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INTRODUCTION TO THE SPECIAL ISSUE

Sagas of the Children of Time: The Importance of Phylogenetic Teaching in Biology

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Abstract Theodosius Dobznahnsky said nothing in biology makes sense except in the light of evolution. Nothing in evolution makes sense except in the light of the historical emergence of species. Species are the biological "children of time." If we seek to understand them, historical narratives are essential elements of our causal explanations. Phylogenetic systematic analysis provides the Rosetta Stone for uncovering that narrative.

Keywords Children of time · Phylogenetic narrative · Teaching · Evolution · Historical explanations

> *We're all children of Time.* – Shevek, *The Dispossessed (*LeGuin 1974*: 385)*

The atomic theory of matter, a transcendental scientific breakthrough, was based in large part on insights gained from classification. Atomic classification takes the form of the periodic table, which describes classes of atoms, called elements, according to their common structure. Every atom having an atomic number 8 is oxygen, and all oxygen atoms have the same properties regardless of their place or time or circumstances of origin. Empirical and theoretical studies have combined to show that the periodic table is the most compact summary of the general and specific properties of elements.

Evolutionary theory, another transcendental scientific breakthrough, also owes a significant debt to classification. Darwin accepted the widely held view among biologists of the early nineteenth century that there was a natural classification of living species. Furthermore, Darwin noted that the natural classification was not a periodic table, but an internested hierarchy, a branching pattern of unique connections among species. Darwin was not the first to suggest that the natural classification looked like a genealogy, but he was the first to integrate natural classification as genealogy explicitly into a theory of causality.

Darwin proposed that biological diversity emerged from the complex interplay of

> ...two factors: namely, the nature of the organism and the nature of the conditions. The former seems to be much more the important; for nearly similar variations sometimes arise under, as far as we can judge, dissimilar conditions; and, on the other hand, dissimilar variations arise under conditions which appear to be nearly uniform. (Darwin 1872: 32)

Darwin's conception of the "nature of the organism" was explicit: it is in the nature of the organism to produce offspring; to produce offspring that are very similar but not identical to each other; and to transmit those similarities and differences to their offspring. Most significantly, these aspects of the nature of the organism occur *regardless of the Nature of the Conditions*. This is *Darwin's Necessary Mismatch* (Brooks & Hoberg 2007; Brooks in press). Without a high degree of autonomy from the nature of the conditions, there would be no reproductive overrun, thus no struggle for survival, and thus no natural selection. For Darwin, while natural selection was the outcome of the inevitable conflict created by the conditions of existence, inheritance was the explanation for the natural classification.

> It is generally acknowledged that all organic beings have been formed on two great laws—unity of type

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> and the conditions of existence... On my theory, unity of type is explained by unity of descent. The expression of conditions of existence...is fully embraced by the principle of natural selection... Hence in fact the law of the Conditions of Existence is the higher law; as it includes, through the inheritance of former adaptations, that of Unity of Type. (Darwin 1872: 194-195).

Living systems are capable of acting in their own behalf but, more importantly, they regularly take the initiative, using what they have inherited. As that inheritance unfolds, organisms also react to the conditions in which they find themselves. In a metaphorical sense, the present is the state in which biological systems create their own futures based on their histories.

Biological systems carry so much of their history with them that most explanations for how they look and how they function today stem from their past. Specific points of origin in space and time play an integral role in explaining the properties of species and the organisms that comprise them, most importantly how they interact with their surroundings, including other species. As well, species and their populations are capable of taking the initiative in ways that do not act on behalf of individual organisms because reproduction based on what they have inherited, rather than on the environment in which they find themselves, heavily influences how, and how effectively they respond to natural selection.

Empirical and theoretical studies have combined to show that the phylogenetic tree is the most compact summary of the general and specific properties of species. Biological classification thus differs from atomic classification because of differences in the nature of the entities being classified. For oxygen, immutable common properties render past, present, and future identical. For living systems, the only immutable property shared is common ancestry. And they carry their history with them in abundance, which allows us to recognize many phylogenetic relationships readily, leading to the natural classification. All naturally occurring internested hierarchies are the result of some kind of evolutionary process, one in which the "elements" actually change through time. Thus, many were able to deduce the reality of evolution prior to Darwin, even in the absence of the theory of natural selection.

Darwin defined species as communities of descent, but they are more like corporate or collective individuals of unique common descent, so I think of them as "children of time." And if we seek to understand these children of time, historical narratives are essential elements of our causal explanations. This is fortuitous for science education. Humans have long known that important lessons are best taught through narratives, to people huddled in small groups around a sputtering flame, gathered boisterously in a royal hall at banquet time, assembled solemnly in a religious convocation, or simply in pairs of parents and children. The most important lessons, the ones given the status of sagas and legends, have always been cast as historical narratives, anchoring the great lessons in specific places and times, even if mythical. Species arise in specific places and times; this is why we give them proper, not categorical names. Biological classifications are dynamic summaries not only of what is, but also of how it came to be as it is (and not as something else).

Given the importance of historical narratives, it might seem astounding that no standardized objective analytical method for reconstructing phylogeny existed before the mid-twentieth century. The German dipterist Willi Hennig first codified the principles of phylogenetic systematics (Hennig 1950), but even that was not widely known until a summary of his ideas was published in English (Hennig 1966). It might seem equally astounding that such a critical advance was greeted with aggressive resentment rather than open arms by the scientific status quo; David Hull (1988) provided a comprehensive account of the nearly 20-year professional conflict engendered by phylogenetic systematics. Eldredge (1985, 1995) posited a key role for this phylogenetics revolution in initiating major changes in evolutionary biology at the end of the twentieth century. Phylogeneticists restored a sense of time to evolutionary biology, especially in the areas of functional biology (Brooks & McLennan 1991, 2002). This led to strong advocacy for the primacy of the nature of the organism in evolutionary explanations at a time when standard evolutionary biology had reduced the nature of the organism to "random variation" (Brooks in press).

The causal influence of time and history in Darwinism is manifested in the conservative elements of inheritance. Thanks to the phylogenetics revolution and modern molecular techniques, biologists know that historically conservative elements form the overwhelming majority of all genomes. And there is now empirical evidence that these elements make evolution affordable. History lowers the cost of innovation, because innovations are modifications of pre-existing information (McLennan 2008). History lowers the cost of ecological specialization, because specialists on widespread resources have many options (Brooks & McLennan 2002; Brooks and Hoberg 2007; Agosta et al. 2010). History also lowers the cost of adaptability, because adaptability is mostly retained history of what worked in the past and has been carried through time without continued selection (Brooks 2001, 2002, in press; Brooks & McLennan 2002). As an analogy, think of populations as mountaineers climbing (adaptive) peaks. If the only goal is to reach the top, you need not remember where you placed your pitons (the historical tokens of your ascent). But if you ever want to get off the mountain, you need to remember where those pitons are. Thus, stored evolutionary history permits biological systems to avoid being trapped on adaptive peaks.

Overview

The contributions herein are envisioned to help show how phylogenetic narrative explanations work, how scientists formulate the narrative lines (phylogenies), and how to implement this kind of explanation in academic biological curricula.

A founder of the phylogenetics revolution in North America, Edward O. Wiley (1981) is known as one of its clearest thinkers and is an ardent champion of systematic biology. It is only fitting that this issue begin with an overview written by Prof. Wiley himself. In addition to a valuable overview of the field, Prof. Wiley emphasizes that phylogenetic trees are not static pictures connecting the dots among species, but rather pictorial representations of a dynamic process, the phylogenetic narrative. Thus, it is always important to recognize that a line connecting any given species to a node in a phylogenetic tree be understood to represent the history of that species beginning at the node representing the speciation event that gave rise to it.

Deborah McLennan is one of the founders of experimental studies in behavioral evolution integrating phylogenetic information (McLennan et al. 1988; McLennan 2000). In one contribution, Prof. McLennan reprises an account she uses in her award-winning teaching, helping students become comfortable reading trees as historical narratives. In a second contribution, Prof. McLennan draws on her internationally recognized research expertise as an ethologist to discuss ways in which phylogenetic narratives can help us talk about important issues in social and behavioral evolution.

The preceding papers set the stage for three integrated contributions by Marcus Kumala, a high school biology teacher from Toronto who has been working on ways to enhance the teaching of evolution within the Ontario high school curriculum. Marcus learned about using phylogenies to study evolutionary processes as an undergraduate at the University of Toronto. In the first contribution, Marcus discusses the lack of instructional material on the principles behind building evolutionary trees, and presents a classroom-compatible tree-building laboratory exercise. Next, he presents a follow-up laboratory exercise, called *The Natural History of You*, designed to emphasize the relevance of the tree-building exercise for students, and to help them see themselves as biological entities. Finally, he presents examples of lesson plans in which he uses a phylogenetic narrative approach to explain fundamental issues generally assigned to "microbiology" and rarely taught within an evolutionary framework. Marcus has contributed additional lesson plans following this approach, establishing a page on the EEO website where teachers can download posted lesson plans and upload their own contributions.

In a collaborative effort by phylogeneticists and an educational psychologist, Profs. Laura R. Novick, Kefyn Catley, and Daniel Funk present evidence underscoring the pedagogical value of the phylogenetic narrative. Students do not comprehend different classes of phylogenetic trees equally well if they are presented simply as static diagrams. However, if markers of the historical narrative producing the relationships depicted by phylogenetic tree, the traits we call synapomorphies, are included, students comprehend the message being depicted far better, regardless of the details of the structure of the tree.

Finally, I am joined by Prof. McLennan in a contribution designed to show how teachers can frame self-directed discussions about biodiversity and conservation, helping students understand the role of evolutionary principles is guiding our efforts to preserve our planet.

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