Coming to terms with biological evolution: a critique of the terms and perspectives embedded in the definition and description of some of its fundamental concepts

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Abstract

The abstract concepts embodied in the theory of biological evolution are difficult for most people to comprehend since humans are not genetically endowed with the cognitive mechanisms to directly perceive biological evolutionary events and must deal with them in a culturally derived intellectual manner. This can lead to inaccurate, misapplied, and poorly conceived terms, and the inappropriate changing of meanings of established terms. More effort should be made by authors when coining new terms or applying existing terms. By not addressing these issues of terms and meanings, future research may go in unproductive directions, thus delaying attainment of a better understanding of the mechanisms of biological evolution.

Keywords: biological evolution, evolutionary terms, science education

Introduction

From the time of the publication of Darwin's *On the Origin of Species* (Darwin 1859), there have existed problems of misunderstanding and misapplication of fundamental concepts in the science of biological evolution, particularly concepts such as random variation, non-random natural selection and descent with modification from a common ancestor. This is despite claims by scientists (Gould 1996; Mayr 1997; Dawkins, 2009), that the concept of natural selection is simple to understand. For example, Weismann (1909) quoted T H Huxley as saying about Darwin's idea of natural selection: "How extremely stupid not to have thought of that."

However, it is evident that a majority of people, even when exposed to biological education, have difficulty in accurately grasping the fundamental concepts of biological evolution. Bishop & Anderson (1990) found that college students who had previously studied biology had three main misconceptions about biological evolution: (1) a teleological or need-driven idea of the adaptive process; (2) variation of traits within a population and subsequent differences in reproductive success were not recognised; and (3) a gradual variation of traits was perceived to occur in all members of the population at the same time. Gregory & Ellis (2009) studied students undertaking an advanced postgraduate degree in science and found that while post-graduate students had a better understanding of concepts of biological evolution than students at lower levels, there were still persistent misconceptions and a lack of working knowledge of biological evolutionary mechanisms even at this advanced level. Many other authors have observed a similar situation in studies of various groups from primary school level to secondary school level biology teachers (Demastes *et al.* 1995; Jensen & Findley 1996; Larreamendy-Joerns & Ohlsson 1995; Ohlsson 1991; Zuzovsky 1994).

While various authors have put forward explanations for the continued misunderstanding of biological evolutionary concepts (*e.g.*, the naïve schema of Larreamendy-Joerns & Ohlsson 1995; the event *versus* equilibration ontology of Ferrari & Chi 1998; or the prior disposition, understanding and parents' education level, determined by Deniz *et al.* 2008), in this paper I suggest that part of the problem is etymologically related in that the embedded meanings of the terms and language employed in defining and describing the fundamental concepts of biological evolution create a (non-conscious) bias in the mind of the user towards a way of thinking that is non-scientific and inapplicable to the actual processes of biological evolution. Further, although the concepts of biological evolution such as natural selection, adaptation, common ancestry, *etc.*, appear straight-forward and simple to understand, these ideas contain abstract, statistical and temporal aspects which are not necessarily compatible with the natural perceptual and cognitive abilities of the human brain. Thus, throughout the paper there will be discussion of two ideas: (1) that of the problems with terminology including misleading, misappropriate or misapplied terms and (2) that of the genetic ("hardwired") nature of human neurologically-based cognitive and perceptual frameworks, particularly in relation to language. In fact, the two ideas are inter-related, in that the nature of human "hardwiring" and its effect on cognitive and perceptual frameworks leads to the misunderstanding of concepts, and the coining and use of misleading, misappropriate or misapplied terms.

The impact of words

Terms have different meanings to different scientists (and people in general, for that matter), depending on their path in life, or background, and the meaning conveyed to readers may not always be the one intended by the writer. Further, not all scientists fully understand the use of terms in their own discipline, or that in other related disciplines, nor can they coin appropriate terms. The misapplication of terms in the history of science, and the changes in meaning of a term in the history of a given discipline provide examples of this problem. Such misinterpretations, misapplications, and misunderstandings, and evolution of the meanings of terms is particularly relevant to the theory of biological evolution, as it is an arena that is mired in controversy, and terms need to be explicit, precise, and not open to misapplication and misinterpretation. Unfortunately, this is not the case, and I proffer the notion that two of the problems in the controversy and debate in biological evolution resides in: (1) the misuse, poor definition, and misunderstanding of terms; and (2) the incorrect and inappropriate coining of terms. These terms can create erroneous perceptions of what constitutes biological evolution, create resistance to the idea of biological evolution, and mislead research directions.

The influence of words on human emotions and thinking has been noted by philosophers and scientists from early in recorded history to the present day. Buddha in the 5th Century BC, advised that "*Whatever words we utter should be chosen with care, for people will hear them and be influenced by them for good or evil*." This can be modified to the theme of this paper as: "*Whatever words we utter should be chosen with care, for people will hear them and be influenced by them from their own perception, training and background*." Carl von Linné (Linnaeus 1707–1778) wrote: *Nomina si nescis, perit cognitio rerum* (If you ignore names, actual knowledge vanishes). Mark Twain (Samuel Clemens), a 19th Century author and social commentator, observed (as related in Paine 1917) that "A powerful agent is the right word: it lights the reader's way and makes it plain." Clearly, words are an important part of communication, and they are an important pathway for lighting the way to further and deeper understanding of a given subject matter.

Recent psychological and neurological studies have investigated how language, human behaviour and neural structures are interrelated (Chomsky 1965; Liberman & Whalen 2000; Scott & Johnsrude 2003; Coppola & Newport 2005; Dehaene-Lambertz *et al.* 2006; Friederici *et al.* 2006; Goldberg 2008; Ledoux & Camblin 2008). Several parts of the human brain are involved in language processing, particularly in the left hemisphere, such as Broca's area, Wernicke's area, and the inferior parietal lobule (Geschwind's territory), so an argument can be made that human response to words, while having cultural causative factors (*i.e.,* each culture has developed its own language and word meanings), also has genetic and hence biological evolutionary underpinnings. Human languages (and the underlying anatomical neural areas) have developed in a social context within common experiences of the physical world and largely deal with a timescale spanning the current instant (several seconds) to a person's lifetime (ideally spanning ~ 80–100 years). In that situation, does it matter that words may have imprecise or multiple meanings? After all, there are many non-verbal cues in social contexts which re-enforce verbal meanings. My thesis in this paper is that it *does* matter when an objective description is required, of processes (*e.g.*, biological evolution, quantum mechanics, amongst others) which occur in the physical world and may have no relation to human social contexts or human time-scales, or common, everyday experiences. Thus, for many of the experiences and natural phenomena described by scientists, there is generally no direct human experience as a calibration, and hence it becomes even more important that words, terms and meanings are correctly conveyed. This is the realm of scientific terminology where nomenclature forms the basis of description and classification as employed in the Scientific Method, and is essential to Science and its communication.

Inherent in the principle of the Scientific Method is the assumption that the language or terms employed in scientific studies are defined such that there is a common understanding of the ideas being conveyed. This understanding of defined terms is a critical component in the process of reproducibility of results, without which scientists cannot be certain that they are talking unambiguously about the same topic. An example of an area where the clarity of scientific terminology is particularly important is in forensic science, especially in criminal cases where non-scientist members of the jury and judiciary are struggling to understand the expert evidence that may or may not convict a person (Edmond 2002).

Unfortunately, scientists are not perfectly logical machines, and the terms that they assign to phenomena are a product of the existing scientific knowledge, perpetuation of erroneous ideas, and the current culture of the times in which the scientists live. The convention of positive to negative flow of electricity in an electrical circuit is an example of the perpetuation of erroneous ideas. An initial conclusion (based on the observations and equipment available in the 1700s), was later proven erroneous (electrons flow from negative potentials to positive potentials as discovered in the early 1900s), however, the original terms are retained to the continuing confusion of innumerable high school students and university students. On the other hand, the meanings of terms in a discipline often evolve with various practitioners redefining the terms in the literature according to their own interpretations and this process may lead to confusion (Fallon & Smyth, 2009), and employing a term with a changed meaning.

To illustrate this principle, an example is borrowed from the discipline of sedimentology. Sedimentologists have employed an adjectival term "sedimentary", to refer to unconsolidated geological material (*e.g.*, sedimentary deposit), but the adjective has also been incorrectly applied to the study of rocks derived from sedimentary materials resulting in the oxymoron "sedimentary petrology". Consider the etymological evolution of the adjective "sedimentary": it has changed in its use in referring to a sediment, to a sedimentary deposit, to a sedimentary rock (change in the strict meaning of "sedimentary"), to sedimentary petrology (another change in the strict meaning of "sedimentary", in that petrology cannot be "sedimentary"), to sedimentary research, *e.g.*, The Journal of Sedimentary Research (where it is implied that the phrase "sedimentary research" conveys the meaning of "research into sedimentary materials, and rocks deriving from sediments, and the petrology of those sediments and sedimentary rocks). The meaning embedded in the adjective "sedimentary" in "sedimentary research" is very different from that in "sedimentary deposit".

Critique of terms in biological evolution

This brings us to the confusing and sometimes unfortunate terms existing in the area of biological evolution. There are many commonly misused, misleading, misunderstood, inappropriate or not well conceptualised terms extant in the biological evolutionary literature and a selection of these is presented in Table 1. Several problematical terms are discussed in detail below.

Darwin himself has the distinction of proposing one of the most misleading terms in the concepts of biological evolution, *viz.*, "natural selection". It was a term that Darwin came to regret, as shown in a letter to his friend Charles Lyell in 1860, where Darwin wrote "Talking of 'Natural Selection', if I had to commence *de novo*, I would have used 'natural preservation'; for I find men like Harvey of Dublin cannot understand me" (Burkhardt *et al*. 1993).

Later, in a letter to the Irish botanist W H Harvey, Darwin replied in part "The term 'Selection' I see deceives many persons; though I see no more reason why it should than *elective* affinity, as used by the old chemists. If I had to rewrite my book, I would use 'natural preservation' or 'naturally preserved'" (Burkhardt *et al*. 1993).

The problem with "natural selection" is that embedded in the word "selection" is the implication of choice by a living agent. The act of selection does not apply to inanimate processes, which is a problem since the process of differential survival and reproduction of organisms (termed as "natural selection") *is* an inanimate, deterministic occurrence, *viz*., the action of

Table 1

Examples of terms employed in the area of biological evolution which are either often misunderstood and consequently misapplied, or poorly designed as conceptual explanatory terms.

Adapt: "to fit"; should be used only for species/populations, not individuals, and only in the intransitive sense *e.g.* "animals have become adapted to their environment", not "the animal adapts to its environment" or "the animal *learns* to [physically] adapt"

Biological evolution: a term that should be used instead of "evolutionary biology" where the main topic, "evolution", has been transformed into a descriptor

Design: a word that should not be applied to a deterministic process such as biological evolution which evidences a variety of states that range from poorly organised to complex

Darwinism: philosophy based on Charles Darwin's ideas; the word has no place in a scientific discussion of biological evolution where "Charles Darwin's concept of evolution" would be more appropriate; one does not see the words "Newtonism" or "Einsteinism" employed in scientific writing

Evo-devo: an unscientific abbreviation of the phrase "evolutionary development biology"; ontogenological phylogeny would more accurately describe this area of study

Evolution: "unrolling" or gradual development; the word has become synonymous with biological evolution, whereas there is evolution of landscape, magmas, societies, language, amongst others; a natural process that should never be personified

Fitness: the success of an organism in surviving in its environment and reproducing its genetic material into the next generation; mistakenly perceived as only physical strength as in "Survival of the Fittest"= survival of the strongest or most aggressive, which is not always the case (*cf*. biological altruism)

Gene: a sequence of nucleotides coding for a protein; by definition, a "non-coding gene" is an oxymoron; exclusive focus by scientists on genes has resulted in a public perception that genes comprise the total genetic material of an organism whereas in reality, genes form only ~ 2% of the DNA (in humans)

Junk DNA: a somewhat short-sighted term for non-coding DNA which comprises 98% of human genetic material. Now found to have important regulatory functions in gene expression

Natural Selection: Darwin acknowledged that this phrase had unintended connotations (the concept of a "Selector"); often personified as in "Natural selection chooses…"; an alternative phrase such as "environment-constrained differential phenotype survival" might be more accurate

Orthogenesis: hypothesis that biological evolution is an intrinsic drive towards perfection; confusing and discredited term

Primitive characters: misleading term for antecedent characters in a lineage; these characters may be quite complex

Random mutation: change in the DNA that is unpredictable by current scientific models; often conflated with biological evolution, ignoring environment-constrained differential phenotype survival (natural selection) which is deterministic, NOT random environmental pressures on variable organisms. It is understandable as to why Darwin chose the term "natural selection". He was concerned that people would not understand or accept the truth of his conclusions, particularly because of the controversial nature of eliminating a need for a Deity in the development of new species. Therefore, he accumulated a vast number of examples of artificial selection (*i.e.*, selective breeding, with himself as the "selector") amongst domestic plants and animals (especially pigeons), producing variation and different "types" (Darwin 1859). He then introduced the concept of "natural selection" as the natural equivalent of "artificial selection" in the hope that people could easily grasp the concept that the same process occurred amongst non-domesticated organisms as in domesticated organisms. The problem begins here, because in his analogous examples involving selective breeding, Darwin in fact *was* a "selector", while natural processes that inanimately exert pressure on organisms are not.

As a direct consequence of the animistic nature of the word "selection", authors and teachers explaining this fundamental concept inexorably personify the term into "Natural Selection" (note capitalisation), which "chooses" or "selects for" a particular event to happen. Even a populariser of biological evolution, the biologist Richard Dawkins, wrote that "Natural Selection chooses…", adding the qualifier that this was the incorrect use of the term but "we know what is meant" (Dawkins 2009). It is evident from the body of work, mentioned previously, on the misunderstanding of biological evolutionary concepts (including natural selection), that students in particular, do *not* know.

Proponents of biological evolution theory have a responsibility to explain the fundamental concepts as accurately as possible and this may involve coining original terms. Dawkins did not do this when he employed a familiar, well-defined human emotional term in describing the genetic basis of altruism as "selfish genes" (Dawkins 1976), and re-defining the meaning of the word "selfish" as being successful in the processes of biological evolution. Brown (1999) relates the furore created by the use of the connotatively morally negative word "selfish", which was taken literally and engendered two main objections: (1) genes, as simple, non-sentient matter, axiomatically are incapable of a complex animal behavioural attribute such as selfishness, and (2) there was resistance to the idea that an advanced human moral quality such as altruism could be the product of mere genes, particularly selfish ones. Perhaps there would have been a better reception of Dawkin's ideas if he had used the phrase "co-operative genes" although this would still be misleading as the word "co-operative" implies intent and purpose on behalf of the genes.

Such purpose-driven explanations incorporated into biological phenomena are espoused in Aristotle's idea of the "Scala Naturae", otherwise known as the "Ladder of Life" or the "Great Chain of Being", a classification of the living world where all species are arrayed in hierarchical order linearly from primitive organisms to the advanced perfection of Humanity. Aristotle's classification was a reasonable model given the knowledge that he had at the time, but one that has been superseded by a greater body of scientific information accumulated since then. However, the fact that the "Great Chain of Being" idea has persisted throughout history in various guises (Lovejoy 1936; Bynum 1975) supports the idea of an anthropocentric bias in human perceptual frameworks. That is, Lovejoy's unit ideas of "plentitude, continuity and gradation" reflects genetic behaviours involved in survival such as obtaining food, reproduction and social hierarchy. This tendency for the human condition to be reflected in the perception of natural order has been noted previously (Durkheim & Mauss 1903).

The terms "primitive" and "advanced" as applied to the more appropriately termed antecedent or derivative, respectively, characters in an organism's lineage are misleading as the word "primitive" is usually equated with "simple" and a primitive character may actually be very complex. Chloroplasts, for example, are considered a primitive character of vascular plants, although, in fact, these organelles are relatively complex. The word "character" also is confusing and poorly defined, as it can refer to a range of features from molecular to morphological, to behavioural, and be applied to a range of taxonomic levels from individual, to species, to clades. That is, the term "character" has different meanings in different disciplines, and even different meanings within the same discipline. Use of this term, therefore, does not convey explicit meaning.

An example of how the meaning of terms can evolve is shown in the history of the term "orthogenesis". Orthogenesis was a popular idea in the 19th and early 20th Centuries, and originally represented the hypothesis of an intrinsic lateral direction in the development of life, and later became conflated with teleological ideas where evolution was unidirectional towards a perfect goal as in "progressive evolution" (*e.g.,* the increasing complexity of organisms from simple prokaryotes to complex eukaryotes culminates in the superior complexity of humans [Bonner 1988]). Orthogenetic ideas became discredited by palaeontological evidence of non-linearity in the fossil record. However, some modern researchers now employ the term "orthogenetic" to describe a local linear trend in the evolution of a trait within a species (Jacobs *et al.* 1995), thus changing its meaning yet again.

Regardless of the discrediting of the orthogenesis idea, the impression of direction and progress in biological evolution still persists among the general public (Scott 1999). This is in spite of the fossil evidence. Additionally, there are many examples of extant lineages producing less complex organisms from complex ancestors (non-linear biological evolution) as, for example, in mites (Walter & Proctor 1999) and parasitic flatworms (Poulin 2006). Other evidence against orthogenesis includes: 1) the vast bulk of life on Earth consists of prokaryotes (and if "progressive" biological evolution has been occurring for ~ 4 billion years, then life on Earth should be dominated by complex forms); 2) there exist prokaryotes and eukaryotes with a range of structural complexity from a microscopic bacterium to a macroscopic cetacean, all *concurrently* undergoing the processes of biological evolution with the result that a modern prokaryote is often more complex than an ancestral prokaryote (biological evolution should only be occurring in the most "progressive" stage if a linear progression is true); 3) many organisms (*e.g.,* the rice plant, *Oryza sativa*) have more complex genomes than that of humans, and 4) cross-species or horizontal gene transfer (Syvanen 1985; Rumpho *et al.* 2008) occurs, thereby eliminating the idea of a unidirectional linear progression of genetic material. As a dénouement of the orthogenetic hypothesis and challenging the teleological and anthropocentric idea that humans, as the most complex organism on Earth (due to their complex brain), are the final goal of biological evolution, recent research has shown that humans have an invertebrate rival for neuronal complexity in coleoid cephalopods (Wollesen *et al.* 2009).

The fact that the idea of "progressive" biological evolution persists, despite the overwhelming evidence against it, is interesting as this phenomenon illustrates more about the cognitive behaviour of humans than any empirical reality of the idea. A possible explanation for persistence of erroneous ideas in the face of empirical evidence is that humans may have cognitive filters in pattern recognition (Van Essen *et al.* 1991) or cognitive frameworks in reasoning (Stenning & van Lambalgen 2008) that predicate them towards deriving false correlations from natural data. In the case of "progressive" evolution, the logic proceeds as follows: eukaryotes biologically evolved from prokaryote organisms (true), and multi-celled organisms are structurally more complex than single-celled organisms (true), and therefore biological evolution is directed towards increasing complexity (false).

One of the most misunderstood words in biological evolution is "random" as in "random genetic mutation". Since events occur axiomatically in a deterministic fashion, nothing is "random", not even genetic mutations – there is just not enough information currently available to predict their occurrence. French astronomer and mathematician Pierre-Simon Laplace was confident that the universe is not random (Laplace 1814) when he wrote the following words:

> *We ought to then regard the present state of the universe as the effect of its anterior state and as the cause of the one which is to follow. Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective situation of the beings who compose it – an intelligence sufficiently vast to submit these data to analysis – it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be uncertain and the future, as the past, would be present to its eyes.* (Translation from Truscott & Emory 1902)

Thus "random" as employed in biological evolution refers to a causal event that is unpredictable as to its occurrence in time and place. The word "random" is often equated with the word "chance" to mean an unpredictable event of unknown cause.

A common misunderstanding of biological evolution is that complex anatomical structures (such as complex eyes) develop *entirely* by chance, which seems impossible. However, chance does not operate in isolation. Complex anatomical structures are a resultant of a cumulative two-stage process: 1) random (chance) genetic mutations in individuals producing variant phenotypes; and 2) differential survival and reproductive success of these phenotypes. Where are the terms that accurately describe and encapsulate this process? Why in the 150 years since Darwin put forward the self-acknowledged inadequate term "natural selection" have no researchers advanced more appropriate terms? An explanation may be that humans generally comprehend simple events better than complex abstract and long term processes, and have neurological systems that cope with either routine common events or novel events (Sitnikova, Holcomb & Kuperberg 2008). Examples abound where scientists and engineers reduce complex, non-linear, and interacting phenomena to simple models in order to cope with understanding them. Perception of biological evolutionary processes has not been necessary for human survival or reproductive success, unlike as for example, perception of the ecological process of predation or the process of reproduction, for which humans have genetic behaviours, and hence I suggest that there is not the genetic "hard wiring" to adequately address the complexities of biological evolution.

"Junk" DNA (Ohno 1972) illustrates an important principle in how terms and words are misapplied, and how there is (potential) creation of misperceptions with ramifications for future research directions. Without fully understanding the function of "junk" DNA, supposedly "non-coding" DNA regions were interpreted to be non-functional genetic relicts, and this interpretation led to molecular biologists focusing on only the 5 % of DNA which coded for proteins and ignoring 95 % of *the entire human genome* for almost 40 years! A term should have been utilised that was objectively descriptive, and that would survive acquisition of additional information, since the use of the adjective "junk" now has to be abandoned, as more information on the functionality of this "junk" DNA has been obtained. Sections of "junk DNA" termed transposable elements, comprising ~ 50 % of the human genome (Smit 1999) have been recognised (retrospectively in some cases), to have a regulatory effect in gene expression (McClintock 1965; Thornburg *et al.* 2006) and cell differentiation (Britten & Davidson 1969), so perhaps the "junk" term will be relegated to the trash bin.

Conclusions

The abstract concepts embodied in biological evolution are difficult for most people to comprehend, since the processes involved occur either over long time-scales or at the microscopic genetic level. As discussed above, humans are not genetically endowed with the cognitive mechanisms to directly perceive biological evolutionary events and must deal with them in a culturally derived intellectual manner. This can lead to inaccurate, misapplied, and poorly conceived terms, and to the inappropriate changing of meanings of established terms. The coining and continued use of inaccurate, misapplied, and poorly conceived terms has only added to the problem of understanding biological evolution. While the scientific discipline of biological evolution is not unique in having a proliferation of confusing or misleading terms (Barrass 1979), more effort than shown in the past should be made by authors when coining new terms or applying existing terms. Terms should be descriptive and not genetic[1], such that the meaning of the word can be "unpacked". Other considerations involved in coining a new term include consideration of the relevant scientific history and possible future directions of the research (whether the new term has older connotations, or whether the term is "fashionable" and likely therefore to become out-dated), and consideration of the cognitive impact of the term (*i.e.*, will the term fit into human language/perception schema, or be invisible in that people will not understand and will ignore it). By not addressing these issues of terms and meanings, future research may go in unproductive directions and resources may be wasted, thus delaying attainment of a better understanding of the mechanisms of biological evolution.

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[1] The term "genetic" is used in the sense of origin, and does not refer to the discipline of genetics. Terms and classification systems may be descriptive, *e.g.*, the phrase "quartz sandstone" is comprised of descriptive terms, and simply provides a description of what is at hand. Alternatively, terms may be genetic, referring to how an author infers something has formed, *e.g.*, the term "aeolianite", implying that the material has been deposited or formed by aeolian processes. In the latter case, if the origin of the material eventually is re-interpreted as non-aeolian then the term "aeolianite" has to be revised. It is therefore preferable to have non-genetic, descriptive terms and classification systems, rather than genetic terms.

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