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## What Is More Informative in the History of Science, the Signal or the Noise?

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In many domains of knowledge, from mechanics (McCloskey, 1983) to thermodynamics (Wiser, 1987) to astronomy (Vosniadou & Brewer, 1992), it has been claimed that conceptual development in the individual resembles theory change in the history of science. Here, Kampourakis takes issue with that claim in the domain of evolution. In particular, he argues (a) that early evolutionary theorists never construed species as possessing essences and (b) that the distinction between pre-Darwinian and post-Darwinian evolutionary thought is muddled and therefore an inappropriate analog for the development of evolutionary thought among today's students of biology. (Kampourakis makes two additional arguments directed at Ware & Gelman, 2013; which I defer to Ware, this issue). My colleagues and I have argued that students' evolutionary misconceptions resemble pre-Darwinian theories of evolution—in particular, the essentialist aspects of pre-Darwinian theories—on numerous occasions (Shtulman, 2006; Shtulman & Calabi, 2012, 2013; Shtulman & Checa, 2012; Shtulman & Schulz, 2008), and I maintain that this comparison is both empirically fruitful and theoretically meaningful.

With respect to the first argument, Kampourakis notes that historians of science disagree about the veracity of the “Essentialism Story,” or the claim that Darwin's predecessors and contemporaries essentialized biological kinds. “While it is true that scholars often wrote about the essences of life, of organs, etc.,” writes Kampourakis, “they never accepted that species had to have jointly necessary and severally sufficient conditions, or that members of a species should bear essential properties” (p. 1). Here, Kampourakis conflates two forms of essentialism: construing species in explicitly essentialist terms, which early evolutionary theorists arguably did not do, and positing theories of evolution that are inherently essentialist in their mechanisms of change, which early evolutionary theorists arguably did do (Gould, 1996; Hull, 1965; Mayr, 1982; Sober, 1980). That is,

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early evolutionary theories may not have been essentialist in their definitions of *species*, but they were certainly essentialist in their theories of *species change*.

Prior to Darwin, evolutionary theorists posited mechanisms of change that treated species as discrete, holistic “types” or “essences” (Mayr, 1982). While the mechanisms themselves varied—ranging from Lamarck’s “inheritance of acquired characters” to Haeckel’s “recapitulation of phylogeny” to Eimer’s “laws of organic growth” (see Bowler, 1983)—all such mechanisms operated on the members of a species as a collective unit. Darwin’s theory of evolution was qualitatively different from those of his predecessors and contemporaries not because Darwin was the first biologist to deny that species can be defined by sets of individually necessary and jointly sufficient traits but because he was the first biologist to posit a mechanism of change that operated at the level of the individual and thus treated species as *populations*. In other words, Darwin’s predecessors and contemporaries may not have been explicitly committed to an essentialist view of biological kinds but they were *implicitly* committed, by virtue of their non-selectionist theories. And it is this implicit commitment that matters most to the comparison between historical and developmental phenomena, as the essentialist biases of today’s students are most certainly implicit in nature (Gelman & Rhodes, 2012; Shtulman, 2006). No one in the conceptual development literature has argued (to my knowledge) that students hold an explicit view of essentialism, let alone a metaphysically sophisticated view.

With respect to Kampourakis’s second argument, I do not agree that it is impossible to draw a distinction between pre-Darwinian and post-Darwinian biology. Darwin’s (1859) publication of *On the Origin of Species* marks the boundary. Kampourakis is, of course, correct that “there was a plurality of views about species and their transformation both before and after Darwin’s *Origin of Species*” (p. 1), but that plurality does not undermine the fact that, prior to the *Origin*’s publication, all such views were essentialist in nature, whereas, afterward, the idea that evolution proceeds via selection over a population became a viable possibility for the first time in the historical record. Darwin articulated a new idea that was revolutionary to scientists at the time of its unveiling and remains revolutionary to those who first encounter it in science texts or science classrooms. The introduction of that idea is what I would point to as the “single transition” between a pre- and post-Darwinian biology. The paradigm shift from essentialist to selection-based views of evolution, as a whole, was no doubt slow and messy—all paradigm shifts are (Kuhn, 1962)—but the theoretical issues at stake in that shift are clear and distinct.

Regardless of how one carves up the historical record, Kampourakis nevertheless maintains that similarities between the historical phenomenon of discovering natural selection and the developmental phenomenon of learning natural selection are “superficial,” owing to “two important differences between students’ conceptions and the views of historical figures: (a) the intuitive development of students’ conceptions is a very different process from the conscious theory development of naturalists of the past and (b) students’ conceptions are developed in private and are based on experience, whereas the views and theories of past naturalists were developed in public . . . and were based on preexisting theories and knowledge” (pp. 1–2). Why these two factors render the comparison between historical and developmental phenomena “superficial” is not obvious. Differences in how

two sets of conceptions are acquired does not automatically yield differences in their representational format or representational content. Indeed, students' preinstructional conceptions of evolution have been shown to be both logically coherent and internally consistent (Shtulman, 2006; Shtulman & Calabi, 2012, 2013), despite their "private," non-conscious pathways of development.

In short, Kampourakis's arguments against comparing historical and developmental analyses of evolutionary thought are tenuous because they focus on the noisy aspects of historical change to the exclusion of any signal that might underlie that noise. Without a doubt, early evolutionary theorists differed in their explicit beliefs about what species are and how species change, and those differences persisted long after Darwin proposed the concept of natural selection. But such "noise" in the historical record does not preclude the possibility of abstracting deeper, more systematic differences between Darwin's theory of evolution and those of his peers, nor does it preclude the possibility of drawing meaningful comparisons between historical and ontogenetic developments in evolutionary thought.

The best support for this position lies in how well such comparisons have informed our understanding of students' evolutionary misconceptions and our ability to address those misconceptions with instructional interventions. To date, dozens of studies have validated an essentialist model of students' evolutionary misconceptions consistent with Shtulman and Schulz's (2008) analysis of the history of science (e.g., Coley & Tanner, 2012; Evans et al., 2010; Gelman & Rhodes, 2012; Herrmann, French, DeHart, & Rosengren, 2013; Nettle, 2010; Opfer, Nehm, & Ha, 2012), and dozens more have begun to shed light on how instructors can best facilitate the transition from an inaccurate, essentialist view of evolution to a more accurate, selection-based view (e.g., Furtak, 2012; Heddy & Sinatra, 2013; Kelemen, Emmons, Schillaci, & Ganea, 2014; Legare, Lane, & Evans, 2013; Shtulman & Calabi, 2013; Spiegel et al., 2012). The empirical utility of developing alternative "frameworks [that] are more appropriate in order to analyze students' preconceptions about evolution" (p. 2) and defining "multiple ways of analyzing and describing students' preconceptions about evolution" (p. 2), on the other hand, has yet to be determined.

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