

## EVOLUTION AS A SCIENTIFIC FACT

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### ABSTRACT

Such is the plethora of observations and experiments that support evolution during the Earth's history, that the evolution of life forms is regarded as a fact within biology, rather than a hypothesis. Attempts to endow creationism as a science, in the form of Creation Science or Intelligent Design, have failed, as these efforts, at their best, are capable of identifying as yet unresolved issues, but are unable to advance alternative scientific propositions. Evolutionary biology, as a scientific field, is however the scene of active investigation, discussion and disagreement regarding, for instance, the tempo and mode of evolution, the importance and interaction among different evolutionary mechanisms, the role of development in the rate and pattern of the evolution of form and novelties, the action of evolution at different hierarchical levels, the process of speciation, and the relationships among different taxa. Within biology it holds a central position, insofar as it pertains to all aspects of the biology of living beings and sheds light upon *why* they are as they are. Evolutionary thinking, including the mechanism of natural selection, has inspired and influenced other branches of science, including economics, computer science, psychology, and medicine. The philosophy of biology and the discussion over the meaning of some of evolutionary biology's central terms (such as fitness, species, adaptation) is one of the most active fields of modern philosophy of science, and evolutionary biology has contributed to a change in our perspective of Science and valid scientific methods. Despite its centrality within Biology, evolutionary biology and population thinking is not firmly understood by many biologists working in more mechanistic fields, regarding *how* living organisms function, who have not received sufficient education in that field, nor by many scientists in other scientific fields, some of which continue to regard evolution as a mere hypothesis.

## RESUMO

Tal é a vastidão de observações e experiências que suportam que a evolução ocorreu durante a história da Terra, que a evolução da vida é considerada como um facto biológico, não como uma hipótese. Tentativas de converter o criacionismo numa ciência, na forma de Ciência da Criação ou Desenho Inteligente, falharam, já que estes esforços, no seu melhor, foram incapazes de adiantar proposições científicas alternativas. A Biologia Evolutiva, enquanto área científica, é área de investigação activa, discussão e discordâncias no seu seio, em várias temáticas, por exemplo, o tempo e modo de evolução, a importância e interacção entre vários mecanismos evolutivos, o papel do desenvolvimento na taxa e padrão da evolução da forma e de novidades evolutivas, a acção da evolução a diferentes níveis hierárquicos, o processo de especiação, e o relacionamento entre organismos particulares. Dentro da Biologia detém uma posição central, na medida em que afecta todos os aspectos da biologia dos seres vivos e ilumina *porque* os seres vivos são do modo que são. O pensamento evolutivo, incluindo o mecanismo da selecção natural, tem inspirado e influenciado outras áreas científicas, incluindo economia, informática, psicologia e medicina. A filosofia da biologia e a discussão sobre o significado de alguns dos termos fundamentais da biologia evolutiva (aptidão, espécie, adaptação) tem sido um dos ramos mais activos da filosofia da ciência actual e a biologia evolutiva tem contribuído para uma mudança da nossa concepção de Ciência e o que são métodos científicos válidos. Apesar da sua centralidade na biologia, a biologia evolutiva e o pensamento populacional não é bem compreendido por muitos biólogos trabalhando em disciplinas mais mecanicistas, isto é sobre *como* funcionam os organismos e suas estruturas, por falhas na sua formação. Tal sucede também por parte de cientistas noutros ramos da ciência, alguns dos quais continuam a considerar a evolução como mera hipótese.

Some misguided ideas have persisted for extended periods of time as part of the common and scholarly accepted canon, to the extent that sinuous solutions were necessary to adjust observations to the standard theories. Such epistemological

Gordian knots were only severed through the persistent work of determined, creative and meticulous scientists who sought the best theories to fit the facts, rather than the other way around. This required unorthodox thinking and considerable courage (at times against life-threatening forces). Yet, in time new ideas came to be accepted, and evidence accumulated in their favor such that previously dismissed heresies became established as scientific facts.

The geocentric model of the solar system was the common belief in ancient Greece, embraced by such luminaries as Aristotle and Ptolemy, and in the Western World until the Renaissance, despite detractors like Aristarchus of Samos and Philolaus (3<sup>rd</sup> century BCE). The Ptolomaic system required the existence of epicycles to explain the eccentric motion of Mars and Mercury, which appeared to invert their motion around the earth. Faced with increasing difficulties, Tycho Brahe advanced an alternative in which the Sun and Moon orbited the Earth – still the center of the universe – while the remaining planets orbited the sun. Slowly, but surely, the heliocentric model gained ground.

First through the works, in the 16<sup>th</sup> century CE, of Nicolaus Copernicus and Giordano Bruno. Later, the 17<sup>th</sup> Century, the astronomical observations of Galileo Galilei, the more elaborate laws of planetary motion of Johannes Kepler, and finally, using Edmond Halley's extensive annotations of the heavens, the *Principia Mathematica* of Sir Isaac Newton, firmly established the heliocentric model as the most acceptable theory. Newton advanced a universal mechanistic law of gravity capable of explaining falling objects on Earth as well as the movement of the planets around the Sun. In the age of the Moon landing and Hubble photography, the earth revolving around the sun, together with the remaining planets, and moons revolving around planets is assumed as a fact. The transition from heresy to well-established fact was possible only through simple yet broadly-encompassing models consistent and corroborated with extensive observations. The idea of biological evolution, as opposed to independent creation of species, has traveled a similar path.

The diversity of life on Earth is the result of an evolutionary process. This is a scientific fact.

The status of *fact* is not one that is attributed haphazardly or frivolously by scientists. Such a statement should not be understood as implying that evolution is a hypothesis – a tentative affirmation, subject to scrutiny – or a premise – an unchallengeable proposition, assumed to be true. Rather, the statement is the outcome of substantial confirmation by a considerable amount of observations and experiments, from a variety of perspectives that converge upon the conclusion that there is an evolutionary history, a conclusion agreed upon by a overwhelming majority of researchers.

That ‘evolution is a fact’ contrasts with stating that the diversity of life is the result of acts of creations, whereby individual species, or groups of species, were independently conceived. In this definition, I allowed for multiple events of creation, for throughout the history of *creationism* there have been several variants, most often resulting from the need to adjust to new observations or changes in world-view (e.g., that the Earth is more than 4 billion years old, rather than merely 6 thousand years). One such variant, catastrophism, espoused by the

18<sup>th</sup> century French naturalist George Cuvier, attempted to explain the variation in diversity on the geological scale of Earth’s history by occasional catastrophes, resulting in extinction (thereby explaining fossils), followed by new stages of creation. Some creationists also admit that species may change through time without branching (*anagenesis*), i.e., without the generation of new lineages or species. Therefore, other processes (or creation events) would be necessary to explain the origin of new lineages.

Both views have long histories. Most religions have creation myths, and the philosophical view of abounding change and transformation dates back to at least the 6<sup>th</sup> century BCE Greek philosopher Anaximander, the 4<sup>th</sup> century Chinese philosopher Zhuangzi, or the 8<sup>th</sup> century Arab philosopher Al-Jahiz, and more recently, Jean-Baptiste Lamarck, Erasmus Darwin (Charles Darwin’s grandfather) and Robert Chambers (who published *Vestiges of the Natural History of Creation*, anonymously).

One may thus contrast the two views, evolution vs. creation, as different answers to the

question of "Whence biological diversity?" Creationism replies "acts of creation", be they resulting from divine intervention or not, whereas evolutionism replies "through a historical process of transformation". While explaining diversity is at the crux of the debate, a second recurring theme is the origin of biological adaptations. Creationists appeal to the existence of a creator or intelligent designer, whereas a greater burden of proof was demanded of naturalist philosophers: discovering a natural process of change capable of producing adaptation.

*On the Origin of Species*, published in 1859, is of great importance in this debate, for in this volume Charles Darwin achieves two main objectives. Firstly, he puts forth a substantial amount of evidence, from a variety of organisms and fields of science, consistent with an evolutionary history of life, including the breeding of domestic species; the fossil record; the geographical distribution of species; and the morphological and embryological affinities among species, among which are "rudimentary, atrophied or aborted organs", structures without apparent function, such as vestigial eyes

in cave vertebrates or fetal teeth and posterior limbs in marine mammals. How are such structures to be comprehended if species were purportedly created by intelligent design? They are, in contrast, predictable if species encase their evolutionary histories. Secondly, he proposes a natural mechanism of change capable of explaining biological adaptations: natural selection; analogous to the process of transformation during domestication: artificial selection.

Whereas at the time, evolutionary history, as such, may have been taken as a hypothesis to be considered, tested and subjected to further scrutiny, this is not the case more than 150 years after the publication of the *Origin*. The scientific field of evolutionary biology has advanced considerably, not only within those branches already initiated by Darwin but also through the integration of new fields, including plate tectonics and, most significantly, genetics (providing a mechanistic explanation for heredity and the origin of heritable variation). For instance, despite inescapable limitations, the fossil record is now considerably more complete, and there are fossil series denoting evolu-

tionary change over long periods of time (millions of years), such as that reflecting the evolution of birds or humans, and even changes over small scales (decades), such as the evolution of the three-spined stickleback from its marine to fresh-water form.

Through the contributions of Sewall Wright, Ronald Fisher, John Haldane and many others, the field also evolved from a more descriptive science to one with a mathematical foundation. Direct observation and experiments, both in the laboratory and in nature, have shown evolution and natural selection at work. The intensive use of antibiotics, pesticides and herbicides have resulted in the evolution of resistant bacterial and agricultural pests, demonstrating that evolution not only occurs but that it can occur on a time scale that has significant impact upon human health and economies.

The use of molecular markers (e.g., proteins and DNA) have inferred relationships among taxa that, by and large, are coherent with those previously inferred from other types of information (e.g., morphology, embryology, geographical distribution). The study of molecular biol-

ogy across a variety of organisms (from bacteria and fungi, to plants and animals) has also revealed that, despite their diversity, they all share some fundamental characteristics: all use the same subset of nucleic acids as elements of heredity, all use the same subset of amino-acids in the composition of their proteins (and only the left-handed isomers), and (with small variations) most share the same genetic code, i.e., the translation from a sequence of three nucleic acids to amino-acids. This provides considerable support to a single origin of the diversity of life, rather than multiple events of creation.

It is important to distinguish between the notion of *evolution* from that of *natural selection*. Evolution simply implies change over time, albeit evidence suggests that biological history entails not only change within species or lineages (*anagenesis*), but also the multiplication of lineages (*cladogenesis*) thus giving rise to lineages that subsequently evolve independently. Additionally, evolutionary history also entails changes in diversity through extinction. Natural selection is an evolutionary mechanism, a particularly

important one as it is capable of leading to the evolution of adaptations. There are however other mechanisms of evolution, such as random drift (change due to stochastic events). The theory of evolution includes a broad area of research involving multiple scales, in time, space and hierarchical biological organization (from molecules to interactions among species), and involving the relative importance and interactions among several mechanisms. Within this field of research naturally there are points of discussion and controversy and there are specific questions as yet unanswered, as is the normal, and proper, condition of a scientific field. That the field of evolutionary biology is increasing in the number of researchers involved, in the number of research programs, in the variety of applications is a testament to its strength and vivacity as a science. The expression *theory of evolution* is thus a reference to this body of knowledge and research, and should not be confused with the use of the word *evolution* in the statement 'evolution is a fact'. Here the word is being used in its simpler meaning, of mere change and diversification through time.

It is the overwhelming amount of data and the diversity of their provenance, converging towards the conclusion that species bear within them traces of biological history, that sustain the statement that evolution is a fact. Before this span of evidence one must ask the question: are these observations more consistent with an evolutionary history or the independent creation of species? Those who cling to a general notion of creation of species must believe that the omnipotence of the Creator or the intelligence of the designer was not only responsible for the creation of living (and extinct) species, but also that they were endowed with characters that are consistent with a historic, evolutionary relationship among them. As Theodosius Dobzhansky put it:

*"They are blasphemies, accusing God of absurd deceitfulness. This is as revolting as it is uncalled for."*<sup>1</sup>

That evolution is a fact has been accepted by many religions, demonstrating that there is no contradiction between what biological science has

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1 Dobzhansky, T., 1973. Nothing in Biology Makes Sense Except in the Light of Evolution. *The American Biology Teacher*, 35: 125-129.

proven and one's religious faith. The manner in which a believer reconciles fact with faith is a personal one. However, the theory of evolution does pose a challenge to believers that perhaps other scientific theories did not pose so bluntly, particularly for those believers that accept laws discovered by science as divine rules, the means through which creation is conducted by God. For instance, Isaac Newton viewed that his role as a scientist was to unveil God's laws, and considered his mechanical laws as divinely ordained, a part of creation. In the 20<sup>th</sup> century, quantum mechanics, by attributing greater importance to stochastic events, famously led Albert Einstein to state that "*God does not play at dice*". Underlying his quote is the idea that if chance plays a role in physical events, how is the will and divine plan of the creator to be achieved. The stochastic events at the quantum level, however, do not translate into events at the human scale, and thus to some degree did not pose too dramatic a challenge.

When one considers the evolutionary history of life on Earth and admits the importance of chance events, with effects ranging from a small impact (such as the characteristics of an island population founded by a few random individuals run adrift) to a large impact (such as the events resulting in the extinction of over 96% of marine species and 70% of terrestrial vertebrates at the end of the Permian, possibly caused by multiple meteorite impacts), one is led to ask, as Steven Jay Gould, whether if we were to replay the tape of the history of life would the present be the same, including the existence of our species. The relative importance of chance in evolution is a matter of debate within evolutionary theory, but I think when considering the accumulated effects of chance events over the course of 4 billions years of life, one would be hard-pressed to dismiss it as insignificant. For a believer, who accepts evolution and its multiple mechanisms, this thus poses the question of the inevitability and importance of our species in god's Creation.