Conceptual Revision: How Darwin's Analogy Supported His Theory

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Abstract

Charles Darwin argued that natural selection produces species analogously to how artificial selection produces breeds. Previous analyses have focused on the formal structure of Darwin's analogical argument, but few authors have investigated how it is that Darwin's analogy succeeds in yielding support for his theory in the first place. This topic is particularly salient since at first blush, Darwin's analogical argument appears to undermine the inference he aims to make with it. Darwin held that natural selection produces new species, but artificial selection produces only varieties—a fact which led many of Darwin's contemporaries to see the analogy as counterevidence to his theory, rather than evidence in favor. I argue that the key to understanding how Darwin's analogy supports his theory is to recognize three core conceptual revisions to the 'received view' of artificial selection for which he argued. Only on Darwin's resultant 'revised view' of artificial selection did his analogical argument support, rather than undermine, his theoretical explanation for the origin of species. These revisions are: 1) the sufficiency of mere differential reproduction for producing evolutionary change; 2) the limitless variation of organisms; and 3) the age and stability of Earth's geological history. I show why Darwin needed to establish these particular conceptual modifications in order for his analogical argument to generate theoretical support, and I further suggest that accounts focused on the formal aspects of Darwin's analogical argument cannot capture the significance of Darwin's conceptual revisions to the success of his analogical argument.

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1. Introduction

Long before he wrote *On the Origin of Species* (1859), it was clear to Charles Darwin that he would argue for his theory of Natural Selection[1] by way of analogy. Darwin held that the familiar domestic breeding practices by which we produce varieties are analogous to some process in nature which produces species. Darwin makes clear in his famous transmutation notebooks that, even twenty years before the *On the Origin of Species* (henceforth "the *Origin"*) was published, he had already privately settled on this argumentative strategy (Darwin 1987/1839). The preliminary problems faced by Darwin's analogical approach, however, were many. Domestic breeding—an instance of artificial selection—produced varieties, but only "by training, & crossing & keeping [the] breed pure" (Ibid.). Breeders knew that if they failed to carefully breed only the most superior of their stock and prevent the crossing of superior and inferior individuals, then no new varieties would be produced from their work. Darwin's contemporaries doubted that nature had any process analogous to the breeder's careful control over reproduction. Further, while artificial selection had undeniable efficacy in producing varieties, it had never produced anything that could uncontroversially be called a new species. Darwin's contemporaries largely took these facts to suggest that while selection (be it artificial or natural) could produce impressive morphological and behavioral change in a population, it could never produce a true species.

It seemed straightforward to many of Darwin's contemporaries that, if artificial and natural selection are indeed analogous, then natural selection must certainly *not* be responsible for the origin of species. After all, nature had no plausible process analogous to the breeder's strict reproductive control, and even if it did, it was not clear that selection would be efficacious in the production of new species even if carried out indefinitely. Nevertheless, when writing the *Origin* nearly two decades later, Darwin

[1]I capitalize "Natural Selection" when referring specifically to Darwin's theory by that name. Where I do not capitalize the term, I am referring to the phenomenon of natural selection itself, instead of Darwin's theory which posits that process as being the main cause of speciation.

remained steadfast in his conviction that arguing by analogy between artificial and natural selection would be the most effective way to support his theory.

Given the glaring complications of his analogy when theorizing in 1839, why did Darwin continue arguing for his theory of Natural Selection by way of analogy with artificial selection? How did Darwin make the analogy work *for* his theory, instead of against it, in the *Origin*? Answering this latter question will be the goal of the present essay. In what follows, I show that Darwin argued for three key conceptual revisions to the 'received view' of artificial selection held by many of his contemporaries, and that *only* on Darwin's resultant 'revised view' of artificial selection did his analogical argument support, rather than undermine, his theoretical explanation for the origin of species. These conceptual revisions, which comprise what I call Darwin's 'revised view,' asserted that 1) mere differential reproductive success in a population is sufficient for selection to spring into action, instead of the strict reproductive control required on the received view; 2) there exist virtually no limits to the variability of organisms due to Nature's great efficacy as a selector, unlike the apparently strict limits of organic variation assumed on the received view; and 3) Earth's geological history has been exceedingly stable and near-indefinitely long, *contra* then-widespread beliefs about the age of the Earth and the mercurial nature of its geological history. I argue that these three conceptual revisions to the received view were the premises needing to be established in order for Darwin's analogical argument to support his theory instead of undermining it, and that Darwin so argued them in view of this necessity. I pause here to briefly discuss Darwin's methodological commitments and previous treatments of Darwin's analogical argument, which will offer historical context and philosophical motivation, respectively, for the analysis that follows.

1.1 Why the analogical approach?

To the motivational question mentioned above: why did Darwin pursue an analogical argument despite its complications?—our answer is found in Sir John William Herschel's *vera causa* doctrine of

scientific inquiry and its well-known influence on Darwin. As Jon Hodge has compellingly argued (Hodge 1977; see also Pence (2018) for further discussion), Darwin built out the structure of his argument in an attempt to adhere to Herschel's *vera causa* framework. Many have written on Herschel's methodological views and how they might be rightly or wrongly applied to Darwin's theorizing; for present purposes, we need only consider how Darwin's avowal of Herschellian scientific method, and the central role of analogy within it, motivated him to employ analogical argument in his writings.

Herschel's notion of a *vera causa* aimed to delimit the allowable methods for the development of scientific hypotheses. For a hypothesis to be suitable for scientific inquiry—for empirical validation or rejection, it must assert the existence of a *vera causa*—a known, existent cause—that supposedly produces some observable effect. Many further considerations flesh out how, according to Herschel, *vera causa* hypotheses can be verified on the basis of experience and fact. But Herschel also acknowledges that, for a diverse range of reasons, some instances of hypothesis development cannot proceed directly from known *vera causae*. Herschel thus emphasizes the importance of analogical reasoning for identifying *vera causae* of phenomena about which little is known: "if the analogy of two phenomena be very close and striking, while, at the same time, the cause of one is very obvious, it becomes scarcely possible to refuse to admit the action of an analogous cause in the other, though not so obvious in itself" (Herschel 2009/1830, section 142). If we seek to identify the cause of some phenomenon we cannot experiment on directly, then we may seek analogous phenomena on which we *can* experiment, or at least observe in greater detail.

Darwin's intention was to establish natural selection as a *vera causa* for the diverse lifeforms in nature, and further, as Hodge (1977) and Pence (2018) suggest, as *the vera causa* competent to and responsible for producing (most) species. Since the natural domain clearly cannot be directly observed in its entirety so as to directly identify a *vera causa* there, Darwin had no Herschellian recourse but to employ analogical treatments from narrower, more observable domains. To wit, Darwin had to establish that artificial selection, a known *vera causa* of animal and plant breeds under domestication, is properly

analogous to natural selection so as to establish the latter as a *vera* causa of species. But this motivational understanding of Darwin's use of analogical reasoning will not take us far in describing how his analogical argument actually succeeded in generating support for his theory of Natural Selection, given the historical fact that his contemporaries, often with good reason, took it to undermine his theory instead.

1.2 Contention over the form of Darwin's analogical argument

Over the past half century, philosophers of science have deftly described the formal and structural features of Darwin's analogical argument, either fitting it into wider theories of scientific confirmation (e.g., Ruse, 1975a; Thagard, 1978) or else cordoning it off as its own special pillar of evidential support separate from the rest (e.g., Recker, 1987; Waters, 1986). Authors usually take their proposals to fully account for the role and features of the analogical argument. The standard interpretation says that Darwin employs an analogical argument by similarity (I call this the "similarity model"). On the similarity model of analogical argument, analogy is used to infer the existence of some property *z* in a domain *B,* based on the fact that another domain *A* is known to have properties *x, y,* and *z,* and it is further known that domain *B* also has properties *x* and *y.* Since *A* has properties *x, y,* and *z,* and *B* has properties *x* and *y,* it seems somewhat likely, based on its other similarities to *A*, that *B* might also enjoy property *z.* On this interpretation, Darwin's writings should be seen as attempts to establish that there exist processes in nature *similar enough* to the processes involved in domestic breeding, such that further properties of the latter domain are likely to also inhere in the former. This model of analogical argument, which traces its modern formulation to Mary Hesse's (1966) influential work and was described much earlier by Thomas Reid (2011/1785), is the one assumed in most philosophical work on Darwin's analogy (e.g., Evans, 1984; Gildenhuys, 2004; Hodge, 1977; Lloyd, 1983; Richards, 1997; Sterrett, 2002; Sullivan-Clarke, 2013).

Roger White, Jon Hodge, and Greg Radick (2021) recently proposed an alternative model of Darwin's analogical argument in their comprehensive book on the subject. These authors argue that Darwin's analogical argument is not based on the modern "similarity model," but rather on the classical Greek version of analogical argument, which emphasizes *proportionality* between two domains instead of similarity (I call this the "proportionality model"). The proportionality model holds that an analogy obtains when we say something of the form, "*M* is to *N* as *P* is to *Q*." Aristotle furnishes many examples, such as: "As wavelessness is in the sea, so is windlessness in the air" (cited in White, Hodge, and Radick 2021, 37). The key difference between the proportionality model and the similarity model is that, on the similarity model, analogical inferences connect *relata*, whereas on the proportionality model, analogical inferences connect *relations*. Aristotle's claim, for example, is not that the sea and the air are so much alike that, since we know the sea displays wavelessness, we are also licensed to think that the air displays windlessness. Rather, what is being claimed is that the *relation* between wavelessness and the sea is the same relation as exists between windlessness and the air. The proportionality view would thus suggest that Darwin's analogical inference is that Man is to new varieties as Nature is to new species. The claim, then, would be that the same relations connect the pairs of relata: Man produces through (artificial) selection new varieties, and Nature produces through (natural) selection new species. The difference is proportional: Nature's selection produces effects of a more extreme degree, such that it is appropriate to call the effects *bona fide* species, while Man's selection is weaker, and so his effects are proportionally more meager—mere varieties (see White, Hodge and Radick 2021, chapters 1 and 5 for further discussion).

Neither formal model of analogical argument can fully capture what is going on in Darwin's analogical argument. In my view, on *either* of the above models of analogy, the same interpretive work needs doing in order to understand how Darwin was able to use the analogy in a supportive manner for his theory. If based on analogy from similarity, Darwin needed to establish the conceptually relevant similarities between artificial and natural selection to justify the general notion that they were analogous

processes, but he also needed to establish certain (again, conceptually relevant) dissimilarities between those domains to explain why domestic breeding has not the power to produce species, while natural selection does. If based on analogy from proportionality, Darwin had much the same work to do in order to explain why natural selection produces effects (viz. the generation of new species) of a degree not seen in domestic breeding. Darwin was not seeking to connect just the *relata* nor just the *relations* between artificial selection and natural selection, but some messy mix of both. Regardless of the logical form of Darwin's analogical argument, the same conceptual modifications to the received view of selective evolution needed to be argued for and established, if Darwin's analogy between artificial and natural selection was to support, instead of undermine, his general theory of descent with modification. Darwin's rightful focus, then, was on establishing these conceptual modifications.

2. Darwin's Conceptual Revisions to the Received View

We now have an idea as to why Darwin was motivated to pursue his analogical approach, despite its drawbacks, in view of Herschel's *vera causa* framework and its influence on the young Darwin. We have further seen that existing formal models of analogy leave unexplained the bare fact that Darwin's analogical argument was somehow able to support his theory, when common wisdom at the time suggested that it should have undermined his theory. This is not to say that Darwin's analogical argument itself was unimportant, superfluous, or unilluminating; only that our understanding of how the analogical argument supported his theory does not turn on which formal model of analogy best describes Darwin's analogical argument. Neither do I mean to imply that nothing whatsoever turns on the question of Darwin's analogy's formal structure. In particular, it is possible that there may be differences in *strength* of the theoretical support offered by Darwin's analogy that depend on whether it was an analogy from similarity or an analogy from proportionality. Thus, our understanding of Darwin's analogical argument stands to benefit from settling the question of which formal framework best captures the analogy. But I maintain that on either formal view of analogy, what remains unclear is *which* specific shared features

between artificial and natural selection Darwin needed to establish, as well as the reasons why *those* were the particular revisions that needed establishing, in order for Darwin's analogical argument to yield support for his theory at all. These are the questions that need answering if we are to understand how Darwin turned the analogy between artificial and natural selection from a point of weakness into a point of strength.

2.1 Differential Reproductive Success vs. Strict Reproductive Control

Artificial selection is the process by which humans cause evolutionary change in a population. A classic example of artificial selection is dog breeding. From a "parent" or "ancestral" stock of wild canines, humans have methodically bred countless distinct dog breeds. These breeds exhibit wide morphological and behavioral variation, but they are nevertheless all the same species. If we limit our understanding of artificial selection to only this type of process, then we approximate something close to the received view among Darwin's contemporaries. On the received view, producing breeds via artificial selection required that the breeder enforce strict reproductive control. If the breeder did not prevent intercrossing—reproduction between desired and undesired individuals—then the nascent variety emerging from the parent stock would inevitably revert to the ancestral state. Darwin characterizes the received view as follows:

> I may here refer to a statement often made by naturalists—namely, that our domestic varieties, when run wild, gradually but certainly revert in character to their aboriginal stocks. Hence it has been argued that no deductions can be drawn from domestic races to species in a state of nature. I have in vain endeavoured to discover on what decisive facts the above statement has so often and so boldly been made. (Darwin 1859, 14)

Darwin's pithy framing of his contemporaries' attitudes is not far off. Upon its publication, the *Origin* was subject to widespread criticism—much of it focused specifically on Darwin's analogical argument. Adam

Sedgwick, a staunch opponent of Darwin's, considers it a straightforward conclusion that the analogy from artificial selection decisively *undercuts* Darwin's theory of Natural Selection.

> The only facts [Darwin] pretends to adduce, as true elements of proof, are the *varieties* produced by domestication … But … the varieties, built upon by Mr. Darwin, are varieties of domestication of human *design*. Such varieties could have no existence in the [natural] world. (Sedgwick 1860, 344, emphasis in original)

Sedgwick asserts that since varieties produced by artificial selection are only achievable through "human *design*" (Ibid.), the analogy between artificial and natural selection does nothing to undermine the immutability of species. On the contrary, the analogy suggests that since selection in nature is not guided by such "designs," the varieties achieved in the domestic breeding could not be similarly produced in the natural setting. This conclusion arises from the aspect of artificial selection most obviously missing in its natural analog: the breeder's methodical reproductive control over the mating behaviors of their population. The received view restriction of artificial selection to just "methodical" selection (Darwin 1859, 34), i.e., the intentional production of new domestic varieties by breeders, is one Darwin suggests we abandon on his revised view. If strict reproductive control were indeed required for the production of varieties, as Sedgwick and others claimed, then Darwin would need to demonstrate that nature has some analogous process of reproductive control, else his theoretical edifice crumble.

These worries about how nature could possibly exert reproductive control akin to breeders' careful mate-pairing and prevention of crossing can be seen in many naturalists' writings at the time, as can naturalists' attempts to identify such segregative natural processes that could account for the existence of naturally-produced varieties. The Swiss botanist Alphonse de Candolle, though not a transmutationist, admits that an ancestral population which becomes geographically divided into two populations, reproductively isolated from one another, often leads to what looks like a new species. De Candolle says that such "new forms which we could consider as distinct species (and which are so by defining the species in a certain way [i.e., by the test of mutual infertility]), can only be forms distributed in countries

separated from each other" (1855, 1098, translation mine). As Frank Sulloway (1979) notes, the entomologist Thomas Wollaston expressed almost the exact same view as de Candolle in his volume on the insects of the Madeira Islands (Wollaston, 1856). For de Candolle, Wollaston, and others, it was clear that when nature does succeed in producing what looks like new species, it is only when natural conditions like geographical isolation produce circumstances similar to the strict reproductive isolation the breeder exerts over his stock in the domestic setting.

But Darwin does not take this approach of searching for natural conditions similar to breeders' reproductive control over their stock. He states repeatedly that the strict reproductive isolation required in "methodical" artificial selection is certainly *conducive* to the creation of new species, but it is not *necessary*. Instead, Darwin seeks to revise the received view conception of artificial selection: he argues that reproductive control is not a requirement for selective evolution at all, and so nature needs not have any process like breeders' mate-pairing practices and prevention of crosses in order for natural selection to produce varieties. This modification to the 'received view' is the first 'revised view' premise mentioned in the introduction.

Darwin observes that humans routinely produce new varieties without any reproductive control whatsoever. In what Darwin calls "unconscious" selection, humans produce new breeds incidentally, just by treating their more desirable individuals better than the less desirable of their stock. By showing that artificial selection can produce new breeds by way of "unconscious" selection, Darwin established that the production of new breeds does not require strict control over reproduction.

> If there exist savages so barbarous as never to think of the inherited character of the offspring of their domestic animals, yet any one animal particularly useful to them, for any special purpose, would be carefully preserved during famines and other accidents … such choice animals would thus generally leave more offspring than the inferior ones; so that in this case there would be a kind of unconscious selection going on. (Darwin 1859, 36)

Darwin rightly points out that reproductive control is not required for the production of new domestic breeds; simple differential reproductive success among individuals in a population will suffice. As long as "choice animals … generally leave more offspring than the inferior ones" (Ibid.), new varieties will be produced over time notwithstanding the free intercrossing allowed by "unconscious" artificial selection.[2]

Even among evolutionists generally sympathetic to Darwin's theory, though, it seemed that for natural selection to produce species there would need to be a natural process analogous to the breeder's reproductive control. An emblem of this attitude is found in the German naturalist Moritz Wagner, who argued that natural selection is a *vera causa* of new species, but *only* when an ancestral population has becomes divided into reproductively-separated subpopulations by geographical isolation. Wagner asserts that "[f]ree crossing, as the artificial selection of animals and plants incontestably teaches, not only renders the formation of new races impossible, but invariably destroys newly-formed individual varieties (1868, 31). Due to his worries about intercrossing between new races and "individuals of the original stock" (Ibid.), Wagner concludes that geographical isolation is a *necessary precondition* for the production of new species, saying that "selection without the migration of organisms, and without long isolation of single individuals from the station of their species, could not be called into action" (Ibid., 51). Wagner explicitly puts this conviction, which he derives from his 'received view' understanding of what is required for artificial selection, in contrast with Darwin's more permissive view.

> [Darwin's] assumption of the continued selection of choice individuals for many generations, in conjunction with the unlimited intermingling of wild or half-wild animals is, in my opinion, a profound error … The invariable consequence of free crossing is, I repeat, uniformity; and the

[2]Bert Theunissen (2012) suggests that Darwin's model of artificial selection was biased by his reliance on evidence from pigeon breeders such as William Tegetmeier, whose practices privileged the "purity" of their breeds, as opposed to livestock breeders such as Robert Bakewell, who advocated crossing as a method of creating new breeds. Darwin's emphasis on unconscious artificial selection, however, highlights the sufficiency of even selection which allows intercrossing to produce new breeds, which may stand in tension with Theunissen's claim that Darwin held a strictly anti-crossing view of breeding.

> experiences of the artificial selection of animals and plants … are directly contradictory to the assumption of natural selection without isolation. (Ibid., 70-71)

But Darwin makes clear that such geographic isolation is not necessary; the only truly necessary condition for selection is that fitter individuals in the population leave, *on average*, more offspring than do less-fit individuals. He further suggests that in nature, this less stringent situation will be the most prevalent one.

> In man's methodical selection, a breeder selects for some definite object, and free intercrossing will wholly stop his work. But when many men, without intending to alter the breed, have a nearly common standard of perfection, and all try to get and breed from the best animals, much improvement and modification surely but slowly follow from this unconscious process of selection, notwithstanding a large amount of crossing with inferior animals. *Thus it will be in nature.* (Darwin 1859, 102, emphasis mine)

In private correspondence, Darwin responds to Wagner's objection by explicitly pointing out the analogy between unconscious artificial selection and natural selection notwithstanding free intercrossing: "I must still believe that in many large areas all the individuals of the same species have been slowly modified, in the same manner, for instance, as the English race-horse has been improved, that is by the continued selection of the fleetest individuals, without any separation" (Darwin, 1887/1868, 3:158). Furthermore, in the fifth edition of the *Origin* where he is introducing the concept of unconscious artificial selection, Darwin includes a brief expository reference to Wagner's assertions about the alleged necessity of geographical isolation for speciation: "Moritz Wagner … has shown that the service rendered by isolation in preventing crosses between newly formed varieties is probably greater even than I have supposed. But from reasons already assigned I can by no means agree with this naturalist, that migration and isolation are necessary for the formation of new species" (1869, 120). Those reasons already assigned being, of course, the demonstration that unconscious artificial selection routinely produces novel varieties, notwithstanding the absence of reproductive isolation akin to the breeder's methodical control.

This first conceptual revision aimed to modify the common understanding of the conditions needed for selective evolutionary change, from requiring strict reproductive control (on the received view) to requiring only differential reproductive success (on the revised view). This took the wind out of the sails of many arguments made against Darwin's analogy. One could not point out that no process analogous to the breeder's careful mate-pairing and prevention of crossing plausibly exists in nature and thereby reject the theory of Natural Selection, because the theory *required* no such process of reproductive isolation between superior and inferior individuals in order for speciation to occur.[3] Instead, one would have to argue that no process by which individuals could gain marginal reproductive advantages over their competitors exists in nature, which is a difficult position to defend indeed. But even admitting that nature does create conditions conducive to differential reproductive success, Darwin's critics could still contend that natural selection could not be responsible for the origin of species because there exist fundamental limits to how far a variety can diverge from its parent stock, even given infinite time. This brings us to Darwin's second revision.

2.2 Man's Selective Ineptitude vs. Nature's Selective Expertise

Darwin's contemporaries were generally dubious about his lax requirements for selection to kick in, but they were more skeptical still that the action of selection, whatever its reproductive requirements might be, could create a new species from an old. This skepticism was borne from the received view

[3] Ironically, Darwin's realization that geographical isolation must not be needed for speciation seems to have been inspired in part by de Candolle's own work on plant varieties. Sulloway (1979) notes that Darwin's insight was engendered by a desire to explain how new plant species could naturally arise, since as de Candolle highlighted, plants do not themselves move, and many do not disperse their seeds over a wide area. De Candolle, who rejected transmutationism, was content to explain such cases (of what we would now call sympatric speciation) as acts of special creation; Darwin, instead, developed new theoretical tools to explain how such phenomena could occur through a process analogous to unconscious artificial selection.

belief that artificial selection has limits in the evolutionary change it can produce, which follows from a belief in fundamental limits on variation. If a breeder selects for, e.g., pointed noses in their hounds, then over time this process will produce a new breed with a highly honed snout. But as the new breed is formed, there will come a point (so the common wisdom went) when there is no longer any potential for further snoutal sharpening. All variation in the direction of pointy-nosedness will have been exhausted, and any further variation in the breed will only ever be in the reverse direction, back toward the blunt-nosed ancestral state. This logic, applied broadly, had damaging consequences for the plausibility of speciation via natural selection.

Assertions as to the fundamental limits of variation can be easily seen in critical reviews of Darwin's work. François Jules Pictet, for example, says:

> If we study the modifications brought about by domestication, remembering that these modifications are probably much more intense than those of natural variation, we still cannot find a single example of an influence which has been able to modify the essential nature of an organ … I know of nothing which proves nor any example which forces me to believe that the contrary *took place in nature*. (Pictet 1860, in Hull 1983, 145, emphasis in original)

Since breeders diligently select with the express aim of achieving certain extreme modifications, and even *they* quickly run up against the limits of variation, Pictet thinks it doubtful that in nature, organic variation could have provided the substrate for selection to have transformed "gills into lungs … or change an oviparous into a viviparous animal" (Ibid.). It is worth noting that among the critical reviews of his work, Darwin was most pleased with Pictet's, writing in correspondence to Asa Gray that Pictet's review "is *perfectly* fair and just, and I agree to every word he says" and that "of all the opposed reviews, I think this is the only quite fair one" (Darwin 2009/1887, 279). We can therefore assume that Pictet's skepticism regarding the unlimited potential for organic variation Darwin supposes is not the result of a misinterpretation or misrepresentation on Pictet's part.

If under domestication we consistently observe strict limitations on variation away from the parent form, why suppose that in nature these limits will be miraculously surpassed to such a degree that a gill might eventually turn into a lung? The urgency of this question was not lost on Darwin. As Schweber (1977) notes, Darwin scrawled in the margins of his copy of the fifth edition of Lyell's *Principles* (1830), next to a passage where Lyell asserts the existence of strict limits to organismal variation,[4] "if this is true, adios theory" (Schweber, 1977, 265).

The supposition of limits on variation was almost a logical requirement for any naturalist who rejected transmutationism, but still sought to understand how processes like domestic breeding could create such great change in a population. Wollaston (1856), for example, says that "[m]any animals and plants, it is true, are capable of considerable modifications and changes ... But what does this prove, except that their capacity for advancement has a slightly wider compass than that of their allies? It touches not the fact, that the boundaries of their respective ranges are absolutely and critically defined" (187). Wollaston sees the alleged fact that variation is always "positively circumscribed" to expose "the absurdity of the transmutation hypothesis" (188). Thus was the received view justification for the claim that even if (as Darwin argued) nature did not need to exert reproductive control akin to the breeder's methodical "picking" in order to produce impressive evolutionary change, there would still be no reason to assent to the transmutationist idea that natural selection could be a *vera causa* of new species.

Darwin, of course, had his reasons for supposing that the limits on variation are only apparent, not genuine. These comprise Darwin's second conceptual revision to the received view: demonstrating the efficacy of nature to leverage numerous sources of untapped variability of which breeders, with their

[4] According to Schweber (1977), this piece of Darwin's marginalia was written in reference to the following passage in Lyell's *Principles* (5th ed., 1837). "The entire variation from the original type, which any given kind of change can produce, may usually be effected in a brief period of time, after which no farther deviation can be obtained by continuing to alter the circumstances, though ever so gradually; indefinite divergence, either in the way of improvement or deterioration, being prevented, and the least possible excess beyond the defined limits being fatal to the existence of the individual" (442).

limited powers, are not even aware. An early such pronouncement comes in Darwin's 1842 *Sketch* and his 1844 *Essay*—two early attempts by Darwin to pen his theory. He notes in the *Sketch* that domestic races, "if not removed to new conditions, and preserved from all cross, after several generations become very true, like each other and not varying. But man selects only on what is useful and curious—has bad judgment, is capricious,—grudges to destroy those that do not come up to his pattern,—has no power of selecting according to internal variations,— can hardly keep his conditions uniform,—does not select those best adapted to the conditions under which [the] form lives, but those most useful to him. This might all be otherwise" (Darwin 1909/1842, 3-4). In his 1844 *Essay,* he goes even further to belabor the stark difference between the limits of variation under artificial and natural selection by employing an explanatory metaphor of Nature as an omnipotent, God-like breeder. Darwin imagines "a Being with penetration sufficient to perceive differences in the outer and innermost organization quite imperceptible to man, and with forethought extending over future centuries" (Darwin 1909/1844, 85). On this metaphor, Darwin thinks it plausible that such a Being could certainly produce a new variety, and even a new species, given the Being's incomparable skill as a breeder. Later on in the *Essay*, Darwin restates his conviction even more forcefully and without reference to a metaphorical Being, saying that "we know nothing of any limit to the possible amount of variation, and therefore to the number and differences of the races, which might be produced by the natural means of selection, so infinitely more efficient than the agency of man." (Ibid., 110).

These emphatic illustrations were intended to justify Darwin's rejection of the superficial limits on variation that are suggested by the experiences of breeders. Darwin held that these apparent limits were mere artefacts of breeders' limited capabilities in comparison to Nature's immense selective prowess. No breeder could ever turn a gill into a lung, it was true, but not because it is prohibited by fundamental limits on organic variation. Instead, breeders are incapable of this feat because achieving it would require selection for variations of internal qualities and viable transitional forms of the organ that could not possibly be recognized by any human observer. The misalignment between humans' selective

ends (for fanciful traits which benefit the breeder) and Nature's selective ends (for adaptive traits which benefit the organism) only widens the gap between the possibilities attainable through domestic breeding and through natural selection. None of the limitations in the domestic case, though, are due to any fundamental limits on the potential variability of the breeder's organisms.

Darwin's early metaphor of the omnipotent breeder, the benevolent Being with infinite powers of discrimination, disappears in the *Origin*. There are a number of reasons for Darwin's excision of this deific figure, but they do not much concern us here (though see Ruse 1975b for discussion). What should be noted is that the function of the earlier metaphor—which was to emphasize what grand evolutionary changes might be effected by a selective force which capitalizes on all the wellsprings of variation hidden from the eyes of human breeders—does *not* disappear in the *Origin*. Darwin is just as concerned in that later work to establish the unlimited potential for organic variation as he was in the earlier, only now he aims to do so without the use of metaphor.

The passages of the *Origin* which emphasize this unlimited potential for variation in nature are too many to fully survey. The first two chapters of the book treat the topic most directly. On variation under domestication, Darwin emphasizes that "Man can hardly select, or only with much difficulty, any deviation of structure excepting such as is externally visible" (Darwin 1859, 38). In contrast, Darwin offers a heap of specific facts about the variability of species in nature, as well as the empirical regularities that seem to govern them.[5] The reason that Darwin supposed Nature to *have* such penetrating powers of selection, of course, came from his famous Malthusian insight: that the constant struggle for existence, created by the population growth in an environment with a static carrying capacity, leads to "a force like a hundred thousand wedges trying [to] force every kind of adapted structure into the gaps in the œconomy of Nature" (Darwin 1987/1838, Notebook D, 139e). The Malthusian epiphany, however, only

[5] Darwin, of course, did not have access to genetic explanations of variation and so only recorded the patterns of variation he noticed without much causal analysis—at least until he proposed his "Pangenesis" theory of inheritance in 1868.

gained its theoretical significance when combined with the fact of unlimited organic variation, which was a separate point needing to be established.

The pains Darwin takes to display the great organic variability of many species in nature serve as cases over which an inductive inference can be drawn: there are no firm limits on variation. But even if Darwin's critics were to accept these first two revisions, they could still contend that nature—even if it really is so powerful as to surpass the apparent limits on variation through mere differential reproductive success—could not *in fact* be the *vera causa* competent to and responsible for producing the innumerable extant and extinct species we observe. This recourse remained open to skeptics because Darwin's proposed mechanism of speciation required exceptionally long, stable periods of natural selection in order for speciation to occur, and the existence of these periods could easily be doubted. Here we run into Darwin's third and final conceptual revision to the received view: establishing an ultra-Lyellian[6] geological theory whose postulates concerning the stability and duration of Earth's history greatly improved the plausibility of widespread speciation via natural selection.

2.3 Catastrophism vs. Gradualist Uniformitarianism

Even if it were granted that differential reproductive success was sufficient for the production of large evolutionary change, it was still the case that artificial selection has never produced a single new species—just varieties that diverge from their ancestral form only as far as natural limits on variation allow. Even if it were further conceded that the reason for this was not some fundamental limit to selection because of limits on variation—i.e., even admitting that speciation via natural selection was *in principle* possible under the right conditions, there would still be a gap to bridge as to the credibility of

[6] I borrow this term from Rudwick (1976) in order to emphasize that Darwin's usage of Uniformitarian geology exaggerated certain features of Lyell's own theory.

natural selection as a *vera causa* of species in nature. For Darwin's proposed speciation mechanism to actually be responsible for the creation of new species, Earth's geological history would need to display some rather specific and somewhat dubious attributes.

By Darwin's own admission, natural selection must require a tremendously long time of stable selection pressure to create new species. This made it absolutely crucial to Darwin's theory that Earth's geological history has, in fact, been characterized by periods of long, stable environmental conditions. Fortunately for Darwin, over the twenty-year period during which he was most intensely developing his theory, older Catastrophist theories of geology were on the way out. I call this development "fortunate" for Darwin because any reader holding a Catastrophist view would most likely reject Darwin's theory of Natural Selection by virtue of their geological commitments. If Earth's geological history has been characterized by repeated cataclysms and a total duration on the order of (merely) thousands of years, as was asserted by the popular Catastrophist theories of Abraham Gottlob Werner (1805/1774) and Georges Cuvier (2018/1813), then it would be quite hard to accept the claim that nature's species are the product of natural selection. By the 1850s, however, Charles Lyell's gradualist Uniformitarianism had displaced Catastrophism[7] as the leading geological theory of the time (Rudwick 1976, 227-228).

Lyell's geological theory was profoundly heterodox at the time of its publication in 1830. Lyell suggested that Earth's history was not marked by regular catastrophes with associated mass extinctions, but was instead characterized by processes of constant but gradual environmental change. In explaining the stark transitions between rock layers in the Paris Basin—the very same geological region that had motivated Cuvier's belief in recurrent catastrophic extinctions—Lyell hypothesized that the Earth is much older than was commonly thought, and thus the sharp geological transitions we see are simply the result of minor fluctuations in the gradual processes by which Earth undergoes environmental change. Even

[7] The labels "Uniformitarianism" and "Catastrophism" were coined by William Whewell, long after the two camps were established (Rudwick 1976, 188). I nevertheless adopt Whewell's convenient nomenclature, despite its semi-anachronistic character in reference to the originators of the two geological stances.

apparently instantaneous transitions between rock layers could have taken place over immense durations. Lyell's suggestion that the age of the Earth was effectively unlimited was crucial in yielding support for Darwin's proposal that the selective processes occurring in nature have produced the innumerable distinct species we observe. Put simply: Lyell's geological theory suggested that the Earth was extremely old, something which needed to be true if natural selection was to be plausible as the mechanism which has produced Earth's species.

In addition to the vast passage of time, in order for natural selection to produce two species out of a parent stock, the selective pressures leading first to the formation of varieties (or as Darwin calls them, "incipient species" [1859, 52]) would need to be *stable enough* for those varieties to eventually become genuine species. The regular, rapid changes in environmental conditions implied by Catastrophism ruled out the long, stable periods of natural selection that Darwin claimed are responsible for the diversity of species in the world today. But if Lyell's gradualist Uniformitarianism were right, then even during the transitional periods plainly observable at the intersection of geological layers, environmental conditions could still be thought to have been changing gradually (albeit less gradually than during non-transitional periods)—gradually enough for incipient species to survive and adapt on their path toward full specieshood. Again: central to Darwin's theory was the claim that speciation is a slow, gradual process. Uniformitarianism provided a foundation on which Darwin could maintain the plausibility of such a speciation process as being responsible for the vast diversity of life that exists.

Darwin openly acknowledges the complete reliance of his theory on the verity of Lyell's gradualist Uniformitarianism, admitting that "[h]e who rejects these [Lyellian] views on the nature of the geological record, will rightly reject my whole theory" (Ibid., 342). Lyell's influence on Darwin's thinking is well-documented: Darwin read Lyell's *Principles of Geology* (1830) while on the second voyage of the H.M.S. Beagle in 1832 (Browne & Neves, 1989). Also on this voyage was Adam Sedgwick, who as we have already seen, would later attack Darwin's theory on the grounds that natural

selection cannot *design* that which it produces, as man does. Sedgwick further criticizes Darwin's theory based on his aversion to Lyellian geology.

> I see no proofs of enormous gaps of geological time … where there is a sudden change in the ancient fauna and flora … [W]here have we proof of any enormous lapse of geological time to account for the change? … To support a baseless theory, Darwin would require a countless lapse of ages of which we have no commensurate physical monuments… (Sedgwick 1860, 334-5)

Sedgwick's remarks betray his skepticism for Darwin's Lyellian views on the age of the Earth and his inadequate defense (as Sedgwick sees it) of Uniformitarianist geology. Darwin suggests that there have been numerous epochs during which *no* sediment was deposited at all. Thus, vast periods have elapsed for which there is no corresponding sediment layer nor fossil records to be found. As evidence Darwin notes that many strata, being only a few feet thick in some regions, are elsewhere thousands of feet thick. Since these are the same contiguous layer, the duration of time represented by both the thinner and the thicker is the same. As Darwin notes, "no one ignorant of this fact would have suspected the vast lapse of time represented by the thinner formation" (1859, 296). This, Darwin says, helps explain why the sudden transitions between sediment layers have misled many geologists into positing catastrophes as *explanans* thereof.

Darwin's adherence to Lyellian geology availed him of the lengthy periods of stable selective pressure needed for speciation via natural selection, despite the frequent lack of fossil layers corresponding to these supposed lengthy stable periods. Sedgwick's attack on Darwin's geological claims stemmed not just from his distaste for Uniformitarianism, but also because Sedgwick understood the importance that a Lyellian stance on geological history had for the theoretical support established by Darwin's analogical argument. Darwin uses his ultra-Lyellian view of geology to explain away the feature of his analogy perhaps most damning in the eyes of his critics: that although artificial selection has never

produced a species, natural selection has supposedly produced uncountably many.[8] In Herschellian parlance, that natural selection is not just one *vera causa* of species, but is the *vera causa competent to and responsible for* the many species of the world.

On a Lyellian geological view, the sudden transitions seen at the interface of consecutive rock layers could be explained by the "vast intervals of time" that often elapse between neighboring formations (Ibid., 290). Further, the vast amounts of time posited by Darwin's Lyellian geological framework made clear why the comparatively brief period during which humans have practiced artificial selection has produced great evolutionary change, but nowhere near the level of change required for speciation. Darwin expresses this sentiment by colorfully contrasting the different outcomes of selection in nature and selection under domestication we should expect, in view of their divergent magnitudes of duration.

> How fleeting are the wishes and efforts of man! how short his time! and consequently how poor will his products be, compared with those accumulated by nature during whole geological periods. … We see nothing of these slow changes in progress, until the hand of time has marked the long lapse of ages, and then so imperfect is our view into the long past geological ages, that we only see that the forms of life are now different from what they formerly were. (Ibid., 84)

The truth of these convictions will strike the modern reader as obvious. We now believe Earth to be ~4.5 billion years old, with life on Earth having existed for ~3.9 billion years of that time. Humanity's reign has lasted for but a blink of the geological eye, so it is unsurprising that a few thousand years of control over the breeding of domestic populations would be insufficient to produce a new species. But at the time of the *Origin*'s publication, these now-commonplace assumptions about Earth's deep history were controversial to say the least.

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[8]I of course do not suggest that Darwin cynically took up Lyell's theory only to support his own argument; Darwin's belief in gradualist Uniformitarianism was surely genuine. It remains true, however, that Darwin leveraged Lyell's theory to undercut (in more ways than just those outlined here) the specific counterarguments levied against his theory of Natural Selection.

Stances on the total age of the Earth among 19th-century scientists varied, but common estimates ranged from about 20 million years up to 100 million years (Dalrymple, 1991). Of particular note was the widely-respected estimate put forth by William Thomson, also known as Lord Kelvin. "Thomson calculated that about 98 [million years] had passed since the solidification of [Earth's] crust … [with] a margin of error stretching from 20 to 400 [million years]. But even the upper limit represented an extremely severe restriction of the Lyellian invocation of unlimited time as an explanatory device" (Rudwick 1976, 259). Such estimates, if true, would rule out natural selection as the process by which species have been produced—it simply would not be enough time for Darwin's evolutionary mechanism to be the one responsible for creating the many different beings we find in the natural world.

While neither Darwin nor Lyell ever explicitly estimated the total age of the Earth, Darwin posited in the *Origin* that it took 300 million years for the formation of the English Weald[9] alone. Darwin was criticized for this estimate in press, but it accorded perfectly with the Lyellian notion that "each geological period lasted for many years, perhaps even hundreds of millions of years, and the age of the earth had to be several times that" (Badash, 1989, 90). Darwin's detractors admitted of no enormous intervals of time during which nature could make a new species out of an old one, and the Catastrophist view of geology did not afford periods of environmental stability long enough for incipient species to develop in to true species. Even for critics who accepted Darwin's conceptual revisions to the received view concerning the unlimited potential for organic variation and the sufficiency of differential reproductive success in producing evolutionary change, holding any geological stance *but* Lyell's gradualist Uniformitarianism would render them unable to endorse Darwin's theory of Natural Selection. To avoid letting the analogical argument for his theory fail upon this geological stumbling block, Darwin went out of his way in the *Origin* to establish that the Earth is much older, and its environment has been much more stable, than most of his readers would have previously believed.

[9]The Weald is an area of English lowland exposed through the weathering of an early Cretaceous rock dome, representing but a small period of Earth's geological record (Rudwick 1976, 259).

3. Assembling the Darwinian Edifice

Let us first consider an important caveat to the foregoing analysis of Darwin's conceptual revisions and their importance to his analogical argument. Although I have argued that *these* conceptual revisions were the ones needing to be established in order for Darwin's analogical argument to play the supportive role he intended for it, I do not thereby mean to imply that his attempts to establish these conceptual revisions were successful, as a matter of historical fact. On all three counts, Darwin's attempts to establish the conceptual revisions discussed above fell very often on deaf ears; this is well known, and the owners of some of those deaf ears have been quoted in this essay. But while Darwin's attempts to establish these conceptual revisions may not have been entirely successful from a rhetorical and historical perspective, my point is that they were nevertheless *absolutely required* from an epistemological and theoretical perspective for his analogy between artificial selection and natural selection to be a source of *support* in his argument for the theory of Natural Selection. It is perhaps owing to the rhetorical ineffectiveness of Darwin's arguments for these conceptual revisions that so many of his critics homed in on the strategy of denying them as a reason to reject wholesale the theory of Natural Selection.

We can now take a broad step back and review the differences we have uncovered between the 'received view' and the 'revised view' of artificial selection, and how they enabled Darwin's analogy to support, rather than undermine, his theory of Natural Selection.

The first difference between these views concerns relaxing the strict reproductive control involved in "methodical" artificial selection to the mere differential reproductive success involved in "unconscious" artificial selection. The received view saw artificial selection as the process in which breeders intentionally create a new variety from a parent stock by breeding together only the best individuals in the population, and preventing crosses between superior individuals and inferior ones. Darwin's revised view portrayed artificial selection as just the process by which humans create selective

pressures that confer reproductive advantages to some individuals in the population over others. This may occur through "methodical" selection, such as in dog or pigeon breeding, or it may occur through "unconscious" selection, where crossing between superior and inferior individuals is not prevented; it is simply that superior individuals are treated more favorably in general and so produce, on average, more offspring than do inferior individuals. Over time, either of these two artificial selection processes can produce a new variety—an "incipient species"—from a parent stock. Since nature clearly *does* have a process analogous to "unconscious" artificial selection, and since "unconscious" artificial selection is capable of producing new varieties, then, by analogical inference, so too can nature produce new varieties in this way. Of course, Darwin's theory was not aimed at explaining the emergence of new *varieties* in nature, but the emergence of new *species*. This brings us to Darwin's second revision.

The second revision Darwin argued was the non-existence of fundamental limits on organic variation. The received view held that artificial selection demonstrates to us certain barriers that cannot be overcome by selection. Domestic breeders can rapidly produce a variety of cow well-suited for maximizing tallow yield, but within a short time their new variety will be unable to become any fattier, even under aggressive continued selection on the breeder's part. Similarly, it was taken, selection could never produce a wing from a leg, a lung from a gill, or any other miraculous metamorphoses Darwin's theory seemed to imply. The natural limits of organic variability strictly circumscribed the degree of evolutionary change that selection was capable of producing. Darwin's revised view framed these supposed limits on organic variation as being completely artificial (no pun intended). Breeders' failures were due not to natural constraints on biological form, but because of their ineptitude as selectors when compared to Nature. In full view of the numerous facts demonstrating Nature's capacity to select for variations of internal qualities and viable transitional forms that could not possibly be recognized by any human observer, Darwin suggests we may appreciate why organic variation appears limited, but really is not.

The third and final difference between these views regards the divergent timescales and the stability of environmental conditions in which artificial selection and natural selection have occurred. On the received view, generally-accepted estimates as to the age of the Earth made it seem that, if the theory of Natural Selection were true, artificial selection ought to have given us a new species by now. Further, even if the Earth were much older than generally thought, it was doubtful that the selective pressures in nature could ever be stable enough for Darwin's slow process of speciation to be the *vera causa* actually responsible for the species seen in nature. This problem was especially salient if one took a Catastrophist stance on the geological record, which posited frequent cataclysms. On the revised view, Lyellian gradualist Uniformitarianism straightforwardly explained the absence of species produced by domestic breeding: artificial selection has just not been running nearly long enough for speciation to have occurred under domestication. In contrast, Darwin's Lyellian position afforded the long stable durations needed to explain how the slow process of speciation could have produced the innumerable species in nature. Further, it explained how even in periods of comparatively rapid geological change, incipient species could have enjoyed stable enough selection pressures to offer them the chance to adapt and continue on with the speciation process. Darwin's Lyellian geological revision thus allowed him to explain why artificial selection has not produced new species, and how in nature, incomprehensibly long periods of geological time have been stable enough to generate the multiplicity of species that exist.

I hasten here to reemphasize the philosophical context of this investigation. In the Introduction, I claimed that the question of *which formal model* best describes Darwin's analogical argument—whether the standard "similarity" view or White, Hodge, and Radick's (2021) "proportionality" view—does not touch the separate-but-related question concerning *which conceptual modifications* needed to be established in order for Darwin's analogical argument to support his theory. The relevance of the conceptual revisions discussed in Section 2 to Darwin's argument for the theory of Natural Selection seems in no case to turn on whether his analogical argument was based on similarity or on proportionality. Rather, they turn on a historically-informed understanding of what were the common views were

regarding artificial selection at the time, and how those views stood in the way of Darwin's analogical argument being able to yield support for his theory. There may well be important ways in which the theoretical relevance of Darwin's conceptual revisions *does* depend on the formal structure of Darwin's analogical argument. For example, certain of Darwin's contemporaries may have been more or less accepting of his conceptual revisions depending on whether they understood his analogy as one from proportionality or one from similarity. But I am skeptical that such hypothetical dependencies pertaining to form would significantly modify the importance of any of the conceptual revisions discussed here to the success of Darwin's argument by analogy or answer the question of how Darwin turned his analogy from a point of weakness into a point of strength.

4. Conclusion

Establishing these three conceptual revisions was required for Darwin to use the analogy between artificial selection and natural selection as *support* for his theory of Natural Selection. Were these tendentious revisions not established, the analogical argument would be seen, as it often was, as an unsuccessful one—or even worse, as an actively damaging one for Darwin's theory. On the received view, the lack of a natural process analogous to the breeder's reproductive control, the apparent limits on organic variation, and the failure of prolonged artificial selection to produce new species were seen as analogical evidence *against* natural selection being the process responsible for the origin of species. Darwin's analogy, seen from a received view perspective, showed that natural selection is not a *vera causa* by which species have been produced. To avoid this analogic fate, Darwin took to establishing his revised view of artificial selection that we have just surveyed. If one accepted Darwin's conceptual revisions, the received view objections to the analogical argument that previously appeared so damning for his theory would simply no longer stand. Of course, as a matter of historical fact, Darwin's efforts to establish these revisions were often unconvincing to his peers. The point remains, though: Darwin's

analogical argument only works, only provides theoretical support at all, if these conceptual revisions go through.[10]

It is well known that Darwin argued for these claims concerning the reproductive conditions required for evolutionary change, the superiority of Nature as a selector over the limited powers of human breeders, and the immense duration and stability of Earth's geological history. It is also widely acknowledged that establishing these facts was part of Darwin's "one long argument" for his theory of Natural Selection in the *Origin.* What I have shown here is *why* it was establishing these premises in particular which allowed Darwin's analogical argument from artificial selection to support his theory of Natural Selection, as well as *how*, specifically, these conceptual revisions enabled his analogy to serve as supportive evidence for his theory. Understanding this background is especially illuminating in recognition of the widespread interpretation of his opponents,[11] on which the analogical argument was thought to resoundingly undercut Darwin's theory. While contemporary analyses have focused on identifying the formal features of Darwin's analogical argument and the type of evidential support it

[10] From a modern perspective, in fact, the first two of Darwin's revisions require some qualification. On the reproductive conditions required for selection, we know now that speciation can occur even when there does not exist differential reproductive success between two subpopulations. For example, some individuals of an insect species might start exploiting a new niche offered by a novel fruit tree on which the species does not traditionally feed. This would reduce gene flow between individuals which feed on the new type of fruit and those which feed on the old type of fruit, thus producing a sympatric speciation event despite no difference in reproductive success between the two subpopulations. On the lack of limits to organismal variability, we know now that there exist certain regulatory genetic constraints that *de facto* prohibit, for example, the evolution of a sea sponge from a marsupial. Thanks to an anonymous reviewer for pointing out this need to qualify Darwin's conceptual revisions from a modern perspective.

[11] It is also worth noting the heavy pressure Darwin received from his allies A.R. Wallace (Wallace and Darwin 1858, 61) and Charles Lyell (Darwin 1985, 363) to abandon the analogical strategy. Both theorists understood that on a received view understanding of artificial selection, Darwin's analogical argument would do more to detract from the evidence for his theory of Natural Selection than it would do to bolster it.

generates, they do not lay bare what the content of that support is, or why it can be said to support his theory in the first place. Here I have sought to do precisely that.

5. Bibliography

Badash, L. (1989). The Age-of-the-Earth Debate. *Scientific American*, *261*(2), 90–97. https://www.jstor.org/stable/24987366

Browne, J., & Neves, M. (1989). Introduction. In *The Voyage of The Beagle: Charles Darwin's Journal of researches*. Penguin Books.

Cuvier, G. (2018/1813). *Essay on the Theory of the Earth*. Routledge. https://doi.org/10.4324/9780203495377

Dalrymple, G. B. (1991). *The Age of the Earth*. Stanford University Press.

Darwin, C. (1859). *On the Origin of Species*. John Murray.

Darwin, C. (1869). *On the origin of species by means of natural selection, or the preservation of favoured races in the struggle for life.* (5th ed.). John Murray.

Darwin, C. (1887). *The Life and Letters of Charles Darwin* (F. Darwin, Ed.; Vol. 3). John Murray.

Darwin, C. (1909). *The foundations of The origin of species. Two essays written in 1842 and 1844.* (F. Darwin, Ed.). Cambridge University Press.

Darwin, C. (1985). *The correspondence of Charles Darwin* (F. Burkhardt & S. Smith, Eds.). Cambridge University Press.

Darwin, C. (1987). *Notebooks, 1836-1844: Geology, transmutation of species, metaphysical inquiries* (P. Barrett, P. Gaurtrey, S. Herbert, D. Kohn, & S. Smith, Eds.).

Darwin, C. (2009/1887). *The Life and Letters of Charles Darwin* (F. Darwin, Ed.; Vol. 2). Cambridge University Press.

de Candolle, A. (1855). *Géographie botanique raisonnée; ou, Exposition des faits principaux et des lois concernant la distribution géographique des plantes de l'epoque actuelle.* (1–2). J. Kessmann.

Evans, L. T. (1984). Darwin's use of the analogy between artificial and natural selection. *Journal of the History of Biology*, *17*(1), 113–140. https://doi.org/10.1007/BF00397504

Gildenhuys, P. (2004). Darwin, Herschel, and the role of analogy in Darwin's origin. *Studies in History and Philosophy of Science Part C: Biological and Biomedical Sciences*, *35*, 593–611. https://doi.org/10.1016/j.shpsc.2004.09.002

Herschel, J. F. W. (2009/1830). *A Preliminary Discourse on the Study of Natural Philosophy*. Cambridge University Press. https://doi.org/10.1017/CBO9780511692727

Hesse, M. B. (1966). Material analogy. *Models & Analogies in Science*, 57–100.

Hodge, M. J. S. (1977). The Structure and Strategy of Darwin's 'Long Argument.' *The British Journal for the History of Science*, *10*(3), 237–246. https://doi.org/10.1017/S0007087400015685

Hull, D. (1983). *Darwin and His Critics: The Reception of Darwin's Theory of Evolution by the Scientific Community*. Chicago University Press.

Lloyd, E. A. (1983). The Nature of Darwin's Support for the Theory of Natural Selection. *Philosophy of Science*, *50*(1), 112–129.

Lyell, C. (1830). *Principles of Geology* (1st ed.). John Murray.

Lyell, C. (1837). *Principles of Geology* (5th ed., Vol. 2). John Murray.

Pence, C. H. (2018). Sir John F. W. Herschel and Charles Darwin: Nineteenth-Century Science and Its Methodology. *HOPOS: The Journal of the International Society for the History of Philosophy of Science*, *8*(1), 108–140.

Recker, D. A. (1987). Causal Efficacy: The Structure of Darwin's Argument Strategy in the Origin of Species. *Philosophy of Science*, *54*(2), 147–175. https://doi.org/10.1086/289368

Reid, T. (2011/1785). *Essays on the Intellectual Powers of Man*. Cambridge University Press. https://doi.org/10.1017/CBO9780511997150

Richards, R. A. (1997). Darwin and the Inefficacy of Artificial Selection. *Studies in History and Philosophy of Science*, *28*(1), 75–97. https://doi.org/10.1016/S0039-3681(96)00008-8

Rudwick, M. J. S. (1976). *The Meaning of Fossils: Episodes in the History of Palaeontology*. Science History Publications.

Ruse, M. (1975a). Charles Darwin's Theory of Evolution: An Analysis. *Journal of the History of Biology*, *8*(2), 219–241.

Ruse, M. (1975b). Darwin's debt to philosophy: An examination of the influence of the philosophical ideas of John F.W. Herschel and William Whewell on the development of Charles Darwin's theory of evolution. *Studies in History and Philosophy of Science Part A*, *6*(2), 159–181. https://doi.org/10.1016/0039-3681(75)90019-9

Schweber, S. S. (1977). The origin of the Origin revisited. *Journal of the History of Biology*, *10*(2), 229–316. https://doi.org/10.1007/BF00572644

Sedgwick, A. (1860, April). Objections to Mr. Darwin's theory of the origin of species. *The Spectator*, 334–335.

Sterrett, S. G. (2002). Darwin's Analogy Between Artificial and Natural Selection: How Does it Go? *Studies in History and Philosophy of the Biological and Biomedical Sciences*, *33*(1), 151–168.

Sullivan-Clarke, A. (2013). On the causal efficacy of natural selection: A response to Richards' critique of the standard interpretation. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, *44*(4), 745–755. https://doi.org/10.1016/j.shpsc.2013.09.010

Sulloway, F. J. (1979). Geographic isolation in Darwin's thinking: The vicissitudes of a crucial idea. *Studies in History of Biology*, *3*, 23–65.

Thagard, P. (1978). The Best Explanation: Criteria of Theory Choice. *The Journal of Philosophy*, *75*(2), 76–92.

Wagner, M. (1873). *The Darwinian Theory and the Law of the Migration of Organisms* (J. L. Laird, Ed.).

Wallace, A. R., & Darwin, C. (1858). On the tendency of species to form varieties; and on the perpetuation of varieties and species by natural means of selection. *Journal of the Proceedings of the Linnean Society of London, Zoology*, *3*(9), 45–62.

Waters, K. C. (1986). Taking Analogical Inference Seriously: Darwin's Argument from Artificial Selection. *Proceedings of the Biennial Meeting of the Philosophy of Science Association*, *1986*(1), 502–513.

Werner, A. G. (1805). *A treatise on the external characters of fossils* (T. Weaver, Trans.).

White, R. M., Hodge, J., & Radick, G. (2021). *Darwin's Argument by Analogy: From Artificial to Natural Selection*. Cambridge University Press.

Wollaston, T. V. (1856). *On the variation of species, with especial reference to the Insecta; followed by an inquiry into the Nature of genera*. John Van Voorst.