.

Note that, if we accept the Central Argument, we must first give up one of the most successful scientific theories of our time – the theory of evolution by natural mechanisms. (Recall the evolutionary geneticist Theodosius Dobzhansky's famous, though perhaps rhetorically overstated, dictum: "Nothing in biology makes sense except in the light of evolution."[11]) We must next give up the dominant and even more successful metaphysics that has grounded science since at least the Copernican era: naturalism. Naturalism is often taken to claim that all that exists in the universe is processes and entities knowable to us through scientific methods, that is, through logic and our senses, with no recourse to entities and processes entirely inaccessible to these methods. When formulated in this way, naturalism makes both metaphysical and epistemological claims, about what may exist and how we may come to know about them. Ultimately, naturalism is the real target of ID because it forbids the reintroduction of divinity into the empirical world. The attack on evolutionary theory is a necessary stage in this campaign because evolutionary theory claims that, not only the entire biological world, but even our most fundamental human features – our minds, our morals – should be accounted for without appeal to extra-natural intervention.

However, a defense of evolution in the present context of what constitutes *science* does not require the metaphysical component of naturalism. All it requires is a very weak form of epistemological naturalism, usually called methodological naturalism, which limits science to those facts that are accessible to naturalistic methods as defined above.

Methodological naturalism allows the possibility of a religious realm to be explored using religious practices. It merely asks that this realm be kept distinct from science. Though Chapter 9 of this book will defend a stronger form of naturalism than methodological naturalism, the weak doctrine is all that we need to defend evolutionary biology against ID creationism.

A demand that we give up a particular scientific theory is not radical: the history of science is littered with examples of highly successful scientific theories being replaced by successors that are even better. The caloric theory of heat gave way to the kinetic theory in the nineteenth century.[12] Heat turns out not to be a fluid called "caloric"; rather, it is the agitation of matter in motion as the kinetic theory demands. Darwin's blending theory of inheritance was similarly replaced by Mendel's particulate theory.[13] Offspring traits are not intermediates between parental traits produced by a mingling of hereditary material. Rather, parents pass on discrete factors or "genes" (more accurately, *alleles* or versions of genes) which help specify offspring traits. Offspring traits may well be identical to those of one of the parents or even one of the grandparents. The growth of science requires the replacement of old theories and their replacement by better new ones.

The Evidence for Evolution

We can reasonably be asked to give up a theory if it fails to save the phenomena. A central claim of ID is that, indeed, there are many phenomena that evolutionary theory cannot explain. We will examine those claims in detail in later chapters of the book. Meanwhile, it will suffice here to sample some of the phenomena that evolutionary theory does explain and which, therefore, provide our evidence for evolution. This is not to suggest that evolutionary theory is complete or that there are no legitimate debates about evolution. We will discuss a host of problems in Chapter 4. But, here, we present the case *for* evolutionary theory.

Evolution means modification by common descent through a variety of natural mechanisms. Most, though not all, evolutionary biologists believe that the most important of these mechanisms is natural selection, the production of more offspring by some types over others. Assuming that some of the traits of the parental types are inherited by the offspring, these traits will spread because of the higher number of such offspring – there is nothing mysterious about natural selection. Modifications arise because of changes in the genes through which parental characteristics are transmitted to the next generation. Some modifications are minor. For instance, a mutation in a single gene in humans can make the bearer produce a different form of hemoglobin than the usual one and become susceptible to sickle cell disease (a painful form of anemia). However, this mutation also makes bearers, provided they also carry a copy of the normal gene, resistant to many types of malaria. Thus, in an environment in which these forms of malaria are prevalent, the modification would be selected for.

Not all modifications are minor and, according to evolutionary theory, the accumulation of many minor modifications may lead to major changes. Thus, humans and the great apes all descended from a common ancestor from which humans have diverged quite radically through successive small modifications. Similarly, birds are generally believed to have evolved out of theropod dinosaurs through small modifications though some recent findings suggest a more complicated story.[14] All mammals similarly evolved from a group of reptiles that lived over 200 million years ago.[15] We will encounter many other examples later in the book.

Though this level of detail is atypical for an Introduction to a book, the rest of this section will document some of the specific evidence for evolution. The aim is to drive home the variety and depth of the evidence that makes the theory so compelling for biologists. ID creationists must seriously confront all this evidence if they are intellectually honest. As the noted evolutionary biologist Ernst Mayr points out, our confidence for evolution comes from the consilience of four major types of evidence: (i) the fossil record; (ii) morphological similarities between organisms; (iii) biogeography; and (iv), of late, the molecular constitution of organisms.[16] What follows is not intended as a systematic survey of all of the evidence for evolution: even a cursory such survey would fill a book much longer than this. Moreover, because contemporary ID creationists generally do not deny either the fact of evolution or the operation of the standard mechanisms of evolutionary change, denying only that these mechanisms suffice to explain *all* of organic change, such a survey is not strictly necessary. Nevertheless, having the concrete evidence of the achievements of evolutionary theory fresh in our minds will help us navigate the issues discussed in this book:

(i) *The Fossil Record*. Darwin and the early proponents of evolution all started from the fossil record, and so shall we. Fossils of extinct organisms are found in geological strata that can be accurately dated using a variety of techniques including radioactive dating with carbon (C-14), potassium (K-40), uranium (U-238), and other isotopes. Fossils found in recent strata are closely related to – and sometimes indistinguishable from – extant organisms. But this similarity diminishes steadily, layer by layer, as we examine fossils from more distant strata. There are gaps in the fossil record but, as time has gone on, these gaps or missing links have become less numerous. Sometimes spectacular discoveries have filled these missing links. For instance, in 1861, a fossil of a bird found in the upper Jurassic era (145 million years ago [Mya]), Archaeopteryx, was discovered in southern Germany. It had teeth, a long tail, and other characteristics of the reptilian ancestor posited for birds by evolutionary biologists. But it also had a large brain, large eyes, feathers, and wings. The latter set of features showed it to be a transitional form between modern birds and the common more reptilian ancestor of both modern reptiles and birds. It was almost certainly capable of flight. Since 1940, at least 12 other "missing" links between birds and their reptilian ancestors have been discovered.[17]

In some cases the fossil record is remarkably complete with most expected transitional forms having already been found.[18] These cases include the lineage leading from therapsid reptiles to mammals and that leading from Eohippus (the ancestral horse) to Equus (the modern horse). Moreover, with virtually no exception, fossils have been found only in the time period evolutionary theory predicts that they should be found. There are no anomalous fossils, for instance, fossils of the same species found in inconsistent geological strata. If we found a fossil rabbit in strata from the Jurassic era (206–144 Mya), as the great evolutionary biologist, J. B. S. Haldane, once remarked, we would consider abandoning the theory of evolution. The fossil record supports evolution – descent with modification – though, by itself, it cannot give direct evidence of the mechanisms of that change, whether it is entirely due to natural selection. To get a handle on why evolution occurred, we must turn to morphological variation among the organisms that exist today.

(ii) *Morphology*. As evidence for evolution, morphological similarity performs even better than the fossil record in providing support for evolution and even helps to resolve the problem of identifying mechanisms of evolution. Morphological similarity is ubiquitous, not only between ancestor and descendant as determined from the fossil record, but also between related organisms today. Even before Darwin, starting especially with the work of the Swedish botanist Carl Linnaeus in the eighteenth century, morphological similarity was used by systematicists to organize all known species in a taxonomic hierarchy allegedly created by God. Evolution, that is, descent with modification from a common ancestor, gave a straightforward earthly explanation of this hierarchy. Descent with modification is why the wings of birds resemble the anterior extremities of mammals – the two structures are *homologous* because their similarity is explained by the fact that they share a common ancestor. Homologies – similarities due to common ancestry – are critical to our arguments because even ID creationists admit that close homologies (that is, overwhelming similarities) between related species point to gradual changes from the common ancestor. We will often argue from homology throughout this book.

In cases such as that of wings we can infer – though not prove conclusively, as skeptics love to point out – the role of natural selection in modifying the form. We can tell a consistent story of such modification through the extensive fossil record. Vestigial organs – for instance, the human appendix – are similarly explained as homologs of functional similar organs in related organisms. Moreover, once we go beyond fossils and also focus on organisms living today, we can elucidate the mechanisms of evolutionary change and, ideally, even test quantitative models of natural selection. Comparative morphology begins to fill in the gap left by the fossil record about the possible mechanisms of descent with modification.

(iii) *Biogeography*. Biogeography provides equally compelling evidence for evolution. For many observed biogeographical patterns there is no explanation other than evolution with branching descent. There is only one species of mockingbird in continental South America (*Mimus gilvus*).[19] However, during the voyage of the *Beagle* Darwin found three different mockingbird species, now called *Nesomimus trifasciatus*, *N. parvulus*, and *N. melanotis*, in three different islands of the Galápagos group. Evolution explains how each of these diverged from a common ancestor they shared with *M. gilvus*. In the case of Darwin's finches, also from the Galápagos islands, quantitative work has detailed how changes in beak morphology in different islands are brought about by natural selection.[20] Evolution explains biogeography at every spatial scale, as Darwin's co-discoverer of the theory of natural selection, Alfred Russel Wallace, showed in detail in the 1870s.[21]

Evolution explains why the faunas of Europe and North America on different sides of the north Atlantic ocean are similar while the faunas of Africa and South America on different sides of the south Atlantic ocean are not. It even explains puzzling discontinuous geographical distributions of related species. For instance, true camels (*Camelus dromedarius* and *C. bactrianus*) are found only in Asia and Africa. Their closest relatives are the llamas (*Lama glama*, *L. glama pacos* or alpaca, and *L. guanicoe* or guanaco) and vicuñas (*Vicugna vicugna*) of South America. But, if evolution is the continuous process that we believe it to be, there should be camels of some sort or other in North America. There are none at present, but the fossil record includes a large fauna of Tertiary era North American camels, now long extinct. Camels are believed to have originated in North America and migrated to South America, Eurasia, and Africa. The fauna of Europe and North America are similar because a land bridge connected the two in the early Tertiary era, 40 Mya. In contrast, continental drift separated Africa and South America 80 Mya and their fauna have diverged ever since. Biogeography, morphology, and the fossil record mutually reinforce each other in the service of evolutionary theory.

(iv) *Molecular evidence*. Finally, the past fifty years have churned out a vast body of molecular evidence all pointing towards evolution. The more related that two organisms are according to evolutionary theory, the more similar should be the molecules constituting them. The agreement between theory and evidence has often been spectacular. Molecules evolve in the same way as other structural elements of organisms: descent with modification is ubiquitous. However, different types of molecules evolve at different rates: fibrinopeptides, molecules involved in the clotting of blood, evolve very rapidly; histones, small chromosomal proteins, are exceedingly conservative, that is, resistant to evolutionary change. Molecular analysis has also cleared up many evolutionary puzzles. Fungi were long regarded as being plants or at least close to plants. Yet, their cell walls consist of chitin, also found in the hard parts of insects, but never in plants. Molecular analysis revealed that the basic chemistry of fungi is close to that of animals. Today, fungi are classified in a separate kingdom distinct from both plants and animals. Once we turn to the DNA in our genetic material, we see evolutionary theory quantitatively confirmed in many cases. For instance, if natural selection is a major force of evolution, we would expect DNA sequences coding for functional protein molecules to be much more constrained, and evolving much more slowly, than non-coding non-functional DNA sequences. That is exactly what we find. Molecular evidence also dispels the view – once also held by the majority of evolutionary biologists – that all modern animal phyla appeared more or less fully formed and almost suddenly, in the pre-Cambrian era, about 550 Mya – there will be more on this in Chapters 4 and 7. Molecular homologies are ubiquitous and we will turn to them in Chapter 6. These homologies are now extensively used to reconstruct evolutionary history.

Rejecting Theories

Convincing scientists – or even the educated public – to give up a theory as powerful as the theory of evolution will not be easy. But, recall that the ID creationists would not be satisfied with merely that; they also want a transformation of our metaphysics. They want us to give up naturalism. On occasion, we do give up metaphysical assumptions. Though naturalism itself has not been called into question within science since its rise to dominance in the seventeenth century, there are several examples of deeply held – and empirically successful – theories being replaced by successors deemed metaphysically impossible in earlier times.

Consider the following four examples, keeping in mind the question whether contemporary ID is on par with any of them. We range over the sciences also to highlight the fact that ID's assault on naturalism is an assault on all of science, and not only evolutionary biology:

(i) *Newton's mechanics*. Let us begin with the part of physics we teach first in high school, and which we continue to use in most of our everyday life: classical mechanics. In 1687 Isaac Newton published *Principia Mathematica* in which he propounded the three laws of motion that still bear his name. He also propounded a new theory of gravitation – the "Law of Universal Gravitation." Newton's theory unified celestial and terrestrial mechanics: it showed that the laws governing the fall of bodies on earth (for instance, Galileo's law of the pendulum) explained the laws which governed the motion of planets, that is, Kepler's three laws. Newton's theory correctly predicted the return of Halley's comet in 1758. There was never much doubt about its predictive power and success.

The trouble was that Newton's theory assumed action-at-a-distance, that distant bodies influence each other instantaneously through gravitation. The dominant scientific metaphysics of the day, the mechanical philosophy of Boyle, Descartes, and Huygens, did not permit action-at-a-distance: all interactions were supposed to be mediated by local contact between impenetrable particles of matter. From the point of view of the mechanical philosophy, action-at-a-distance was "occult," as Leibniz put it, or even "absurd," as Huygens opined.[22] But the mechanical philosophy had no convincing account, let alone a quantitative explanation, of planetary motion. Descartes, for instance, had a purely qualitative theory of vortices that was never successfully quantified. Attempts to find a quantitative mechanical explanation of planetary phenomena continued well into the eighteenth century, at times co-opting the efforts of such eminent mathematicians as Leonhard Euler.

But all this effort was expended to no avail. By the end of the eighteenth century it was clear that the mechanical philosophy probably did not have the conceptual resources to account for all physical phenomena: gravitation had remained recalcitrant for over a century, and Newton's simple law saved the phenomena though it required a change of metaphysics. Action-at-a-distance had come to stay and the mechanical philosophy was on its way out by the nineteenth century. In a last-ditch effort, some figures such as Hermann von Helmholtz tried to resuscitate the mechanical philosophy by changing its assumptions to allow action-at-a-distance so long as it was governed by "central" forces (roughly, forces directed along lines joining the centers of material bodies). But these efforts were of no avail. The phenomena had forced a change of metaphysics.

(ii) *General relativity.* Newton's eminence in the eighteenth century is aptly captured by Alexander Pope's intended epitaph for him:

> "Nature and Nature's Laws lay hid in night
> God said: let Newton be and all was light."

Central to Newton's reputation was his law of gravitation discussed earlier. By 1798 Henry Cavendish had measured the gravitational constant found in Newton's law, obtaining a value the accuracy of which has not been very significantly improved to this day. The early nineteenth century only saw Newton's theory of gravitation extend its success. Using

Newton's law, in the 1840s, John Couch Adams and Jean Joseph Le Verrier showed that well-known anomalies in the motion of Uranus, that is, deviations from what was predicted by Newton's law, could be explained by positing the existence of an eighth planet and retaining Newton's law. Le Verrier's prediction was immediately confirmed in Berlin by Johann Gottfried Galle in 1846. Adams was English, Le Verrier French, and a bitter priority dispute broke out with each backed by his own national scientific establishment. At stake was the name of the new planet which eventually came to be called "Neptune."

The discovery of Neptune was the high point of the history of Newton's theory of gravitation because another much more recalcitrant anomaly soon emerged. In 1859 Le Verrier pointed out that there was a discrepancy between the observed motion and the predicted motion of the perihelion of Mercury (the point at which it is closest to the Sun) as predicted by Newton's law.[23] Le Verrier found the discrepancy to be 38″ per century; by 1882 it was known to be 43″. Over the years many solutions were proposed: Venus was 10% more massive than believed; there was another planet or a ring of matter within Mercury's orbit; Mercury had a moon; the Sun was more oblate than observed; and so on. It was also proposed that Newton's theory required modification, and this was the only proposal not soon ruled out by experiment or observation. At the beginning of the twentieth century the perihelion problem remained unresolved.

The solution came from Einstein around 1915.[24] But it required more than any ordinary modification of Newton's law of gravitation. Einstein's new theory of gravitation, also known as general relativity, reinterpreted gravitation as the curvature of space-time. It cast aside the view, then doubted by no one, that space and matter were independent of each other. Along with that metaphysical principle went the claim that the Euclidean (or flat) geometry of space is a necessary truth. We live in a curved space-time, one in which that curvature is continually changing as pieces of matter move around. General relativity did more than only explain the perihelion shift of Mercury. It predicted that light would bend around matter. A 1919 British expedition led by Arthur Eddington to the western Pacific to record the passage of light during an eclipse found just what was predicted. Subsequent experiments have only added to our confidence in the theory in spite of the metaphysical readjustments it has demanded. It is fitting to conclude with an addendum, by John Colling Squires, a British journalist, to the couplet by Pope with which we started:

> "It did not last: the Devil howling 'Ho!
> Let Einstein be!' restored the status quo."

(iii) *Quantum mechanics*. Let us turn to what is regarded as the most radical conceptual change in physics in the twentieth century: quantum mechanics. One important innovation of early nineteenth-century physics was the wave theory of light, a departure from Newton's view that light consisted of particles. Shortly afterwards, in the 1830s and 1840s, Michael Faraday and others showed that electricity and magnetism were related phenomena. Between the 1850s and 1870s James Clerk Maxwell developed Faraday's intuitive ideas about "fields" of electrical and magnetic forces to formulate a unified mathematical theory of electromagnetism. One consequence of this theory was that light consisted of electromagnetic waves. Like all other waves, light waves were believed to be continuous. Light is both emitted and absorbed by matter creating what are called emission and absorption spectra: the precise distributions of the wavelengths at which light is either emitted or absorbed. These spectra are characteristic of the material being studied. By the 1890s several laws governing these spectra were empirically well established.

However, between 1900 and 1905 Max Planck and, especially, Einstein showed that these laws could be made consistent with the rest of physics only if we deny the unlimited validity of Maxwell's theory of light and accept that light comes in discrete chunks or "quanta." It took a quarter-century, until the late 1920s, to make any sense of quantum theory. It was a joint effort, with contributions from many physicists including Niels Bohr, Werner Heisenberg, Max Born, Erwin Schrödinger, and Paul Dirac. The result, quantum mechanics, is arguably the greatest achievement of physics to date. Quantum mechanics provides the foundation for chemistry, explaining the rules of valency. At the practical level, it provides the basis for electronics. It is indispensable for the understanding of particle physics. As the physicist Eugene Wigner liked to point out, with quantum mechanics, for the first time, we can explain the stability of matter, why matter does not decay spontaneously. Indeed, within the biological context, Schrödinger believed, erroneously as it turned out, that quantum mechanics would be necessary to explain the stability of genes (alleles) across hundreds of generations.[25]

But the acceptance of quantum mechanics came at an unprecedented metaphysical cost. We have been forced to abandon determinism: the doctrine that, given the present state of the world, the laws of nature are such that, at any future instant of time, there is only one possible state of affairs.[26] Traditionally, that assumption lay at the foundations of the scientific enterprise, the attempt to understand the universe in terms of exceptionless general laws. Quantum mechanics denies that. Moreover, it decrees that some individual systems may also not be in a determinate (or definite) state at all times, contrary to anything permitted in classical physics (and, indeed, the rest of science). Yet the empirical success of quantum mechanics forced a re-evaluation of such foundational claims. Einstein, for one, was never satisfied with the new metaphysics that quantum mechanics requires, and contemporary philosophers of science (and some physicists) continue to debate its interpretation. There are even those who retain the hope that future developments will allow us to regain the metaphysical certainties of old without eschewing the empirical success of the new physics. We will return to quantum mechanics in Chapter 10.

(iv) *Natural selection.* The fourth example is the one central to the concerns of this book: Darwin's and Wallace's theory of evolution by natural selection which will be treated in detail in Chapters 2 and 3. The success of the theory of natural selection removed design and teleology from nature, replacing them with explanations in which causes always precede effects, and nothing but physical law guides the course of all systems, including biological ones. As Francisco Ayala puts it: "It was Darwin's greatest accomplishment to show that the directive organization of living beings can be explained as a result of natural process, natural selection, without any need to resort to a Creator or other external agent."[27] ID creationists want to resuscitate design and teleology – *ipso facto*, they have to reject evolutionary theory or at least seriously delimit its domain.

Each of these examples is a successful path-breaking episode in the history of science. In each case a revision of metaphysics was forced by the astounding empirical success of a new bold theory which challenged established metaphysical principles. If ID creationists want their claims of revolutionary success to be taken seriously, what they must show is that the choice between ID and conventional evolutionary theory is similar to the choices faced in these examples. Otherwise we would have no reason to forsake well-established metaphysical principles. Moreover, in none of the first three examples, radical as they are, is naturalism itself at stake. To make us question naturalism itself, ID creationists must do even better than the proponents of the new theories in all these cases.

They must do at least as well as Darwin and Wallace and their followers when they reinterpreted the history of life in the nineteenth century without recourse to a designer.

In fact, they must do better. With respect to naturalism, the case of the theory of natural selection is curious. Before the acceptance of that theory, the adaptation of organisms was beyond what natural law could explain:[28] they were yet to be brought within the realm of science in the same way many aspects of our mental and cultural lives today are beyond what contemporary science can explain. (This is not to say that some scientists, for instance, human sociobiologists and Evolutionary Psychologists, do not claim to provide such explanations. It is to deny that these claims are credible – there will be more on this point in Chapters 2 and 4.) What the theory of natural selection did was to draw adaptation into the realm of science. Now ID wants to reclaim complex adaptations from the scientists. But they are faced with the situation that naturalism works not only for the study of adaptations, but for all of the rest of science.[29] So, ID creationists are faced with an even more difficult task than the one that confronted Darwin and Wallace. The founders of evolutionary theory were only establishing consistency between a recalcitrant domain (the study of adaptations) and the rest of science. ID creationists want to reject all of it. We should be impressed by the audacity of the project though, as this book will show, some humility would have served the ID creationists better.

Let us set aside evolutionary theory for the time being – after this chapter, the rest of this book, except Chapter 8, will only concern it. The other three examples provide reliable methodological principles for us to adopt.[30] There are at least six lessons to be learned:

(i) we should abandon theories only when there is compelling unimpeachable evidence against them, unimpeachable in the sense of not being merely a question of controversial interpretation of the evidence.[31] There was no doubt about whether the successful predictions made by Newton's law of gravitation posed a problem for the mechanical philosophy. There was also no doubt about the relevance of the anomalous motion of the perihelion of Mercury to Newton's law of gravitation: even proponents of the law regarded the anomaly as a problem;

(ii) before abandoning a theory altogether, it is reasonable to attempt to modify it minimally or change our other less important assumptions to see if we can accommodate the recalcitrant data. This point is exemplified by the relatively minor modifications of Newton's law attempted in the nineteenth century, as well as the modifications of assumptions about the mass of Venus, the shape of the Sun, and so on, all to save Newton's law of gravitation;

(iii) in the face of problems with a theory, before abandoning the metaphysical principles underlying the theory, it is again reasonable to try to find alternatives to the theory that remain consistent with those principles. Trying to find mechanical explanations of planetary phenomena was entirely appropriate. Trying to modify Newton's law minimally to save the basic framework of his theory was also appropriate. Metaphysical principles which lie at the foundation of a science are not for everyday exchange, as Thomas Kuhn and Imre Lakatos pointed out long ago;[32]

(iv) we should abandon an old metaphysical principle and adopt a theory based on new ones only when there is clear and compelling evidence for the latter – every example above illustrates this point;

(v) mere metaphysical difficulty with a theory is not sufficient for its rejection: there must be a compelling empirically successful alternative. Contrary to Philip Johnson, "purely negative arguments," criticizing alleged explanatory failures of evolutionary theory, is not good enough.[33] Thus Newton's law triumphed over the mechanical philosophy, relativity eventually replaced Newton's mechanics, etc., only because of unimpeachable positive evidence supporting the successful alternatives. Moreover, so long as a theory is empirically successful, in the absence of such an alternative, we will tolerate any deviant metaphysics it embraces. Empirical success trumps metaphysical scruples. Action-at-a-distance was palatable so long as Newton's law faced no anomaly. Quantum mechanics continues to be endorsed in spite of all its discomfiting metaphysical commitments; and

(vi) all these examples and the preceding points show that confidence in metaphysical principles is based, ultimately, on empirical facts, in exactly the same way that confidence in a particular theory is. Yet, this is what proponents of ID try to deny.[34]

Two final comments about these four examples are relevant to our context: (a) we continue to tolerate empirically successful theories, while we hope to do better eventually, even if they invoke inconsistent scientific or metaphysical principles. It is well known that the deterministic world of general relativity is in conflict with the indeterminism of quantum mechanics, and both theories claim to have all physical systems within their domains. Theories that would resolve this conflict remain speculative at present. Nevertheless, we continue to hold both theories because, in practice, they are used in sufficiently different domains so that the potential conflict can be ignored: quantum mechanics is used for atoms and smaller entities, general relativity for planets, stars, galaxies, and larger entities. Good theories are rare: we use them wherever we have them and we do not give them up easily; (b) our examples come from both physics and biology. This is important because part of the rhetoric of ID is to argue that there are relevant differences between physics and biology which show that the reliability of mature biological theories is not anything like that of mature physical theories. To show that changes of metaphysics and changes of theory in physics follows the same pattern as in biology undercuts that claim.

The first three lessons listed above are relevant to the "no conceptual resources" claim of the Central Argument but only when that claim is based on the incompleteness option (that is, there remain recalcitrant phenomena unexplained). The inconsistency option – rejecting a theory because what it permits, at a very general level, is inconsistent with observed phenomena – has rarely been deployed in the history of empirical science though there is one ambiguous example among the cases we have already introduced.[35] Einstein's dissatisfaction with quantum mechanics led him to formulate an alternative deterministic framework in the 1930s.[36] These ideas were developed by John S. Bell in the 1960s to derive a mathematical inequality which violated quantum mechanical predictions.[37] A large number of experimental tests since have uniformly come out in favor of quantum mechanics. This example may be regarded simply as a case in which two theories make definite predictions and one of them does so correctly. However, it is probably more useful to regard it as a case where the inconsistency option is being deployed against a theory. The Einstein–Bell argument is based on very general and compelling assumptions of what any deterministic theory should look like, rather than being an explicit theory, and the theoretical predictions of quantum mechanics are inconsistent with what is permitted by this deterministic framework.[38]

In spite of the rarity of its deployment in the history of science, much of this book will concern the inconsistency option because of its systematic use by ID creationists. To that extent we will charitably allow negative argumentation: it will not make any difference to the conclusions we reach. Typically ID creationists provide what they take to be an abstract characterization of evolutionary theory, then examine what they claim to be the range of possibilities that are permitted by it, and then produce an alleged empirical counter-example from the biological world. Rare though it may be in the history of science, this is a legitimate strategy so long as the characterization, the derivation of the range of possible outcomes, and counter-example, is each correct. (Moreover, *reductio ad absurdum* proofs, which provide a useful analogy, are commonplace in mathematics.) But the very fact that ID creationists use an option so rarely used in the history of science already suggests that ID creationists do not wish to play by the everyday rules of scientific practice. But, perhaps, this is inevitable since their claims are so radical – after all, in demanding a rejection of naturalism, they want a change of metaphysics more fundamental than all but the last of our examples.

Plan of the Book

We will conclude this Introduction by sketching the course of the book. Chapter 2 of this book deals with Darwin, Wallace, and the first formulation of the theory of natural selection. It delves into some details of those aspects of the development of evolutionary theory that remain salient to discussions of ID today. It includes a discussion of Wallace's heresy, his endorsement of the existence of a spiritual world interacting with ours, which has been surprisingly ignored by ID creationists. Chapter 3, which is also mainly historical, turns to the question why the theory of natural selection required a change of worldview or metaphysics at least as profound as that required by Newton's theory of gravitation, relativity theory, or quantum mechanics. This chapter also disposes of the most traditional objection to natural selection, Paley's argument from design, and its attempted recent resurrection by Dembski. This refutation is not particularly difficult or insightful but, nevertheless, is included here for the sake of completeness. For all the wild enthusiasm of ID supporters, Dembski's resurrection is ultimately no better than Paley's original argument.

Chapter 4 gives a historical account of the emergence of contemporary evolutionary theory and of its central claims today. The history is used to provide a survey of contemporary evolutionary theory. The chapter also includes a discussion of several issues that remain in legitimate debate within evolutionary theory. It also introduces distinctions that will be enforced throughout the rest of this book: those between contemporary evolutionary theory, the more restricted theory of natural selection, and Darwinism in the sense of what Darwin historically said. ID creationists routinely conflate these categories for rhetorical purposes, for instance, to use some limitation of Darwinism to argue against contemporary evolutionary theory. The illegitimacy of such a move will be a recurrent theme in this book.

Chapter 5 turns to the so-called No Free Lunch (NFL) theorems from computation theory that are supposed to show that natural selection is no better than random search in attempting to find a well-designed solution to evolutionary problems. This chapter points out that evolution is largely not an optimization process and very rarely falls within the orbit of such theorems. Even where it does, the ID creationists' interpretation of the NFL theorems is illegitimate. Chapter 6 turns to what Behe calls "irreducibly complex systems" that are supposed to be "in principle" unevolvable because their functioning requires the coordinated action of unsubstitutable parts. This chapter shows through the detailed examination of a variety of examples – both Behe's and others – that the claim of "in principle" unevolvability is false. Moreover, though there are many instances of complexity that continue to challenge evolutionary explanations, there is a growing set of cases in which this challenge has already been met.

Chapter 7 turns to the question whether modern information theory poses a challenge to the theory of evolution. It points out that the standard quantitative models of information allow accumulation of information through evolution by natural selection. It notes that Dembski's account of "information" is idiosyncratic. Consequently, information theory cannot be legitimately be used to challenge – or defend – evolutionary theory. This chapter also analyzes – and disposes of – Dembski's claims about the challenge posed by "complex specified information" to evolutionary theory. Claims such as Dembski's law of the conservation of information are largely figments of an apparently over-excited imagination.

Chapter 8 turns to an issue somewhat beyond the mainly biological concerns of this book: the "fine-tuning" argument which is supposed to show that certain cosmic coincidences lie beyond the scope of naturalistic explanation. It shows that this argument is no better than Dembski's failed argument from design. Chapter 9 turns to the question of whether ID – including the fine-tuning argument – poses a credible challenge to naturalism. Distinguishing between methodological and metaphysical naturalism, it argues that no such challenge has been launched against the former, noting that this modest conclusion is all that is required to fully defend evolutionary theory. In contrast, the legitimacy of metaphysical naturalism (even if that doctrine is correct) is irrelevant to that question. Nevertheless, to the extent that practice of science brings with it metaphysical commitments, it defends metaphysical naturalism. But this defense is limited – the practice of science does not require religious belief or disbelief properly understood, when religion and science are seen to perform different, perhaps complementary, individual and social functions. Chapter 10 draws some conclusions, pointing out that scientists do take credible challenges to evolutionary theory seriously, examines the ways in which ID fails to be *science*, and considers whether it belongs in high school curricula.

An alert reader will have noticed that though this chapter has recapitulated ID's Central Argument against evolutionary theory and, in the process, has given a cursory description of what evolutionary theory claims (at least, as described by ID creationists), we have not been presented with a summary of ID theory: though books entitled *Intelligent Design* have appeared, ID creationists are remarkably evasive about what their theory is besides vague claims such as intelligence guides organic evolution or that ID has something to do with the transfer of information.[39] ID creationists have largely concentrated on attacks on evolutionary theory – hence the focus of this book.

Finally, though this chapter began with a mention of the socio-political agenda of the ID movement – to return God to the classrooms, and though the Preface laid out the political context in which we work as philosophers and scientists, this book is not about the politics of the ID movement. We only return to the socio-political arena in Chapter 10 and, even there, do so only very briefly. As the outline above delineates, the aim of this book is to provide a general analysis of the arguments and evidence presented by ID creationists and to do so accurately but accessibly because some ID creationists tend to mislead ordinary readers by clothing disreputable claims in vestments of impenetrable symbolism.[40]