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PHILM0007 History of Science

What's in the Black Box?

Was the lack of knowledge of the mechanisms of variation and inheritance a viable objection to Darwinian Natural Selection?

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Abstract

In this essay we shall consider whether in 1880 the lack of knowledge of the mechanisms of variation and inheritance gave reasonable grounds to reject Darwin's theory of evolution *by Natural Selection*. To this end we shall analyse Darwin's arguments on three fronts: on the basis of evidence available at the time; with respect to historically proposed mechanisms of variation and inheritance; and from the perpective of Herschellian and Whewellian philosophies of science. We will also consider an objection put forward by Jenkins. We shall conclude that this lack of knowledge led to reasonable doubt, and that while Natural Selection should not have been rejected outright, a healthy degree of scepticism should have been maintained.

1 Introduction

We should start by explaining two things: Why 1880 and what is 'the Black Box'? Let us explain the year first. The idea behind this essay is to consider how viable a theory evolution by Natural Selection looked *historically*. As such we need to decide a cut-off date to mark when our use of the word 'historically' ends. The most non-arbitrary date would appear to be 1880, which saw the publication of Huxley's *The Coming of Age of "The Origin of Species"* ([8]), a retrospective considering the success and development of Darwin's theory during the twenty-one years since its first publication.[1] Furthermore, this is also before the rediscovery of Mendel's work on genetics, which would later cast the debate in a whole new light.[2]

Let us now explain this mysterious 'Black Box'. In the *Origin*, Darwin admits that the mechanisms for variation and inheritance are 'quite unknown' (pp. 102–103 of [4]). Thus Darwin's argument is based upon a 'Black Box', which generates the variation and inheritance necessary for Darwin's argument to go through, but whose inner workings are

[1] From this point on we shall refer to *The Origin of Species* simply as the *Origin*. We shall use [4] as our version.

[2] Since we are stopping at 1880, Weismann's notable refutation of Lamarckian inherited adaptation will not come under our discussion.

unknown.[3] In this essay we shall discuss how this Black Box affects Darwin's argument, and we shall arrive at the conclusion that its opaqueness gave sufficient grounds for scepticism.

In this essay we shall focus on Natural Selection; that is, we shall not consider how the Black Box affects the arguments for species transmutation and common descent (we shall explain these terms in §2), but only how it affects Natural Selection as a mechanism for evolution. Indeed, Peter Bowler talks about the 'non-Darwinian Revolution' ([1]), whereby many people at the time were convinced by species transmutation and common descent, but not by Natural Selection as a mechanism. Our essay will to some extent explain why this was the case, but we will not, however, consider sociological or theological causes for the lack of acceptance of Natural Selection, restricting our discussion to the scientific, philosophical and logical aspects of Darwin's argument. It is perhaps anachronistic to consider these factors in isolation,[4] but these are the factors that we wish to explore.

Let us outline the structure of this essay. In §2 we shall outline Darwin's argument for evolution by Natural Selection, pointing out the logical independence of Natural Selection from species transmutation via common descent in Darwin's reasoning. In §3 we will consider a compelling objection put forward by Jenkins. In §4 we shall consider evidence available at the time, in particular evidence adduced by Darwin himself and a historical objection put forward by Mivart. In §5 we shall consider two historically proposed mechanisms for the Black Box, namely Lamarckian use and disuse and Darwin's own theory of pangenesis. In §6 we shall consider Darwin's theory from Herschelian and Whewellian viewpoints, and finally in §7 we shall draw our conclusions.

2 The arguments in the *Origin*

In this section we shall present the main arguments from the *Origin*. We naturally do not have space to go into even a fraction of the detail in which Darwin presented his argument, but rather we shall give a précis that brings out the relevant points for our discussion. We will also highlight the logical structure of the argument; in particular we shall point out that Natural Selection is not necessary for species transmutation via common descent to occur.

Darwin's argument for Natural Selection relies on three premises:

(i) More offspring are born than survive to reproduce.

(ii) There is variability amongst individuals in a species, and some variations are beneficial to the individual's survival and some are detrimental.

(iii) Many traits are inheritable.

[3] I owe this analogy to Andrew Pyle.

[4] Richard Owen, who was a staunch opponent of Darwin (and his theory), wished to distance himself from the so-called 'sacerdotal revilers' (people who objected to Darwin's theory on purely religious/theological grounds), such as Adam Sedgwick, and instead criticise the *Orgin* on purely scientific grounds ([12]), so this isolation may not anachronistic after all.

Let us explain these premises in more detail. Premise (i) was summed up by Darwin as 'the Struggle for Life' – many organisms are killed or die before they reproduce. This is easily seen in nature: a goose will usually produce a large gaggle of goslings, but only a few will make it to maturity; out of the seeds produced by a tree, only a small number will germinate and an even smaller number will survive to reproduce; and so forth.

Premise (ii) is really two premises in one. The first part says that not all individuals in a species are exactly the same. This much would seem evidently true: some horses run more quickly than others; individual plants in a species often produce differently coloured petals; humans grow to different heights; etc. The second part says that some variations are advantageous while others are disadvantageous. This again is evidently true. For example, in the Arctic, a rabbit with whiter fur is less likely to be caught by a predator than a rabbit with darker fur; in the Savannah, faster gazelles are less likely to be killed by lions than slower ones; and conversely, faster lions are more likely to catch prey than slower ones.

Premise (iii) can be summed up by the old phrase 'like begets like': an offspring will inherit some – but not necessarily all – of the traits of its parent(s). This again would seem to be true: fast horses more often than not produce fast colts and foals; red roses produce red roses; tall parents have taller children than average; and so on. Some characteristics are of course not inherited: the offspring of a chicken with clipped wings will have fully functioning wings, for example. Moreover, some traits can be inherited, but not always are: children of brown-eyed parents sometimes have brown eyes and sometimes have blue eyes.

Okay, so the premises are true. But how do we arrive at Natural Selection? Well, the argument goes like this: By premises (i) and (ii), those individuals with advantageous variations will, *on average*,[5] produce more offspring than the rest of the population; and those individuals with disadvantageous variations will, on average, produce fewer offspring than the rest of the population. Thus, by premise (iii), more offspring will be born with the advantageous variations than with the disadvantageous ones. Accordingly, over several generations, the proportion of individuals in the population with advantageous variations will increase and the proportion with disadvantageous variations will decrease.

This is a sound argument: Natural Selection, as described above, must occur. The question is whether Natural Selection is *enough* to drive evolution, or whether Natural Selection is but a secondary cause to a more fundamental evolutionary mechanism. We shall discuss this further shortly, but at this point we need to clarify some terminology and some logic.

So far we have already been making distinctions between *Natural Selection*, *evolution*, *species transmutation*, and *common descent*. We now know what *Natural Selection means*,

[5] It is crucial to the argument that we look at *average* reproduction. For example, a fast gazelle might be unlucky and be struck by lightning before producing any offspring. However, when we look at averages – assuming the population is not too small – this kind of "bad luck" no longer factors in. (If the population is small, then "bad luck" can factor in – in modern biological terms this is called *drift* – but this is fairly uncommon and for our purposes we need not consider it.)

but what about the others? Well, *evolution* is the general idea that species are not constant and change over time, which is very closely related to *species transmutation*, which is the idea that species are not immutable and that they change over time into new species. *Common descent* is the further thesis that as well as species being mutable, any two species have a common ancestor, i.e. the history of species change forms a so-called 'Tree of Life', with each current species being at the tip of a 'branch'. Common descent is to be contrasted with other possible ideas of species transmutation, for example that of Lamarck (which we shall discuss in §5), where each species evolves linearly from a distinct ancestor. For brevity, we shall refer to species transformation by common descent as *descent with modification*. As we stated in §1, we shall not examine how the opaqueness of the Black Box affects the arguments for descent with modification, but only how it affects the arguments for Natural Selection as a driving force for evolution. Indeed, as we shall see in §4, the evidence in the fossil record for descent with modification was quite compelling, but we shall demonstrate that this evidence did not back up the claim that Natural Selection is the driving force behind such evolution.

Darwin believed in descent with modification by Natural Selection. He described the *Origin* as one long argument (p. 116 of [13]), seeing Natural Selection as the driving force behind evolution. However, as Mayr ([10]) and Waters ([13]) have pointed out, descent with modification and Natural Selection are logically independent, for there is no reason why there cannot be a different mechanism driving evolution, with Natural Selection as a weaker, secondary phenomenon. Indeed, in §5 we shall consider just such a possibility. So, the question that we need to address is this: Are premises (ii) and (iii) strong enough for Natural Selection to drive evolution? That is, does the Black Box generate enough inheritable variation to allow a fish to eventually evolve into a human, or is there a limit on variation and what can be inherited? If there were such a limit, then Natural Selection would only be a conservative force, weeding out the weaker members of a species and maintaining an average. It is this question that we shall be addressing in the rest of this essay, and we shall conclude that while it would have been incorrect to claim outright that the Black Box was too weak for Natural Selection to drive evolution, it would also have been incorrect to claim outright that the Black Box was strong enough to facilitate Natural Selection as the mechanism for evolution. In short, the most rational position would have been that of scepticism.

Now, before we move on, we need to briefly mention a counterpart to Natural Selection. Darwin did not claim that Natural Selection was the only form of Selection: he also suggested that in nature there is *Sexual Selection*. This is very similar to Natural Selection, except that the Selecting agent is not survival, but rather acquiring a mate. So, the idea behind Sexual Selection is that those individuals with traits advantageous for attracting a mate will have more offspring, thus meaning that more offspring will be born with advantageous traits. For example, peacocks with more elaborate plumage attract more peahens, and thus large plumage has Sexual Selection advantage. We do not have room to discuss the subtle differences between Natural and Sexual Selection, and since they both require that the Black Box be powerful enough to drive evolution (as discussed in the previous paragraph), we shall group them together under the heading of 'Natural Selection'.

3 Jenkins' objection

In [9], Jenkins put forward a compelling objection against Natural Selection. The original objection is extremely racist by today's standards,[6] so I shall present a similar but inoffensive argument. Imagine an island inhabited by wild horses and suppose we introduce a Derby-winning race horse. Furthermore, suppose that our prize-winning stud[7] is also extremely attractive to the local mares, much more so than the local studs, and that he has many offspring by many females. Now, under a so-called *blending* mechanism of inheritance, each of his offspring will be 1/2 'superior' (where our original race horse is 1 superior). In turn, each of their offspring will be 1/4 superior, or 1/2 if two offspring of the original race horse mate – but this will be rare since there are more average horses than 1/2 superior ones. In turn the third generation will be 1/8 superior, and so on. Jenkins' objection is then that over successive generations, the traits of our original prize stud, despite their superiority (and consequent Selection advantage), will be "blended out" and thus the population will remain average.

Darwin believed in a blending mechanism of inheritance and took Jenkins' objection seriously (see Darwin's letter to Hooker on p. 302 of [7]). Darwin took Jenkins' objection to highlight the importance of *individual differences*, e.g. height amongst humans, over *single variations*, e.g. a human growing a sixth finger (see Darwin's letter to Wallace on p. 302 of [7]). Prima facie this looks to be a nice solution, since individual differences are perhaps more in accord with the variation described in premise (ii) of §2 above. However, this leads us to the question of how organisms develop entirely new traits. For while different heights may have different Selection advantages, and so tall people may have more offspring, say, how is a completely new trait supposed to come about? Surely we need single variations for a fish to eventually evolve into a human? The answer to this last question of course brings us to the Black Box, and without the knowledge of its inner workings, we cannot answer it. Accordingly, we cannot properly assess the strengths of either Jenkins' argument or Darwin's response. For if the true mechanism is a blending one, then Jenkins's objection would look very compelling; but if it is not, then Darwin would have the upper-hand. Furthermore, this question will enter into the debate regarding the limits of variation under domestication and in nature, which we shall discuss next in §4.

[6] Jenkins considers the introduction of a 'dominant' white man on to an island 'inhabited by negroes'.
[7] For the purposes of this example we shall overlook the fact that studs aren't entered into races.

4 The evidence

In this section we shall analyse the evidence that was available at the time. We shall consider Artificial Selection; the fossil record of the time; and a problematic example for Natural Selection put forward by Mivart in *The Genesis of Species* ([11]).

Darwin started the *Origin* by building up to Natural Selection via an analogy with what he called *Artificial Selection*. He used breeding of domestic plants and animals (most notably the various breeds of domestic pigeon) to illustrate how man chooses, both consciously and unconsciously, what he sees as favourable characteristcs and artificially selects these traits by breeding. So, in Artificial Selection, the most successful traits will be those that man finds useful or aesthetically pleasing, as opposed to Natural Selection, where the most successful traits will be those that help an organism survive and/or acquire a mate. Prima facie this analogy seems compelling: if man can create such a diverse range of breeds – take the domestic dog for a striking example – over only a few centuries, then surely nature, which won't simply concern itself with external characteristics such as beak length and hair colour, can do so much more with the great aeons of geological time? Darwin put it best himself:

> '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. Can we wonder, then, that nature's productions should ... plainly bear the stamp of far higher workmanship?' (p. 146 of [4])

There is, however, a problem with this analogy: All the evidence points to there being a limit on variation under domestication. Breeders can only make a horse run so fast and a pigeon's beak so long. They cannot change a dog into a fox. The 'grandfather of palaeontology' Georges Cuvier and the founder of modern geology Charles Lyell, whose geological ideas Darwin held in high regard, both claimed that while species vary, they can only do so within limits. In a review of 1867, the engineer Fleeming Jenkin perhaps put this objection best by talking of 'spheres of variation' ([9]). In this analogy, species may vary, but only up to the edge of their assigned sphere. This explains the tendency of breeds to revert to the regular form of their species if left to breed on their own, since at the edge of the sphere one can only go towards the centre. It also explains why breeders can initially make great changes within two or three generations, but later find that they can only make much smaller changes; since once one has approached the edge, there is little further one can go.

This is a problem for Darwin's argument for Natural Selection as the evolutionary driving force, since if Artificial Selection has limits, why shouldn't Natural Selection? If such limits existed, then Natural Selection would only be the conservative force we described at the end of §2. Now, if we knew the inner workings of the Black Box, we might be able to demonstrate that variation has no limits. However, this option was not available in 1880, which would have led to reasonable doubt.

A counter argument to the observation that Artificial Selection appears to have limits would be that even small changes, which we can cartainly see under domestication, when multiplied over geological time could amount to very large changes. But again this relies on there being no limit to variation by Selection, for which there was no evidence, and thus was a matter of hypothesis, not fact. Indeed, as we saw in §3, it was not known whether inheritance was governed by a blending mechanism, and so the relative limits of the two forms of variation considered by Darwin, namely individual differences and single variations, both under domestication and in nature, were unclear.

We shall now consider the fossil record of the time. The existence of fossils that did not match any living organisms was one of the factors that led to the idea (before the publication of the *Origin*) of the mutability of species. However, palaeontology was a very new subject in the 19th century, and Darwin himself highlighted that the evidence for species transmutation *via common descent* in the fossil record was limited, since there were very few examples of transitional forms (chapter IX of [4]).[8] Darwin put forward various arguments as to why the fossil record was incomplete in this way, one of which being that not enough fossils had yet been discovered. However, Huxley pointed out in his 1880 retrospective ([8]) that in the years between the publication of the first edition of the *Origin* (1859) and 1880, a great deal of evidence of transitional forms had come to light; for example, he pointed out the discovery in 1875 of toothed birds in cretacious rock, adding evidence to the theory that birds evolved from reptiles. This was excellent news for believers in descent by modification, but was it good evidence for Natural Selection? We must conclude that it was not, for the discovery of transitional forms says nothing about the mechanism of evolution. We are again left with the problem of the Black Box: as with Artificial Selection, the lack of knowledge of the inner workings meant that one could only have speculated about the fossil record's bearing on Natural Selection as a driving force. That is not to say that it contradicted Natural Selection, but only that it did back it up.

We now come to a problem put forward by St George Mivart. In his 1871 book *The Genesis of Species* ([11]), Mivart attacks Natural Selection as a mechanism for evolution by citing various problematic organisms, suggesting in each case that a particular trait could not have come about by Natural Selection. A lot of the cases are in fact easily explained by Natural Selection, but his example of the eyes of a flat fish does appear to be genuinely problematic. At birth, the eyes on a flat fish are on either side of the fish's body, but as the fish matures, one eye moves from the underside of the fish to the top side. This can be seen in Figure 4.

This seems to be a problem for Natural Selection, as it is unclear how the fish moving

[8] A *transitional form* is an organism that is an intermediate between two species, one of which has evolved from the other; that is, roughly, it has some of the features of the older species and some of the features of the new species.

Figure 1: A talbot (*Psetta maxima*). During maturation the right eye moves from the underside to the top side of the fish.

its eye slightly generation-by-generation has any Selective advantage: the advantage only comes when the eye is completely on the top side of the fish. Now, with modern biological knowledge of genetics, it may well be possible to explain how this trait developed through Natural Selection, but without this knowledge of the inner workings of the Black Box, it posed a serious challenge for Natural Selection as a mechanism for evolution, and as such would have raised reasonable doubt.

Let us summarise what we have argued in this section. We have shown that neither Artificial Selection nor the fossil record could be used as evidence for – or against – Natural Selection as a mechanism for evolution. We have also highlighted a compelling example put forward at the time which, while not undermining Natural Selection, certainly would have left one wanting an explanation. Overall, we have put forward evidence for our claim that Natural Selection should neither have been rejected nor accepted outright, but rather seen as a theory requiring further investigation.

5 Proposed mechanisms

In this section we shall consider two historically proposed mechanisms for variation and inheritance. With our running analogy, we shall "put them in" the Black Box and see if Natural Selection still functions as a mechanism for evolution. We shall also consider the historical evidence for each proposed mechanism. The examples we shall consider are use and disuse; and Darwin's own theory of pangenesis.[9]

In 1809, Jean-Baptiste Lamarck published *Philosophie zoologique* in which he extolled a theory of evolution based on two principles. The primary principle was that organisms have a natural tendancy to increase in complexity due to fundamental chemical laws and,

[9] We will not consider the mechanism put forward by Chambers in *Vestiges of the Natural History of Creation* (1844), since his hypothesis was not taken seriously by the scientific community at the time and, moreover, was inconsistent with known facts.

due to these same laws, primitive organisms are continually being created from inorganic matter. The second principle, which Lamarck saw as subsidiary to the first, was that of *use and disuse*. The idea behind use and disuse is that organisms can aquire new traits during their lifetime which, importantly, they pass on to their offspring. They aquire these traits (or lose them) through increased (or decreased) use of a particular organism. The much quoted example is that of the giraffe: each individual giraffe would, during its lifetime, stretch its neck to reach the higher leaves on the acacia trees, increasing the length by a small amount. It then passes this slight increase in neck length to its offspring, who in turn stretch their necks and so on, until over many generations the giraffe gains a long neck. In this way organisms become adapted to their environment. The overall picture then is that very simple organisms are generated from inorganic matter and over time increase in complexity linearly, with use and disuse acting as a lateral force. Importantly, under this view each species has a unique origin and so we do not have common descent.

Lamarck's theory was widely discredited, most notably by fellow French naturalist Georges Cuvier. The first principle was based on pre-Lavoisierian chemistry which had been demonstrated to be wrong. The second principle, however, was in fact accepted by Darwin as a secondary cause of evolution, although he phrased it in a different way to Lamarck (chapter V of [4]). Lamarck's exposition had been ridiculed by Cuvier because he had suggested that animals could gain new traits through willpower: the giraffe *really wanted* to reach the higher leaves, and so, by *really trying* to stretch its neck, it increased its length. In this form it does perhaps look somewhat questionable. Darwin, however, suggested that use and disuse simply came about through increased or decreased exercise of a particular organ; willpower didn't come into it. For example, he suggests that it is probable that the drooping of ears in domestic cattle 'is due to the disuse of the muscles of the ear, from the animals not being much alarmed by danger' (p. 101 of [4]), and that flightlessness in some species of birds may in part be due to disuse of the wings (p. 180 of [4]). It is this form of use and disuse that we shall consider as a possible mechanism in the Black Box. Indeed, while most rejected Lamarck's idea of chemical laws causing complexity to increase, the so-called 'neo-Lamarckians' of the late 19^{th} century took use and disuse as the primary mechanism of evolution.[10]

So how does Natural Selction fare if use and disuse is the mechanism in the Black Box? Well, the adaptationalism of use and disuse is diametrically opposed to Natural Selection, since it contradicts the non-directional nature of the variation in premise (ii) in §2; that is, the variations described by premise (ii) can be either beneficial *or detrimental*, while the variation from use and disuse is purely beneficial.

[10] The neo-Lamarckians, unlike Lamarck, accepted common descent. For while Lamarck believed that each species had a unique common ancestor and evolved linearly along its own evolutionary line, with use and disuse only "pulling" laterally, the neo-Lamarckians believed that use and disuse, as a primary mechanism of evolution, led to species branching.

Does use and disuse fit the evidence? Well, it would seem to fit with the progression seen in the fossil record, since it is in accord with common descent. It also explains how organisms all appear to be adapted to their environment; indeed, historically use and disuse could well have been seen to better explain this aspect of nature than Natural Selection. For instance, take Mivart's flat fish example: the migration of the eye is much more in accord with use and disuse than with Natural Selection, since increased use of the underside eye could lead to slight movement generation-by-generation, eventually leading to the eye migrating fully to the top side of the fish. So far so good. But use and disuse certainly has problems. For example, it is unclear how use and disuse can explain latent characters, such as a maternal grandson having a similar beard to that of his grandfather. It is also unclear how it can explain atavism, the phenomenon of offspring having traits of ancient ancestors that their parents and immediate ancestors lack, such as a horse being born with stripes similar to those of a zebra. However, while it is not obvious how use and disuse can explain these phenomena, they do not contradict it. So, in the same way that the flat fish is a problem for Natural Selection that requires explanation, but does not rebuke the theory outright, latent characters and atavism require explanation from use and disuse, but they do not prove the theory false.

We now come to Darwin's theory of pangenesis. Darwin first put forward this theory in his book *Variation of Animals and Plants under Domestication* (1868) ([5]). The idea behind pangenesis is that every cell in an organism produces minute particles that Darwin calls *gemules*. These gemules accumulate and form the sexual elements of an organism, and thus are passed on to the offspring. The crucial idea is that these gemules are what transmit the characteristics of an organism to its offspring: they are the mechanism of inheritance. These gemules are then affected by the environment, which leads to variation amongst organisms, as Darwin alluded to in the *Origin*.

So is Natural Selection a consequence of the hypothesis of pangenesis? The answer is yes. For the gemules allow traits to be inherited, satisfying premise (iii) of §2, and the effects of the environment produce directionless variations amongst individuals, satisfying premises (i) and (ii). So pangenesis certainly rules in favour for Natural Selection as the mechanism for evolution.

So far pangenesis seems to offer us a good explanation of Natural Selection. Indeed, it accounts for various aspects of inheritance and variation that hitherto appeared mysterious, such as atavism and latent characteristics. There is, however, a big problem with the hypothesis of pangenesis, that it is just that, a *hypothesis*. There was no empirical evidence for gemules whatsoever, so while it was an interesting theory, there certainly was scope for reasonable doubt regarding its validity.

6 Herschel and Whewell

In this section we shall consider Darwin's theory of evolution by Natural Selection from the point of view of two prominent philosophers of science of the time, John Herschel and William Whewell. We shall in turn give brief outlines of their views of science and see how they apply to Darwin's theory.

Let us first analyse Darwin's theory of evolution by Natural Selection from a Herschelian viewpoint. Herschel's fundamental view of science is that it should uncover *vera causa* (= *true cause(s)*); that is, 'causes recognised as having real existence in nature, and not being mere hypotheses or figments of the mind' (p. 144 of [6]). But how are we to demonstrate a *vera causa*? Waters (p. 120 of [13]) sums up the requirements succinctly:

(a) We must show that the cause *exists*.

(b) We must show that the cause is *adequate* to produce the effects to be explained.

(c) We must show that the cause is *responsible* for the effects.

(b) and (c) are quite similar, so let us clarify their distinction: (b) says that we must show that the cause *can* produce the effects in question, while (c) says that we must show that the cause *does* produce the effects. Clearly (c) implies (b), so why list (b) separately? Well, Herschel further required that we must demonstrate the responsibility of the cause independently of how we demonstrate the existence and adequacy of the cause.

So, let us assess Natural Selection *as a mechanism for evolution* on these three points. (a) is easy: in §2 we produced a sound argument demonstrating the existence of Natural Selection. (b) also holds, since while there are troublesome cases such as the flat fish that require explanation, Natural Selection – if the variation in premise (ii) of §2 is unlimited – is enough to drive descent by modification. So far so good. What about (c)? This is where the Black Box comes in: Without the knowledge of its inner workings, we cannot demonstrate that Natural Selection does in fact drive evolution. This is the point we made in §2: we do not have evidence to show that the variation in premise (ii) of §2 is unlimited. Consequently, Natural Selection *as a mechanism for evolution* should not have been seen as a *vera causa*.[11] Indeed, even if we regard Natural Selection as a consequence of pangenesis, we cannot demonstrate pangenesis as a *vera causa*, since we have no evidence to satisfy (c).

We now come to Whewell. William Whewell, in his 1847 book *The Philosophy of the Inductive Sciences* ([14]), took a different approach to scientific investigation from Herschel. What Whewell believed to be the sign of a good theory was *consilience*. A theory is said to be consilient if it explains a wide range of phenomena, especially phenomena that the theory did not originally set out to explain. For example, Newton's theory of gravitation is

[11] We have twice put 'as a mechanism for evolution' in italics to stress that while Natural Selection is a *vera causa* in the sense that it certainly occurs in nature and produces at least some limited effects, there was not enough evidence to demonstrate that it is the *vera causa* of evolution.

consilient, since not only does it explain the motions of objects on earth, but it also explains the motion of the planets; indeed, Newton's theory could explain the discrepancies between Kepler's laws and the actual motions of the planets.

We come to the question whether Darwin's theory of evolution by Natural Selection is consilient. It would seem that Darwin thought so, judging by the following excerpts from two of his letters.[12] In a letter to Hooker, Darwin wrote:

> 'I have always looked at the doctrine of Natural Selection as an Hypothesis, which, if it explained large classes of facts, would deserve to be ranked as a theory deserving acceptance.' ([2])

And in a letter to de Candolle, Darwin responded to his correspondee's unwillingness to accept the theory of Natural Selection with:

> '...the subject hardly admits of direct proof or evidence. It will be believed in only by those who think that it connects & partly explains several large classes of facts.' ([3])

Natural Selection as a mechanism for evolution does indeed explain large classes of facts; for example, it explains why species are adapted to their environment, the evidence from the fossil record, and why we can breed plants and animals under domestication. There is a problem here though: is evolution *by Natural Selection* consilient, or is just descent with modification, perhaps driven by some other mechanism, consilient? It seems that the former has to be the case. For if we do not have Natural Selection, we do not have consilience. For example, if we placed use and disuse in the Black Box, the consequences of which we explored in §5, we can explain some of the evidence, such as the fossil record and why species are adapted to their surroundings, but, as we saw in §5, we find it hard to explain such phenomena as atavism and latent characters. So, despite the opaqueness of the Black Box, evolution by Natural Selection does do well from a Whellelian approach, which at the time would have leant evidence for its support.[13]

So what can we conclude from this section? It would seem that while Darwin's argument does well from a Whewellian perspective, a Herschelian would find it wanting. This adds to our thesis that the best position to have taken at the time was scepticism.

7 Conclusion

Let us summarise what we have considered in this essay. In §2 we saw that Natural Selection must occur, but we also noted that it is not a logical necessity that it drives evolution. In §3 we discussed a compelling historical objection against Natural Selection, but concluded that due to the opaqueness of the Black Box, the objection is not a fatal one for Natural Selection

[12] Darwin was a friend of Whewell when he was at Cambridge and certainly read Whewell's work. Whewell himself did not consider Darwin's theory of Natural Selection to be consilient, which sadly lead to a cooling of their friendship.

[13] It is perhaps ironic that we have drawn the opposite conclusion from Whewell himself, who rejected Natural Selection outright.

as a mechanism for evolution. In §4 we considered the evidence available at the time. We concluded that the analogy of Artificial Selection with Natural Selection was insufficient to prove Natural Selection as a mechanism for evolution, since the limits of variation were unknown; and that the fossil record, without the knowledge of the inner workings of the Black Box, could only be adduced as evidence for descent with modification and not Natural Selection. We also noted that Mivart's flat fish example presented a problem for Natural Selection, one that could not be solved until the Black Box was opened. Finally in §6 we saw that while the Black Box did not prevent Natural Selection from looking valid from a Whewellian viewpoint, a Herschelian would have rejected it on the grounds of our ignorance of the mechanisms of variation and inheritance.

So what conclusions can we draw from our work? Well, we have seen that the opaqueness of the Black Box presented problems for Natural Selection as a mechanism for evolution, since it prevented various arguments for Natural Selection from being conclusive. However, the Black Box certainly did not *disprove* Natural Selection; it only raised doubt. Consequently, our overall conclusion must be that in 1880, the lack of knowledge of the mechanisms of variation and inheritance was indeed a viable objection against Natural Selection, but that it was not a fatal one. Indeed, Natural Selection did look to be a promising theory, and as such the opaqueness of the Black Box should have been taken as a challenge to try to open it and discover its inner workings, and not as a reason to reject Natural Selection outright.

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