SOME MISLEADING CONCEPTS AND INTERPRETATIONS IN EVOLUTIONARY BIOLOGY

Julio E. Pérez, Carmen Alfonsi and Sinatra K. Salazar

SUMMARY

The scientific community at large accepts evolution as the cornerstone of the life sciences, but many people do not agree or understand it, mainly because of wrong concepts and interpretations used by teachers, texts, and the media. The concepts include: evolution, facts, hypotheses, laws, and theories, which nurture the confusion regarding the importance of laws and theories. As regards interpretations, they include: the idea of the directionality of evolution; the acceptance of Lamarck's ideas; the intentionality of evolution. The correct use of evolutionary concepts and interpretations would lead to a greater acceptance of evolutionary theory by the community at large.

Introduction

Evolution is a process that occupies a central position in the life sciences. However, although the scientific community at large has accepted that evolution is the unifying principle in biology, unfortunately, many people have misconceptions about evolution. Some of these misconceptions are misleading notions; others are understandings or ideas that develop in the course of learning about evolution, possibly from school experiences and/or from the media.

In preparing their classes, many science teachers use books riddled with misconceptions. Many teachers also have an inadequate knowledge of evolution, thus feeling understandably insecure and unable to motivate their students. The content, its graphic representation, or the language of the textbooks used, can be the origin of the erroneous conceptions often held by students (González-García and Tamayo-Hurtado, 2000). In science journals and textbooks, but especially in popular science publications, one of the main errors is a tendency to misuse the words hypothesis and theory. In plain, everyday language, these words can be used interchangeably, but the scientific literature must be careful to distinguish between these two terms.

Partly as a consequence of the above, surveys such as those conducted by Miller *et al.* (2006) in general populations of 32 European countries, Japan and United States, and by Pérez *et al*. (2009) among biology students and teachers of Panamá, Chile and Venezuela, reflect a low acceptance of evolution. It seems appropriate and necessary to analyze the situation to ensure a clear understanding of evolution. Therefore, the purpose of

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Julio E Pérez. M.A. in Zoology, University of Kansas, USA. Ph.D. in Biology, University of Southampton, UK. Professor, Instituto Oceanográfico de Venezuela (IOV), Universidad de Oriente (UDO), Venezuela. Address: Instituto Oceanográfico de Venezuela, Universidad de Oriente, Núcleo Sucre, Cumaná, Venezuela. e-mail: jeperezr@yahoo.com

Carmen Alfonsi. M.Sc. in Marine Sciences, IOV-UDO, Venezuela. Dr. in Zoology, Universidad Central de Venezuela. Professor, IOV-UDO, Venezuela. e-mail: calfonsi@sucre.udo.edu.ve

Sinatra K. Salazar. Doctor in Marine Science, IOV-UDO, Venezuela. Professor, UDO, Venezuela.

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RESUMEN

La comunidad científica en general, acepta la evolución como la piedra angular de las ciencias de la vida. Pero muchas personas no la comprenden o no están de acuerdo con ella, debido principalmente a conceptos e interpretaciones erradas, usadas por los profesores, textos y los medios de comunicación. Los conceptos incluyen: evolución, hechos, hipótesis, leyes y teorías, lo cual aumenta la confusión referente a la importancia de leyes y teorías. En cuanto a las interpretaciones estas incluyen: la idea de la direccionalidad de la evolución, la aceptación de las ideas de Lamarck y la intencionalidad de la evolución. El correcto uso de los conceptos e interpretaciones evolutivas conducirán a una mayor aceptación de la teoría evolutiva por la comunidad en general.

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RESUMO

A comunidade científica em geral, aceita a evolução como a pedra angular das ciências da vida. Mas muitas pessoas não compreendem ou não estão de acordo com ela, devido principalmente a conceitos e interpretações erradas, usadas pelos professores, textos e os meios de comunicação. Os conceitos incluem: evolução, fatos, hipóteses, leis e teorias, o qual aumenta a confusão referente à importância de leis e teorias. Quanto às interpretações estas incluem: a ideia da direcionalidade da evolução, a aceitação das ideias de Lamarck e a intencionalidade da evolução. O correto uso dos conceitos e interpretações evolutivas conduzirá a uma maior aceitação da teoria evolutiva pela comunidade em geral.

this paper is to identify some persistent misconceptions in evolutionary biology that are broadly found not only in textbooks and popular science publications, but also in scientific journals; and to stimulate awareness and discussion regarding them in order to produce a template for a more logical, historically and scientifically correct treatment of evolutionary terms and concepts. A forthright discussion of ambiguities should eventually improve the presentation of evolution to the public.

Misleading Evolutionary Concepts

An important cause that determines the low acceptance of evolution is the confusion created by the employment of several misleading concepts, such as evolution, fact, hypothesis, theory, and law (Scott and Branch, 2009; Allmon, 2011).

Evolution

Evolution as a fact is not currently the subject of debate. The scientific community accepts evolution as a change of hereditary properties in a population over generations. The definition of evolution, summarized by Darwin in just three words: 'descent with modification'. On the other hand, the mechanisms explaining the transformation and diversification of species (evolutionary theory) are still under intense scientific scrutiny; and new hypotheses, based on empirical data from living organisms about mechanisms of evolutionary change are emerging (Pérez *et al.*, 2010). These differing concepts (fact and theory) sometimes create confusion.

Fact

The common use of this term indicates its invariability; however, this is not true. The National Center for Science Education (NCSE, 2008) defines fact: "In science, an observation that has been repeatedly confirmed and for all practical purposes is accepted as 'true'. Truth in science, however, is never final and what is accepted as a fact today may be modified or even discarded tomorrow". Fact does not mean absolute certainty. Gould (1981) gave us another interesting definition: "In science fact can only mean confirmed to such a degree that it would be perverse to withhold provisional assent".

Hypothesis

Hypothesis is "a tentative statement about the natural world leading to deductions that can be tested. If the deductions are verified, the hypothesis is provisionally corroborated. If the deductions are incorrect, the original hypothesis is proved false and must be abandoned or modified. Hypotheses can be used to build more complex inferences and explanations" (NCSE, 2008).

Glenn Branch (personal communication) adds that it is usually necessary to appeal to auxiliary assumptions when the experiment fails to verify the predictions; it may be those assumptions and not the hypotheses that are wrong.

Science writers have a tendency to misuse the words hypothesis and theory. In the vernacular these two words can be used interchangeably (Cushing, 2004). As indicated by Gregory (2008) no matter what the information, a hypothesis never becomes a theory.

Law

In science, law, as defined by NCSE (2008) is: "A descriptive generalization about how some aspect of the natural world behaves under stated circumstances". Laws are important but they rarely explain natural phenomena. That is the role of the final stage in the hierarchy of explanation: theory.

Scientific laws are not immutable (as most people believe); these can change or not hold under some conditions. When apparent counterexamples to a law are discovered, it is often necessary to a) discard the supposed law as not genuine; or b) modify the law, this option being the most frequent (Gregory, 2008).

Let us use an example given by Scott (2009): "Mendel's law of independent assortment tells us that the hereditary factors will behave independently as they are passed down from generation to generation". But later it was found that the law can be 'broken' if the genes are very closely associated on the same chromosome. Is it the proper reaction to conclude that Mendel just got it wrong, and to discard the law altogether? But Mendel was clearly detecting a real pattern in his data, so discarding the law altogether would have been an overreaction. So, he might have concluded that the law of

independent assortment needed to be restricted to different genes that are on different chromosomes or not closely linked during gamete formation.

Theory

Theory is the most misunderstood word in science. In popular usage, theory means guess or hunch; however, according to NCSE (2008), theory in science is "a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses." However, Glenn Branch (personal communication) disagrees with the inclusion of the term 'well-substantiated', which makes it impossible to refer to obsolete theories.

Theories, therefore, are more important than hypotheses, laws, and facts; and thus scientists place them at the top of the hierarchy of explanation (Scott, 2009).

A theory is an explanation rather than a guess. Unfortunately many high school (and even, some college) textbooks describe theories as tested hypotheses, as if a hypothesis that is confirmed is somehow promoted to a theory. As Branch and Mead (2008) indicated, despite the efforts, the vernacular use of the term theory persists.

Evolutionary theory includes several aspects submitted for discussion under hypotheses. This situation indicates that we are dealing with a theory in constant revision**.** For example one of the most controversial topics analyzed by Darwin (1859) was the origin of the asymmetrical skulls with both eyes on one side of the head, in the flatfish.

The Flatfish Eye: Hypotheses on the Evolutionary Theory

Adult flatfish have asymmetrical bodies with both eyes on one side of the head. This asymmetry has long been difficult to understand (Darwin, 1859). From the study of the peculiar anatomy of flatfish two questions arise. First, how did this asymmetry start? Second, can the presence of both eyes on one side of the head be explained by a gradual effect of natural selection? Darwin (1859) accepted the hypothesis that during metamorphosis the Pleuronectiformes symmetrical larvae could not long retain a vertical position because of the excessive depth of their bodies and the loss of the swim bladder.

The larvae sink to the bottom, lying on its blind side on the underlying surface. Dawkins (1986) added "But this raised the problem that one eye was always looking down into the sand and was effectively useless. In evolution this problem was solved by the lower eye 'moving' round to the upper side."

It seems that, in the development of asymmetrical bodies in flatfish, a very important factor is the loss of the swim bladder. However, there are several fish groups (i.e. Gobiesocidae, Saccopharyngiformes, Aulopiformes, Synbranchidae, and Blenniidae, among others) that have also lost the swim bladder but are symmetrical. The explanation: their bodies are not laterally compressed. Molidae, however, although laterally compressed and lacking a swim bladder, possess symmetrical bodies. Therefore, that family has developed a different solution to maintain equilibrium and buoyancy. It was demonstrated that, despite missing a swim bladder, *Mola mola* are neutrally buoyant in sea water, and that a thick layer of low density, subcutaneous, gelatinous tissue plays a major role in providing such buoyancy (Pope *et al*., 2010). That gelatinous tissue is uncompressible, enabling rapid depth changes without the changes in buoyancy that would be experienced by fish possessing a swim bladder. Its skeleton is mostly poorly ossified, made of cartilage that also likely contributes to buoyancy (Pope *et al*., 2010).

Some evolutionary biologists, including Darwin, have argued that the trait evolved gradually over many generations of flatfish. However, since Darwin did not find an intermediate fossil (in relation to the position of the moving eye), this situation led to attacks on natural selection and arguments for saltatory change. The situation changed when Friedman (2008, 2012) found two different genera (*Amphitium* and *Heteronectes*) of extinct spiny-finned fishes from the Eocene period of Europe. Those fossil fishes had their eyes in different places on the two sides of their skulls, one in normal position and the other closer to midline. The specimens were adults, not larvae with migrating eyes. The hypothesis to explain the movement of one of these eyes**,** according to Friedman (2008, 2012), is that the evolution of the cranial asymmetry of extant flatfish was gradual in a way consistent with evolution via natural selection, not sudden. Both the initial and final states make sense because they offer evolutionary advantages for swimming in open water or along the bottom. However, the intermediate forms seem to offer no clear advantage for natural selection to act.

In conclusion, based the facts presented, we think that it is possible to find many hypotheses on the migration of the flatfish eye, some of them tested hypotheses that will enrich the evolutionary theory.

The hypotheses are:

a) Migration of eyes is gradual, with natural selection operating. This hypothesis is provisionally corroborated.
b) The intermediate forms offer no obvious advantages for natural selection. The initial and final states make sense, to swim in open water or along the bottom.
c) The asymmetrical eyes may allow fishes to simultaneously bottom-feed and watch for predators above. Hypothesis provisionally corroborated.
d) The loss of the swim-bladder could be a key to the asymmetry.

Misleading Evolutionary Interpretations

Most of these misunderstandings are predicated on the assumption that evolution proceeds straightforwardly, and that somehow individuals exert an influence on their own evolution.

a. Evolution proceeds straightforwardly in a particular direction (Linear unidirectional evolution view): Biological evolution timelines and biological evolution representations, commonly seen in books and media, show a sequence such as bacteria-jellyfish-trilobite-dinosaur-mammoth. These timelines may give the impression that disparate forms evolved into each other. Clearly, these timelines are intended to show the dominant life forms during geologic eras, but they could mislead. Conceptually, a more appropriate timeline would depict branch evolution rather than replacement. There are evolutionary trends of many kinds, but organisms do not move to a point on an evolutionary continuum; therefore, it is better to avoid language that suggests it (Padian, 2013). In relation to human evolution one must keep in mind that humans did not evolve from chimpanzees; humans and chimpanzees share a recent common ancestor that was neither chimpanzee nor human.

b. Lamarckian thought: A common misconception among students is the Lamarckian idea that an organism can transmit the traits acquired during its lifetime to its progeny, two main points (use and disuse) in the theory of Lamarck - the inheritance of acquired characteristics.

Darwin refuted the Lamarckian notion that variation arises through parental experience mechanisms of inheritance, although he admitted the Lamarckian ideas of use and disuse. In *The Origin of Species* he wrote that the vestigial eyes of both moles and

cave dwelling animals are "probably due to gradual reduction from disuse, but aided perhaps by natural selection." Leys *et al.* (2005) hypothesized that permanent loss of eyes in subterranean animals results from the slow accumulation of mutations, in the absence of purifying selection, that inactivate genes specific to the eye development pathway.

The theory of Lamarck entered in conflict with the findings of genetics and was largely abandoned. However, new scientific advances as adaptive mutations (a new kind of mutations that differs from spontaneous mutation and appears to be induced by stress; Rosenberg and Hastings, 2004) and epigenetic processes (a suite of interacting molecular mechanisms that alter gene expression and function without changes in DNA sequences) that occur at the molecular level in particular organisms under stress conditions (Richards, 2006), rekindled a new interest in some Lamarckian ideas such as that variance in a population can arise and be maintained by environmental effects, at least at the molecular level.

These changes make it difficult for teachers and textbooks to avoid misconceptions.

c. Organisms that 'try to evolve' and evolution have intentionality: Natural selection has no intentions; it cannot sense what a species 'needs'. If a population happens to have the genetic variation that allows some individuals overcome a particular challenge better than other individuals can overcome the same challenge, then those individuals will have more offspring in the next generation, and the population will evolve.

Evolution does not design new organisms; rather, new organisms emerge from the inherent genetic variation that occurs in them. Yet, some books, popular publications, and even scientific journals continue to publish the misleading conception of 'evolve for', purpose or intentionality in evolution, giving the impression that there is a direction to evolve to.

Padian (2013), for instance, illustrates this kind of misguidance with this example: feathers did not evolve 'for' flight. They were already performing several functions (such as thermal insulation) for the dinosaurs that had them before a lineage happened to use them aerodynamically.

Another example of this kind of deception is found in the paper of Vignolini *et al.* (2012), who state that the fruit of the African herb *Pollia condensata*, "by imitating the appearance of a fresh nutritious fruit, may have evolved to mislead their seed dispersers without offering them any nutritious reward." This strategy could avoid the energy cost of producing fresh pulp. After this publication one coauthor of the Vignolini *et al.* (2012) paper published in the News of the Week section of *Science* the story 'All That Glitters' (Glover, 2012): "The fruit`s dazzling display may have evolved to capitalize on birds' attraction to sparkly objects" or "to trick them into eating something that looks like a blueberry".

Burdett (2012) rebuked the interpretation given by Vignolini *et al.*, (2012) and Glover (2012) to their results regarding the iridescent herb *P. condensata*. According to the basic mechanism of evolution, nothing has evolved to do a specific task. Both, the *Science* news story and the PNAS article are indicative of how widely and unfortunately a misleading language is now used in the scientific literature (Burdett, 2012).

Conclusion

There is a complex relationship between teachers, students, and specialized texts that replicate misconceptions and misinterpretations about evolution. It is, therefore, imperative that the sources of deception be readily identified and addressed, and that strategies be developed to eliminate them. In addition, it is necessary that teaching in the classroom be improved through constant text revision and better preparation of teachers.

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