This is a preprint of the following chapter: Joël Dolbeault, "Is Darwinism a Metaphysical Research Program? Analysis and Discussion of Karl Popper's Position", published in *Unity and Disunity in Evolutionary Biology*, edited by R. Delisle, M. Esposito, D. Ceccarelli, 2024, published by Springer. Reproduced with permission of Springer (as it appears on the copyright page of the book). The final authenticated version is available online at: https://doi.org/10.1007/978-3-031-42629-2_9

Is Darwinism a Metaphysical Research Program? Analysis and Discussion of Karl Popper's Position

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Abstract Whether defended or criticized, Darwinism is generally considered a scientific theory. However, Popper contests this point. According to him, Darwinism (defined as the explanation of evolution by natural selection) is less a scientific theory than a metaphysical research program: a theoretical framework that has a heuristic function for science, but that does not fulfill the necessary condition for any science, namely testability. In terms of taking a new look at Darwinism, Popper's position is therefore interesting. It constitutes a radical deconstruction of Darwinism, in the sense that it challenges the status of science generally accorded to this theory – a status that the defenders of the theory sometimes oppose to other conceptions of evolution, considered negatively as "metaphysical." First, I analyze Popper's position. According to him, Darwinism is rationally defensible, but difficult to test because it is not capable of making precise and sufficiently specific predictions. Darwinism is therefore more metaphysical than scientific, even if it has a heuristic function for science. Moreover, Popper proposes an improvement of Darwinism by asserting that it must give a more important place to the activity of organisms in evolution. In a second step, I discuss Popper's position, taking into account the criticisms that this position has generated. As regards the non-testability of Darwinism, it appears that the tests proposed in the literature do not meet the defects pointed out by Popper. On the metaphysical character of Darwinism, I discuss Popper's assertion on two levels: on the possibility of a clear demarcation between science and non-science, and on the value of the demarcation criterion proposed by Popper. Finally, on the improvement of Darwinism, I try to underline the originality of the Popperian proposal.

Keywords Darwinism · Popper ·Demarcation problem · Testability · Falsificationism · Baldwin effect · Teleology

1 Introduction

In 1974, in his "Intellectual Autobiography," Popper asserts that Darwinism is not a scientific theory, but a metaphysical research program for science (Popper 1974a: 133–143). The aim of this chapter is to analyze and discuss this position. More precisely, it is to answer the following

two questions: by claiming that Darwinism is less scientific than metaphysical, what exactly does Popper mean? And considering the discussion that this position has generated in the literature, what should we think of it today?

Popper's position has been commented on by many philosophers of biology. But the debate does not seem to be settled. Proof of this is that this position has never stopped being discussed since the 1970s (Ruse 1977, Watkins 1995, Settle 1996, Stamos 1996, Hull 1999, Stamos 2007, Vecchi and Baravalle 2015, Bradie 2016). Another element is that there is no real consensus on this position. Many commentators have criticized Popper, but others have instead defended his position (Platnick and Rosen 1987, Settle 1996, Vecchi and Baravalle 2015). A reexamination of the issue is thus warranted.

In this new examination, I will insist on the most misunderstood points of Popper's position. Thus, we will see that, for him, there are degrees of testability in science, and that Darwinism is only *hardly testable*. We will also see that, for Popper, science and metaphysics are always linked, and that the notion of metaphysical research program is not at all pejorative. Finally, we shall see that, contrary to a widespread idea, Popper never changed his mind about the metaphysical, i.e. speculative, character of Darwinism.

In the discussion part, I will insist on the question of the Popperian criterion of demarcation between science and non-science, because the criticism of Popper's position seems to have evolved in this direction: even if it is true that Darwinism is hardly testable, is this a sufficient reason to exclude this theory from the field of science? In this respect, Popper's position is threatened on two fronts: the first is to know if the Popperian project of demarcation between science and non-science is relevant; the second is to know if the demarcation criterion proposed by Popper is relevant, for science in general, and for biology in particular. Without claiming to settle a rich and complex debate, I will attempt to bring out two points. The first is that the rejection of a clear demarcation between science and non-science only leads to a reformulation of Popper's position in other terms. The second is that, provided it is not over-interpreted, Popper's criterion of demarcation can be applied to other sciences than physics, notably biology.

For the sake of clarity, the chapter will be divided into two distinct parts. The first part will be essentially devoted to the analysis of the position defended by Popper. The second part will be devoted to the discussion of this position.

2 Analysis of Popper's Position

The idea that Darwinism is a MRP (metaphysical research program) for science is developed in one writing (Popper 1974a). But Popper addresses the question of Darwinism in other writings, before and after 1974. Here are the main ones:

- *The Poverty of Historicism*, ch. IV, section 27 (Popper 1957)
- *Objective Knowledge*, ch. VI and VII (Popper 1972)
- "Natural Selection and the Emergence of Mind," in *Dialectica* (Popper 1978)
- "Evolution," a letter to *New Scientist* (Popper 1980)
- "The place of mind in nature," in *Mind in Nature* (Popper 1982a)
- "A New Interpretation of Darwinism," Medawar lecture 1986 (Popper 2014)

When Popper asserts that Darwinism is an MRP, he is speaking about modern Darwinism, i.e. the Modern Synthesis (1974a: 135). Moreover, he is speaking only of the theory of natural selection (1974a: 120, 136–137), that is, of the Darwinian theory of the mechanism of evolution. In other words, Popper does not question the scientificity of all the ideas contained in what is

commonly called "Darwinism," in particular the idea that living species are the result of evolution. This is clear in the 1974 writing, and repeated in the years that follow (1978: 344; 1980: 611; 2014: 117–118). Thus, in his letter to the *New Scientist*, Popper explains that he in no way denies that the "historical sciences" have a scientific character, notably paleontology and the science of evolutionary history. For him, indeed, the latter satisfy the criterion of testability that he defends (Popper 1980).

In summary, with regard to Darwinism in the sense of *the theory of natural selection*, Popper defends the following three theses:

1. Darwinism is rationally defensible, but difficult to test.
2. Therefore, it is not a scientific theory, but an MRP for science.
3. Moreover, as an MRP, Darwinism needs to be improved.

In the following sections, I analyze each of these theses in turn.

2.1 Darwinism is Rationally Defensible, but Hardly Testable

In most of his writings on the subject, Popper emphasizes the interest of Darwinism in understanding evolution. In his view, the Darwinian approach to evolution is clearly more interesting than all other approaches: theistic (Popper 1972: 267; 1974a: 137), animist and vitalist (Popper 1972: 270; 1974a: 143), or Lamarckian (Popper 1972: 268; 1974a: 143). Certainly, these non-Darwinian approaches assert different things. To explain evolution, the theistic approach invokes a purposeful cause external to the living; the animist approach, a purposeful cause internal to the living; the vitalist approach, a special cause internal to the living; and the Lamarckian approach, a physiological cause internal to the living (the principle of use and non-use, and the heredity of acquired characters). However, all these non-Darwinian approaches have in common that they formulate an ad hoc hypothesis to explain evolution. This is their main weakness. In contrast, Darwinism proposes to explain evolution without invoking an ad hoc force or mechanism. This is its main strength (Popper 1972: 267–270; 1974a: 137).

In other words, for Popper, the main value of Darwinism is to propose a reductionist explanation of evolution, because from a methodological point of view, reductionism has a great interest:

> In the course of this discussion, I will defend three theses. First, I will suggest that scientists have to be reductionists in the sense that nothing is as great a success in science as a successful reduction… A successful reduction is, perhaps, the most successful form conceivable of all scientific explanations, since it achieves what Meyerson (1908, 1930) stressed: an identification of the unknown with the known. (Popper 1974b: 259–260)

From this point of view, for Popper, Darwinism is rationally defensible. However, in his view, this is not enough to make it a scientific theory. For Popper, indeed, the domain of rationality is broader than that of science because the latter implies a precise condition: *testability*.

Let us first recall some fundamental elements concerning what Popper calls testability.

First, for Popper, the testability of a theory lies essentially in its falsifiability, or refutability. This means that the theory must be formulated in such a way as to define the empirical conditions that could show that it is false. Without this, it is impossible to use experience to criticize the theory, which is to say that it is impossible to estimate the empirical value of the theory.

Secondly, for Popper, testability is *a necessary condition* for the scientificity of a discourse. This is true for theoretical sciences (which formulate universal statements), but also for historical sciences (which formulate singular statements) (Popper 1957: 143–144; 1972: 354). The question of whether, for Popper, testability is also a sufficient condition for scientificity is discussed. Popper is unclear on the issue (Hansson 2021: 4.2). We will have to talk about it in the discussion part.

Thirdly, for Popper, the testability of a discourse admits of degrees. Popper underlines this point as early as 1959, in *The Logic of Scientific Discovery* (1959/1992: ch. VI), and he comes back to it several times, as shown by this text from 1963:

> There are, moreover (as I found later), *degrees of testability*: some theories expose themselves to possible refutations more boldly than others. … This indicates that the criterion of demarcation cannot be an absolutely sharp one but will itself have degrees. There will be well-testable theories, hardly testable theories, and non-testable theories. Those which are non-testable are of no interest to empirical scientists. They may be described as metaphysical. (Popper 1963: 346)

In particular, Popper emphasizes the fact that, all other things being equal, the degree of testability of a theory depends largely on its capacity to make precise numerical predictions (Popper 1959/1992: 108–110; 1963: 346).

Let us now turn to the question of the testability of Darwinism. On this point, Popper sometimes claims that Darwinism is not testable (1974a: 134, 136). But in other passages, he only asserts that Darwinism is *hardly* testable (1974a: 137; 1978: 344; 1994: 90). In fact, the arguments given by Popper allow us to understand that, for him, Darwinism is only *hardly* testable. This means that its testability is not zero, but very weak.

First of all, it is obvious that Darwinism cannot make precise predictions about the formation of a new species, in a given place and at a given time. Its confrontation with experience must therefore depend on more global predictions. Popper mentions two possibilities.

The first concerns evolutionary divergences. According to Popper, Darwinism suggests that life must evolve in a *strongly* divergent manner, at least in a relatively large and varied environment. But this suggestion is not a true prediction in the sense that Darwinism remains logically compatible with a *weakly* divergent evolution:

> For assume that we find life on Mars consisting of exactly three species of bacteria with a genetic outfit similar to that of terrestrial species. Is Darwinism refuted? By no means. We shall say that these three species were the only forms among the many mutants which were sufficiently well adjusted to survive. And we shall say the same if there is only one species (or none). Thus Darwinism does not really *predict* the evolution of variety. It therefore cannot really *explain* it. At best, it can predict the evolution of variety under "favourable conditions." But it is hardly possible to describe in general terms what favourable conditions are – except that, in their presence, a variety of forms will emerge. (Popper 1974a: 136)

Since Darwinism is logically compatible with extremely different degrees of divergence, it cannot be said to make any predictions on this subject. Popper thus writes that the theory "almost predicts," or "suggests," a great variety of forms of life (1974a: 136, 137). This suggestion can be presented as a test for the theory. But this test is not severe enough, in the sense that a negative result cannot be enough to refute the theory.

The second possibility mentioned by Popper concerns the speed of evolution. In this case, Popper claims that Darwinism makes a true prediction. But he explains that this prediction cannot stand as a true test:

> Gradualness is thus, from a logical point of view, the central prediction of the theory. (It seems to me that it is its only prediction.) Moreover, as long as changes in the genetic base of the living

> forms are gradual, they are – at least "in principle" – explained by the theory; for the theory does predict the occurrence of small changes, each due to mutation. However, "explanation in principle" is something very different from the type of explanation which we demand in physics. While we can explain a particular eclipse by predicting it, we cannot predict or explain any particular evolutionary change (except perhaps certain changes in the gene population *within* one species). (Popper 1974a: 137–138)

The prediction of Darwinism is that evolution is gradual, and observations in genetics are consistent with this prediction. However, this prediction is very general, in the sense that Darwinism does not predict the gradual formation of a particular species. Therefore, the gradual formation of a particular species is just compatible with Darwinism. This compatibility is what Popper calls "explanation in principle." The problem is that other theories than Darwinism can predict that evolution is gradual: certain forms of animism, vitalism or Lamarckism (knowing that the notion of gradualness, as such, is not very precise, and therefore easily adaptable to many different theories). Therefore, the gradual formation of a particular species is also compatible with various non-Darwinian theories. In other words, these theories can also explain "in principle" the gradual formation of any species. Conclusion, the prediction of gradualness is not a sufficiently discriminating test for Darwinism.[1]

Without talking about prediction, we can think that the capacity of Darwinism to explain the survival of a species by its adaptation to an environment (interpreted as an effect of natural selection) plays as a real test in favor of the theory. According to Popper, this is not the case. Indeed, for this to be a true test, it would be necessary to determine adaptation *independently* of survival. But this appears to be very difficult, so Darwinism is tempted to define adaptation *by* survival. This leads to the following tautology: the survival of a species in a given environment can be explained by the adaptation of this species to this environment, defined as the survival of this species in this environment. This is why Popper writes that, on the question of adaptation, Darwinism is "almost tautological" (1972: 241–242; 1974a: 135, 137). As some commentators have noted, the formula is problematic: a theory is either tautological or it is not (Hull 1999: 486). However, it is easy to understand that, by this formula, Popper means this: Darwinism is not fundamentally tautological; but for lack of a true test on adaptation, it is tempted to function as a tautology.

To conclude this analysis, let us briefly point out what Popper adds in 1978 about the testability of Darwinism. Some commentators suggest that Popper changed his mind on this topic in favor of Darwinism (Bradie 2016: 152–153, 164; Hansson: 4.2). A detailed analysis shows that this is not the case.

In the 1978 article, Popper argues that Darwinism (understood as the theory of natural selection) can be defined in a restricted way, *without including sexual selection*. From this point of view, according to him, Darwinism is empirically testable, but also empirically refuted: refuted precisely by the known cases of sexual selection that force one to think that, at best, Darwinism only partially explains evolution (1978: 343–346). On the one hand, therefore, it is true that in 1978 Popper proposes something new about the testability of Darwinism, which he himself emphasizes (1978: 345). On the other hand, this change is very relative because it consists essentially in playing on the definition of Darwinism – with a consequence on its testability. When it comes to Darwinism in the broad sense (including sexual selection), Popper's position remains unchanged: this theory is hardly testable. Moreover, Popper's new proposal is not favorable to Darwinism since it places the latter before the following dilemma: to be based on a broad definition of natural selection (including sexual selection) and to be an

[1] Some may think that other tests can falsify animism, vitalism, and Lamarckism, so that these theories are off the table, and that a test of gradualness is sufficiently severe for Darwinism. But the situation is not so simple because these theories are very general, which means that they can take various forms (incorporating various empirical data). Extending Popper's analysis, we can say that these theories are also difficult to test.

untestable theory; or to be based on a narrow definition of natural selection (excluding sexual selection) and to be a testable but refuted theory (1978: 346).

Popper knows that his narrow definition of Darwinism is questionable (1978: 346; 2014: 127–128). Moreover, this definition is not accepted by biologists today, who include sexual selection in natural selection. Therefore, for the remainder of the chapter, the most interesting point of view is to consider the "broad definition" of Darwinism. And from this point of view, Popper's position is that Darwinism is hardly testable.

2.2 Darwinism is a Metaphysical Research Program for Science

For Popper, the idea that Darwinism is an MRP (1974a: 120, 133–134, 137) is the consequence of three things. The first is that Darwinism is difficult to test. The second is that it is inspired by some metaphysical conception of reality. The third is that it serves as a guide for scientific research. I will analyze these three points in turn.

The first point refers to the previous part. However, something needs to be clarified. As we have seen, Popper thinks that Darwinism is *hardly* testable. But in 1963, concerning the degrees of testability, he asserts that only *non*-testable theories should be considered metaphysical (see the text quoted above). Why assert then that Darwinism is metaphysical? The most likely explanation is that there is a certain wavering of Popper's position on the demarcation between science and non-science. On the one hand, in 1963, Popper affirms that there are degrees of testability, but without affirming that there are degrees of scientificity. And he adds that a hardly testable theory is still scientific. On the other hand, if there are degrees of testability, it is logical to think that there are degrees of scientificity, and then to underline the rather scientific, or rather metaphysical, character of a theory. In 1974, Popper seems to adopt this point of view: because he considers that Darwinism is very difficult to test, he emphasizes its metaphysical character.[2]

In section 3.2, we will return to the question of the criterion of demarcation between science and non-science. We will see that Popper's position has been discussed by many philosophers.

The second point concerns the inspiration of Darwinism, bearing in mind that we are not talking here about Darwin's Darwinism, but about modern Darwinism, developed in the first part of the twentieth century.[3] For Popper, a MRP is inspired by a metaphysical conception of reality, defined as an attempt to explain the fundamental structure of reality (Popper 1982b: 161). A metaphysical conception answers questions like: is reality only made of ideas (idealism) or not (realism)? Of determined processes (determinism) or not (indeterminism)? Etc. Therefore, if Darwinism is a MRP, it must be inspired by a certain conception of the fundamental structure of reality. Popper does not explicitly specify this conception. But given its reductionist approach to evolution, it is easy to understand that Darwinism is inspired by *mechanism*. Metaphysical mechanism considers that all the processes in nature, including those which are apparently intentional, are in fact mechanical processes (i.e. obeying blind laws). And indeed, Darwinism seeks to explain evolution without any recourse to intentions, external or internal to the living.

Obviously, this does not mean that Darwinism, as a MRP, is dictated by professional philosophers. For Popper, the scientific world itself determines its own MRPs. Rather, it means that, since the beginning of the twentieth century, evolutionary biology has presupposed a certain metaphysical conception of reality – a conception considered taken for granted, and therefore rarely discussed.

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[2] Note that this amounts to adopting a position similar to that of Lakatos on the degrees of scientificity (Lakatos 1999: 20).

[3] For the place of the theory of natural selection in Darwin, see in particular Delisle (2021).

The third point concerns the usefulness of Darwinism for science. Regarding the usefulness of MRPs in general, Popper writes:

> I call them "research programmes" because they incorporate, together with a view of what the most pressing problems are, a general idea of what a satisfactory solution of these problems would look like" (Popper 1982b: 161. See also 1974a: 120).

A MRP serves as a guide for a science. It helps determine which problems are relevant to a science, and what kinds of solutions are acceptable. Thus, Popper believes that Darwinism serves as a guide for biology.

To illustrate this idea, Popper uses the following example:

> In trying to explain experiments with bacteria which become adapted to, say, penicillin, it is quite clear that we are greatly helped by the theory of natural selection. Although it is metaphysical, it sheds much light upon very concrete and very practical researches. It allows us to study adaptation to a new environment (such as a penicillin-infested environment) in a rational way: it suggests the existence of a mechanism of adaptation, and it allows us even to study in detail the mechanism at work. And it is the only theory so far which does all that. (Popper 1974a: 137)

The experiment shows that some bacteria adapt to penicillin. The scientist wants to understand why. Darwinism suggests an explanatory scheme: a random genetic variation in these bacteria, with possible consequences on the ability to live in a penicillin-infested environment; and a natural selection mechanism of the individuals best adapted to this environment. In this sense, it directs the research towards the discovery of precise empirical elements (corresponding to this explanatory scheme).

According to Popper, the possible success of this kind of research reinforces the interest of Darwinism as a MRP, but it does not constitute a real test for the theory. First, because this success concerns a limited number of cases: it says nothing about evolution as a whole, especially macroevolution. Secondly, because this success does not constitute a sufficiently discriminative test: it does not allow us to exclude a non-Darwinian explanation of adaptation.

For Popper, Darwinism thus fulfills the three conditions that make it an MRP: weak testability, metaphysical inspiration, and the role of guide for scientific research. But before ending this section, let us emphasize that Popper has a positive conception of metaphysics, as something rational and useful to science. Concerning the metaphysical theories of matter,[4] here is what he writes:

> Such research programmes are, generally speaking, indispensable for science, although their character is that of metaphysical or speculative physics rather than of scientific physics. Originally they were all metaphysical, in nearly every sense of the word (although some of them became scientific in time); they were vast generalizations, based upon various intuitive ideas, most of which now strike us as mistaken. They were unifying pictures of the world – the real world. They were highly speculative; and they were, originally, non-testable. Indeed they may all be said to have been more of the nature of myths, or of dreams, than of science. But they helped to give science its problems, its purposes, and its inspiration. (Popper 1982b: 165)

This point must be emphasized because certain criticisms addressed to Popper about Darwinism can no doubt be explained by the fact that many philosophers and scientists have a

[4] Popper mentions in particular the Parmenidian conception of matter, opposed to the existence of the vacuum; ancient atomism (which admits the existence of the vaccum); the Pythagorean and Platonic idea that the physical world is geometrizable; Aristotle's potentialism; the theory of the clock-world in the 17th century (Hobbes, Descartes, Boyle); the dynamical conception of matter (Newton, Kant, Boscovich); the idea that matter could be reduced to fields (Faraday, Schrödinger, Einstein) (Popper 1982b: 162–163).

very negative conception of metaphysics, as arbitrary discourse, even devoid of meaning, and in any case as useless for science. This very negative conception is largely due to philosophy itself, in particular to the positivist critique of metaphysics – in Auguste Comte first, then in logical positivism. In several writings, Popper sought to show that this positivist view of metaphysics is erroneous (Popper 1963: ch. VIII and XI; 1983: ch. II and III).[5] According to him, metaphysics is not an arbitrary discourse: it aims at *rationally interpreting experience*, even if it is not able to predict it. Nor is metaphysics a discourse devoid of meaning: despite all their efforts, logical positivists have never managed to demonstrate this. Finally, metaphysics is not totally separated from science: it suggests ideas to be developed in science, and empirical research to be undertaken.

To avoid the negative ideas associated with the word "metaphysics," one could also say that, for Popper, Darwinism is a *philosophical research program* for science. This would also express quite well the view he defends.

As Popper points out in this text, let us add that a metaphysical (or philosophical) idea can eventually become testable, and therefore scientific.[6] In the case of the theory of matter, think for example of atomism, that is to say the idea that matter is fundamentally made up of clearly distinct particles. This idea was initially metaphysical, in antiquity and in the 17th century, before becoming scientific. By integrating science, it has also become more complex[7] than what the philosophers had first conceived.

Thus, in Popper's mind, the fact that Darwinism is *today* hardly testable does not imply that it will always be the case. Human inventiveness and/or the accumulation of new empirical data can always change the situation.

2.3 Darwinism is a Research Program that Needs to Be Improved

As I explained at the beginning of section 2.1, Popper defends Darwinism against all other approaches to evolution: theistic, animist, vitalist and Lamarckian. However, according to him, Darwinism needs to be improved. Indeed, it does not explain some things well:

- *Orthogenetic trends*, that is, the "sequences of evolutionary changes in the same 'direction' (nonrandom walks)" (Popper 1974a: 138). Popper does not give an explanation. But one can assume that he is referring to the classical problem of the appearance of a complex organ in multiple separate steps.
- *Evolution towards "higher" forms of life*, such as the human species for example, as opposed to bacteria (Popper 1974a: 141). According to Popper, from the point of view of Darwinism, the appearance of "higher" forms of life is less likely than the improvement of the reproduction rate of "lower" forms of life.[8]
- The *separation of species during speciation*. According to Popper, Darwinism must necessarily appeal to the geographical separation of two populations to explain speciation, whereas another type of separation is possible (Popper 1974a: 141).

[5] According to Popper, positivism's error about metaphysics is linked to its error about science. In both cases, positivism fails to see that the demarcation between science and non-science (of which metaphysics is only a part) is based on falsifiability, not on verifiability.

[6] For this point, see also Popper (1963: 347; 1994: 88–89).

[7] And partially refuted, because of the importance taken by the notion of field in physics, which corresponds rather to the idea of a fundamental continuity of the material world.

[8] Popper suggests this point in 1972 (Popper 1972: 271).

Note, however, that for Popper these criticisms of Darwinism are not refutations. Otherwise, that would imply that Darwinism is testable. For him, these criticisms point out weaknesses of Darwinism, but without refuting it.

Similarly, Popper does not claim to make Darwinism more testable. His proposal to improve Darwinism only aims at eliminating certain weaknesses of the theory. Contrary to what some commentators say (Bradie 2016: 153, 158), there is no ambiguity on this point, and Popper emphasizes it again in 1982 (1982a: 44).

Popper's proposal can be summarized as follows: to Darwinism as it exists, we must add the idea that *the preferences of living organisms* have a determining influence on the natural selection that they undergo, and thus on their evolution. But before going into detail about this idea, let us clarify a few things right away. The first is that Popper conceives this idea as an improvement (1974a: 120) or an enrichment (1974a: 138) of Darwinism, not as something opposed to it. The second is that Popper does not claim that, from a fundamental point of view, his proposal is totally new. In all the writings in which he presents it, he explicitly refers to certain thinkers who had already made a similar proposal, notably Baldwin[9] (1972: 268; 1982a: 42; 1992: 209; 2014: 119), Schrödinger (1972: 268; 1974a: 138), Waddington (1972: 268; 1974a: 138), and Hardy[10] (1982a: 42; 1992: 209). The third is that, according to him, Darwinism has already more or less integrated the idea that the activity of living organisms plays a determining role in evolution. The problem is that some Darwinians minimize this role:

> My problem is exactly the same as that of my forerunners, such as Baldwin, who felt that the activities, the idiosyncrasies, and the preferences of individual organisms have played a far more important role in the history of evolution than Darwinists as a rule have admitted. My problem is that some Darwinists are inclined to attribute creative powers to what they call natural selection, forgetting for the moment that "natural selection" is no more than a highly suggestive and very useful metaphor. (Popper 2014: 119)

Popper develops his proposal in two writings: *Objective Knowledge* (1972) and "Intellectual Autobiography" (1974a). As the 1974 writing is the more accomplished of the two, it is the one that we will analyze.

Popper first postulates that there are different classes of genes: p-genes that control preferences (or goals), s-genes that control skills, and a-genes that control anatomy. Moreover, he postulates that, because of their genes, some organisms may have a certain variability of behavior. On this basis, he proposes a four-step mechanism:

1. Due to certain changes in the environment, some individuals in a given population may adopt *new preferences*. This is an attempt to adapt to the environment.
2. If this attempt is successful, then natural selection will tend to favor individuals carrying the p-genes that induce the new preferences.
3. Following this, natural selection will tend to favor individuals carrying the s-genes that improve the skills related to the new preferences (which will reinforce the selective value of p-genes).
4. Following this, natural selection will tend to favor individuals carrying the a-genes that improve the organs useful for the skills related to the new preferences (which will reinforce the selective value of p-genes and s-genes) (Popper 1974a: 138–139).

[9] James Baldwin (1861–1934) was an American psychologist. For his contribution to evolutionary thought, see in particular Baldwin (1896, 1897).

[10] Alister Hardy (1896–1985) was an English biologist. For his contribution to evolutionary thought, see in particular Hardy (1965).

In summary, according to this mechanism, the change of preferences in a population determines the genetic change of that population (of p-genes, s-genes and a-genes), via natural selection. Even more strikingly, this is equivalent to saying that *the aims of organisms* determine their biological evolution, via natural selection.

Of course, this mechanism involves feedbacks. The change in p-genes also determines the change in preferences, in the sense that it reinforces the adoption of the new preferences within the population. Similarly, the change in s-genes also determines the change in p-genes, in the sense that it reinforces the selective value of the latter. Etc. However, the impulse comes from the behavior of organisms.

Let us now see how Popper uses this mechanism to answer the different points raised against Darwinism as MRP.

On *orthogenetic trends*: according to Popper, the proposed mechanism helps to understand how natural selection can act continuously in a certain "direction." The idea is that when a population adopts new preferences, it creates a kind of need (in instinct, skill and anatomy) that makes it possible for natural selection to act for a long time in the same direction (Popper 1974a: 139).

On *the evolution towards "higher" forms of life*: as this mechanism affirms that evolution is determined by the preferences of organisms, it helps to understand that evolution can go towards "higher" forms of life. Because the preferences of organisms are not necessarily to maximize the rate of reproduction. They can be, for example, to build a shelter, to find a place for this shelter, to exploit this or that food source, etc. (Popper 1974a: 141–142).

On *the separation of species during speciation*: as this mechanism states that the change of preferences in a population precedes and determines the genetic change of this population, it makes it possible to understand that the separation between species can concern the preferences, before concerning the geography (Popper 1974a: 141).

In an article published in 1982 (Popper 1982a), and in a lecture delivered in 1986 (Popper 2014), Popper revisits his proposal for improving Darwinism. Several points should be noted.

First, to make his proposal better understood, Popper introduces the distinction between "passive Darwinism" and "active Darwinism" (Popper 1982a: 37–42; 2014: 119–120). For the first, evolution can be explained by two things: the variability of the genome and the physical environment (including other organisms). In contrast, for the second, evolution depends on a third thing: the activity of living organisms. For Popper, this activity plays a fundamental role: "I shall claim that the *only* creative element in evolution is the activity of the living organisms" (Popper 2014: 119).

Second, Popper presents his proposal without entering into a discussion of the different types of genes (p-genes, s-genes, and a-genes) and the order of modification of these genes. One can therefore assume that this element is not essential. What is essential is the idea that the adoption of new preferences by organisms directs the selective pressure they undergo (Popper 1982a: 40–42; 2014: 119).

Finally, Popper emphasizes *the teleological dimension* of the activity of living beings. In 1974, he hesitates to affirm that living beings act according to an aim, preferring to affirm that they seek to solve problems (1974a: 142; 1974b: 272). But the distinction seems thin, if not null. In 1982, and again in 1986, he frankly uses the notion of aim:[11]

> If we assume that such active and explanatory and mindlike (and presumably partly conscious) behavior is the result of the very early evolution brought about by passively Darwinian forces, then we can also assume that, once this stage has been reached, evolution is no longer the passive result of heredity and a hostile environment. Mindlike properties of the organism will begin to play an increasingly important part in evolution: aims, such as preference for certain kinds of

[11] Obviously, this aim is not necessarily elaborated, nor conscious (Popper 1974a: 143; 1974b: 272; 2014: 125).

> mates, preferences for certain locations for breeding, of for certain types of food; but also curiosity and explanatory behavior and, by contrast, conservative behavior; or change from one kind of behavior to another. (Popper 1982a: 40)

> Activity is a movement with an aim. And I think that we have to attribute some sort of activity to even the lowest organism… There cannot be adaptation without any aim. They cannot be knowledge without any aim. So, an aim is there. And we have to attribute all this to the lowest organisms. It is part of the distinction between living organisms and not-living crystals, let us say, liquid crystals. Crystals have many similarities with organisms, but they do not show activity in the sense in which organisms do. They do not show trial and error movements, which we find in the lowest organisms that we know. (Popper 2014: 125)

> The strange thing is that teleology enters the world with adaptation. Organisms are problem-solvers. Organisms seek better conditions. All of these are thoroughly teleological terms (Popper 2014: 124)

This last point is important, because Popper makes a logical link between the modified Darwinism he proposes and his conception of the irreducibility of the living to the inert (1974a: 141–143; 1982a: 40–41; 2014: 123–126). This link can be summarized as follows: thinking that the living is irreducible to the inert, because of its teleological dimension, leads to thinking that the living is a source of behavioral innovations; and this leads to thinking that the activity of the living plays a central role in evolution.

Table 1 highlights this logical connection between metaphysics of life and MRP for biology, comparing Popper to "passive Darwinism."

	Some Darwinists	**Popper**
Metaphysical position on the living:	*Reducibility of the living to the inert*: The apparently teleological activities of the living (including conscious activities) are in fact physical mechanisms.	*Irreducibility of the living to the inert*: The living act in a teleological way. They have aims (conscious or not, elaborated or not).
Consequence:	⬇ Underestimation of the innovative capacity of the living	⬇ Idea that the living has a capacity for innovation
MRP for biology:	⬇ *Passive Darwinism*: Evolution is explained by two things: the variability of the genome, and natural selection.	⬇ *Active Darwinism*: Evolution is explained by three things: the activity of organisms, the variability of the genome, and natural selection.

Table 1 Metaphysics of life and MRP for biology. Comparison between Popper and the Darwinists that he criticizes

To conclude this part 2 of the chapter, let us remember that Popper has two reasons for wanting to modify Darwinism. The first is that he considers that Darwinism does not explain

certain things well. The second is that he thinks that Darwinism is inspired by an erroneous metaphysical conception of life.

Popper then proposed what he considered an improved Darwinism: "active Darwinism." On the one hand, for him, this new MRP remains Darwinian in the sense that natural selection still plays a central role in evolution. On the other hand, this new MRP breaks with the mechanistic conception of life. In part 3, we shall see that there may be a tension between these two points.

3 Discussion of Popper's position

The aim of this part is to discuss Popper's position on Darwinism, taking into account the criticisms that have been addressed to him. For maximum clarity, I will follow the order of part 2, discussing successively Popper's three assertions: first, on the testability of Darwinism; then on the criterion of demarcation between science and non-science, notably on its application to biology; finally, on his proposal to improve Darwinism.

3.1 Discussion on the Testability of Darwinism

On this issue, several authors are opposed to Popper: Ruse (1977, 1981), Watkins (1995), Stamos (1996), Hull (1999), Bradie (2016). Other authors, fewer in number, defend Popper's position: Platnick and Rosen (1987), Vecchi and Baravalle (2015). But let us add that those who defend Popper's position refer to some philosophers of biology whose analysis on the testability of Darwinism echoes Popper's, notably Brady (1979) and Brandon (1980).

A first criticism, developed by some commentators, says that Popper contradicts himself by affirming, on the one hand, that Darwinism is not testable, and on the other hand, that Darwinism predicts gradualness (Ruse 1977: 649–650; Watkins 1995: 194). However, as I pointed out in 2.1, for Popper this prediction is not sufficiently discriminative to be a good test: Darwinism implies gradualness, but the reverse is not true, and many non-Darwinian theories also predict gradualness – Lamarckism, most of the theories of orthogenesis (W. Haacke, H. F. Osborn, etc.),[12] or the Bergsonian theory of the *élan vital*. Another important element is that gradualness admits of degrees. Therefore, if the prediction of gradualness is not *quantified* in some way, it is impossible to say whether or not it matches the facts, including in the fossil record.

A second and more often developed criticism is to reject Popper's central argument, claiming that Darwinism can make predictions on evolution, and that these predictions can serve as tests. We will discuss some of these proposals in detail. But I would like to point out at the outset that these proposals still have two weaknesses. First, they concern predictions that are not precise enough, which makes it difficult to know whether the prediction is true in a particular situation. Second, they concern predictions that are not specific to Darwinism, and that do not specifically test that theory.

The proposal made by Ruse in 1977 deserves a detailed examination, because Ruse discusses at length an example taken by Popper, while modifying his conclusion. In the previous section, we saw that, according to Popper, Darwinism does not *necessarily* predict strong evolutionary divergence. To justify this idea, he argues that the discovery of only three species of bacteria

[12] For the various theories of orthogenesis in the nineteenth and twentieth centuries, see in particular Levit and Olsson (2006). For Osborn's theory in particular, see Ceccarelli (2021). Osborn's non-Darwinian theory includes the idea of a certain gradualness of evolution, and a certain adaptationism (Ceccarelli 2021: 175–177).

on Mars (or any other planet) would not contradict the Darwinian theory, because this theory could assert, for example, that the conditions for greater divergence were not present.

According to Ruse, Popper's mistake is that he does not specify certain conditions. The idea is that if certain conditions are better determined, it is possible to make a prediction that can serve as a test for Darwinism. Ruse mentions the following three conditions: different ecological niches, relatively isolated from each other; some genetic variability in existing organisms; and a sufficiently long time (Ruse 1977: 643–645). His conclusion then is as follows:

> Had one reason to believe that life on the planet was fairly old (e.g., through the fossil record or general complexity of structure), yet were one to find that absolutely no speciation at all had occurred, then I suggest that, *contra* Popper, modern evolutionists would be worried. Their theory, parts of it at least, would have been falsified. The claims that they make about speciation would seem not to hold. (Ruse 1977: 645)[13]

Ruse is right to specify certain conditions left out by Popper. However, this does not fundamentally change things, because we find the two weaknesses I mentioned. First, none of the conditions given by Ruse are quantified, so that if speciation is not observed, or only very little, it is possible to say that the conditions are not *sufficiently* fulfilled: the ecological niches might not be *sufficiently* different from each other, or/and not *sufficiently* isolated (or too much) from each other; or/and the genome of the populations might not be *sufficiently* variable; or/and the time needed for speciation might not be *sufficiently* long. Another problem is that the expected result is not quantified either, in the sense that the number of expected species of bacteria, in order of magnitude, is not indicated: 10, 1000, 1 million, more? How then can we know if the prediction matches the fact? Second, this test proposed by Ruse is not discriminating enough because most non-Darwinian conceptions of evolution admit, or can admit, a certain adaptationism. For example, in Bergson's theory, evolution is conceived as being directed by a force immanent to life (the *élan vital*) towards the appearance of organisms endowed with reflexive consciousness. But this force is finite, so that evolution must adapt to given physical and historical circumstances. Evolution thus follows no plan, and its success is not guaranteed (Bergson 1998: 261, 265–267). In short, a certain teleology and a certain adaptationism are logically compatible.

The proposals made by Hull, in 1999, also deserve a detailed examination, because Hull refers directly to Darwin in trying to show that the latter already proposed various ways of testing his theory. Hull mentions the following Darwinian proposals:

> If it could be demonstrated that any complex organ existed, which could not possibly have been formed by numerous, successive, slight modifications, my theory would absolutely break down. (Darwin 1859: 189)

> [Some naturalists] believe that very many structures have been created for beauty in the eyes of man, or for mere variety. This doctrine, if true, would be absolutely fatal to my theory. (Darwin 1859: 199)

> If it could be proved that any part of the structure of any one species had been formed for the exclusive good of another species, it would annihilate my theory, for such could not have been produced through natural selection. (Darwin 1859: 201)

> The abrupt manner in which whole groups of species suddenly appear in certain formations, has been urged by several paleontologists … as a fatal objection to the belief in the transmutation of

[13] Watkins (1995: 194) proposes a similar test.

> species. If numerous species, belonging to the same genera or families, have really started into life all at once, the fact would be fatal to the theory of descent with slow modification through natural selection. (Darwin 1859: 302)
>
> He who rejects [the imperfection of the geological record] will rightly reject my whole theory. (Darwin 1859: 342).[14]

These quotations show that Darwin was concerned with testing his theory. On this point, his sincerity is therefore obvious. But the problem is to know if what he proposes can play as a real test for his theory.

Proposal 1 amounts to the following: if the existence of a complex organ cannot be explained by the mechanism of natural selection, then the theory is refuted. But, as Popper notes, the mechanism of natural selection explains things "in principle," without making any precise predictions (Popper 1974a: 138). It is therefore difficult to see how this mechanism could not apply, "in principle," to every complex organ. Again, without introducing a quantification (of complexity, and of the time needed to produce a certain level of complexity by natural selection), how can we obtain a true test?

Proposals 2 and 3 amount to saying this: if it is proved that certain traits do not constitute a selective advantage for the individuals which possess them, then the theory is refuted. But here we find the two difficulties. First, given the multiple possible effects of a trait in a given environment, it may be difficult to know whether that trait constitutes a selective advantage or not (I will come back to this point shortly after). Second, Darwinism implies adaptationism, but the reverse is not true. Therefore, testing adaptationism is not specifically testing Darwinism.

Finally, proposals 4 and 5 concern gradualness. Here Darwin asserts that his theory would be refuted if it were shown that some species "have really started into life all at once," which is equivalent to speaking of a total absence of gradualness. But, again, without quantification, the notion of gradualness is imprecise. Moreover, many non-Darwinian theories also predict some gradualness. Therefore, this test is not discriminative enough.

Reading the responses that Ruse, Hull, and others make to Popper, one gets the impression that, for them, testing Darwinism amounts to showing its explanatory superiority over theories that deny evolution – in short, over the classical forms of creationism. But the problem does not end there. Historically and logically, there are several non-Darwinian conceptions of evolution, and some of these conceptions support a certain adaptationism and a certain gradualness.

In contrast, some biologists or philosophers of biology agree with Popper on the question of the testability of Darwinism: Platnick and Rosen (1987: 12-13),[15] Vecchi and Baravalle (2015).

In their article, Platnick and Rosen refer to Brady (1979) who shows that the principle of natural selection is very difficult to falsify. This principle leads to explaining differential reproduction by fitness, but it is very difficult to establish an empirical criterion of fitness that is independent of differential reproduction. For Brady, this is because fitness depends on *an indefinite number of parameters* and, in practice, it is impossible to take into account and quantify all these parameters (Brady 1979: 604–606). In other words, it is impossible to reduce the interactions between an organism and its environment to a determinate system:

> Neither Darwinism nor, in its present form, neo-Darwinism, contains a theoretical reduction of the organism to a determinate system, and thus neither contains a way of determining the contributions of various parameters, or even the number of parameters. In practice, of course, predictions are made on the basis of individual traits, but whenever anything goes wrong the

[14] All these passages are quoted by Hull (1999: 487–488).

[15] In another article, Platnick seems to oppose Popper (Platnick and Gaffney 1978). In fact, in this article, Platnick and Gaffney try to show that Darwinism is not, in principle, untestable. But they recognize that it is hardly testable, which is in fact Popper's position.

> resulting foray into ad hoc speculations invokes the notion that the summation of effects is really indeterminable – any parameter could be interfering in who knows how many ways. (Brady 1979: 615–616)

Brady then concludes that the principle of natural selection has not yet been seriously tested:

> If other parts of neo-Darwinism have been well scrutinized, natural selection has escaped any serious testing and will continue to do so until we know a great deal more about organism-environment interactions. We are so far from a science that can reduce these interactions to a determinate system that some critics have wondered whether it makes any sense to attempt to operationalize the principle at all. (Brady 1979: 616)

In the same sense, Vecchi and Baravalle (2015) refer to Brandon (1980) for whom the principle of natural selection is not an empirical principle, but an "organizing principle":

> The principle of natural selection is an organizing principle, or to put it another way, a schematic law. As a general schema, it is without empirical biological content, but it does serve to structure particular biological explanations of differential reproduction. (Brandon 1980: 432)

The tone of the text is not as critical as in Popper, but the idea is not fundamentally different: the principle of natural selection has no empirical (testable) content; it is *a heuristic principle*.

In conclusion, even if Popper's position on the testability of Darwinism has often been criticized, this position retains a certain solidity, and it finds an echo among certain philosophers of biology.

3.2 Discussion on the Popperian Criterion of Demarcation between Science and Non-Science

Popper's position on Darwinism can be discussed at another level, that of the criterion of demarcation between science and non-science. According to Popper, this criterion of demarcation is testability, conceived as falsifiability. But by disputing this point, one could reject Popper's conclusion, that is, admit that Darwinism is hardly testable, while maintaining that it is a scientific theory.

The Popperian criterion of demarcation between science and non-science has been much discussed in philosophy, without thinkers reaching a consensus (Hansson 2021). In this section, without being able to take into account the entire literature on the subject, I will try to briefly address the following three questions, with a particular emphasis on the third one:

1. Is the problem of the demarcation between science and non-science really relevant?
2. Is the Popperian criterion of demarcation relevant to science in general?
3. Is the Popperian criterion of demarcation relevant to biology?

On the first question, Larry Laudan points out that the search for a criterion of demarcation between science and non-science presupposes that there are certain invariants of what is commonly considered as science. But this is not obvious. In fact, the opposite seems to be true:

> But we can go further than this, for we have learned enough about what passes for science in our culture to be able to say quite confidently that it is not all cut from the same epistemic cloth. Some scientific theories are well tested; some are not. Some branches of science are presently showing high rates of growth; others are not. Some scientific theories have made a host of successful predictions of surprising phenomena; some have made few if any such predictions. Some

> scientific hypotheses are *ad hoc;* others are not. Some have achieved a "consilience of inductions;" others have not. (Similar remarks could be made about several non-scientific theories and disciplines.) *The evident epistemic heterogeneity of the activities and beliefs customarily regarded as scientific should alert us to the probable futility of seeking an epistemic version of a demarcation criterion.* (Laudan 1983: 124)

For Laudan, the relevant philosophical question is therefore not: "what makes a belief scientific?" Rather, it is "what makes a belief well founded (or heuristically fertile)?" (Laudan 1983: 125).

Without claiming to decide between Popper and Laudan, I will first try to relativize the criticism developed by Laudan for the question that interests us, that of Darwinism. Then I will try to develop an argument in favor of Popper's position.

Let us assume that Laudan is right, i.e. that the problem of the demarcation between science and non-science is not relevant in philosophy, what does this mean for Popper's thesis on Darwinism? First, following academic usage, one must continue to assert that Darwinism is a scientific theory. But second, using the notions considered relevant by Laudan (Laudan 1983: 124–125), one can affirm that, for the moment, Darwinism has not managed to make predictions that are sufficiently precise and specific to be tested. In this sense, it belongs to the set of *non-predictive* scientific theories, as opposed to *predictive* scientific theories, and its value is essentially heuristic. And consequently, it resembles a certain number of theories traditionally considered as metaphysical. Conclusion: in Laudan's terms, Darwinism can be considered a scientific theory whose specific characteristics make it resemble some metaphysical theories. Are we very far from Popper's position?

I now turn to an argument in favor of Popper. As Laudan notes, the scientific world presents epistemologically diverse theories: some are clearly predictive and well-tested, others not, whose value is then only heuristic. However, Popper could point out that, in science, testability remains central in the sense that it is either given or hoped for: *given* by testable theories, and *hoped for* by theories whose value is only heuristic. For, in science, the goal of a theory whose value is heuristic is to produce empirical knowledge, i.e. testable knowledge. For example, some physicists claim that, for the moment, string theory is not testable (Smolin 2006). But it is clear that one of the main hopes of this theory is to become testable, and corroborated by tests. This also applies to Darwinism. Now, how to name these theories, in science, whose value is only heuristic? On the one hand, we understand Laudan's logic: since these theories are developed by scientists, and since their goal is empirical knowledge, they should be called "scientific." On the other hand, one can also understand Popper's logic: since these theories do not yet constitute empirical knowledge, it is exaggerated and misleading to call them as the theories which constitute empirical knowledge.

On the second question, there is a large literature. The set of criticisms addressed to Popper seems to form two groups. A first group of critics claims that falsifiability is not *a sufficient condition of scientificity*, because it leads to considering as scientific things that are usually considered as non-scientific. In particular, practical knowledge, for example carpentry or football strategy (Laudan 1983: 123). But also unserious theories, for example astrology, the flat earth theory, etc., provided that these theories specify the conditions that would make them false (Laudan 1983: 121). A second group of critics asserts that falsifiability (as thought by Popper) is *not really applicable in science*, because a prediction not corroborated by experience is not a sufficient reason to abandon a theory. This uncorroborated prediction can indeed concern a point that does not specifically belong to the theory being tested (epistemological holism), or a minor part[16] of the theory that can always be changed (Lakatos 1970, 1974).

[16] What Lakatos calls an "auxiliary hypothesis."

In response to the first group of criticisms, it should be noted that these criticisms do not challenge the idea that falsifiability is *a necessary condition of scientificity*. And this is what is at stake in the question of whether Darwinism is scientific or not. Moreover, it is possible to complete the Popperian criterion of scientificity by introducing other necessary conditions. In particular, the idea that scientificity concerns theoretical knowledge, as opposed to practical knowledge,[17] which excludes carpentry or football strategy. Or the idea that scientificity requires falsifiability, but also the fact of having resisted serious attempts at falsification, which probably excludes all unserious theories. Obviously, this last condition is not mechanically applicable: it requires a certain judgment.[18] But this is not surprising in human things, and science is a human thing.

In response to the second group of criticisms, it should be noted that these criticisms do not question falsificationism in general, only Popperian falsificationism. Thus, Lakatos proposes what he calls a "sophisticated falsificationism," in which the possibility of falsifying predictions remains a major criterion of scientificity (Lakatos 1970).

The third question concerns biology specifically: is the Popperian criterion of demarcation between science and non-science relevant to biology? For some philosophers of biology (Stamos 2007), but also for some biologists (Holliday 1999, Fincham 2000, Gallant 2000),[19] the answer is negative. For them, Popper relies only on physics to develop his epistemology, which makes that his conclusions are not applicable to other sciences, in particular to biology.

Among biologists, there are more precisely two criticisms. The first criticism is that, in contrast to what Popperian epistemology says, in biology certain hypotheses *can be verified*, in the sense that one can obtain complete certainty. To illustrate this idea, Holliday mentions the example of Harvey's discovery of blood circulation. According to him, the hypothesis that a circulation of this type exists in all vertebrates is verified, i.e. certain. It is therefore useless to try to falsify this hypothesis (Holliday 1999: 890). A second criticism is that, in contrast to what Popperian epistemology says, in biology some hypotheses *cannot be falsified*. On this point, here is what Holliday writes:

> Thus, we do have certainty in genetics, but at the same time there are many exceptions to Mendelian inheritance in various biological adaptations to specific situations, where an alternative form of inheritance is beneficial. No matter how many such cases are documented, they in no way undermine the truth of Mendelian inheritance. How could this truth possibly be falsified? (Holliday 1999: 890)

In a few words, Holliday alludes to the fact that in biology, most natural regularities have exceptions. For him, the consequence is that in biology, a negative test is not a good reason to reject a theory. In other words, the consequence is that Popper's falsificationist method cannot work in biology, and therefore cannot define scientificity.

With respect to the first criticism, note that it does not challenge the idea that scientificity requires falsifiability. Thus, in the example taken by Holliday, we can continue to think that Harvey's hypothesis is scientific in the sense that it allows us to make falsifiable predictions. Therefore, this criticism does not change the problem encountered by Darwinism. Moreover, without claiming to settle the question of a possible "verification" in biology (in certain cases only), it should be noted that the Popperian critique of verification is purely logical: it only leads to assert that a statement cannot be absolutely certain if it concerns *a non-finite class of objects*. Thus, in the example taken by Holliday, it only leads to assert that Harvey's hypothesis

[17] This condition only takes up a philosophical tradition dating back to antiquity.

[18] For such an attempt to complete Popper's falsificationism, see in particular Lakatos (1970).

[19] Between 1999 and 2000, in the Correspondence pages of the journal *BioEssays*, several biologists took positions for or against Popper concerning method in science. I draw on these exchanges for the analysis which follows.

cannot be absolutely certain for past, present and future terrestrial mammals (and even for possible extraterrestrial mammals). It does not claim that it is appropriate to devote one's efforts to trying to falsify any hypothesis.

The second criticism is more interesting for our reflection, because it directly concerns the Popperian criterion of demarcation between science and non-science. However, it appears that this criticism is based on a misunderstanding of falsificationism. When a biologist formulates a theoretical hypothesis, he/she necessarily defines *a field of application* for this hypothesis, at least as a conjecture. For example, they may assert that their hypothesis is valid for all mammals, all animals, or all living organisms. And from this hypothesis, they may deduce a set of falsifiable predictions. If a test now gives a negative result, rejecting the original hypothesis may simply lead to redefining its scope, incorporating exceptions. For example, all mammals except mammals A, B and C. From a logical point of view, the original hypothesis is falsified, because to speak of a scientific hypothesis without *a defined field of application* does not make sense. But the formulation of a new hypothesis is easy because it is only a matter of integrating certain exceptions. Popper's falsificationism does not exclude this possibility at all. It can therefore answer the "problem of exceptions" in biology.

This second criticism is sometimes expressed in another way. Thus, Stamos explains that Popper's falsificationism cannot be applied to biology because this falsificationism is thought to apply to a science that formulates laws, whereas it is difficult to think that biology formulates laws (Stamos 2007: 366–371). According to Stamos, the notion of law implies that of "physical necessity" (Stamos 2007: 368), whereas biological regularities are physically contingent. And this contingency would be the fundamental reason for the multiple exceptions observed for various regularities. However, Stamos introduces here obscure and unnecessary metaphysical considerations, absent from Popper's analysis. It is true that Popper sometimes asserts that the goal of theoretical sciences (as opposed to historical sciences) is to discover the "laws of nature." But one must keep in mind that his approach to science is logical, not metaphysical. Thus, for him, a "law of nature" is nothing more than a causal regularity whose knowledge allows us to make testable predictions (see for example Popper 1959/1992: 38–39, 105–106). From this point of view, a "law of nature" does not necessarily have a cosmic scope, in the sense that it does not necessarily concern the most fundamental regularities of the universe, with the idea that these regularities would be invariable (when Stamos speaks of "necessary" laws, he seems to be talking about invariable laws). It may, for example, concern only a few species, or even a single species, i.e. something that live only on Earth, and for a given time – even if, in fact, the word "law" is rarely used in this case, probably because this word has a metaphysical connotation.

Finally, we come back to the same idea: for Popper, theoretical science is essentially characterized by its capacity to predict phenomena, because the latter present regularities. What he calls "law of nature" is thus defined only in relation to this capacity.[20] Consequently, for Popper, biology can *logically* proceed like physics, by producing predictive theories. And this does not imply that the living would be reducible to the inert (Popper thinks the contrary), or that it would not present certain specificities, such as for example the absence of invariable regularities.[21]

[20] Obviously, the expression "law of nature" can designate something else in philosophy, in particular in metaphysics. But this is not the case in Popper. For such a minimalist conception of laws in science, see in particular Mitchell (2000).

[21] Evolution is not specific to the living world since, according to contemporary physics, it also concerns the universe. However, the theoretical framework favored by physics is that the universe evolves by obeying fundamental laws that *do not evolve*. That said, this framework is only a hypothesis, and some physicists do not hesitate to discuss it (see for example Smolin 2013: ch. 11).

As an alternative to the Popperian criterion of demarcation, Stamos argues that scientificity depends on the *more or less complete* satisfaction of a set of epistemic values and practices.[22] In particular, Stamos thinks of the following values: "simplicity, predictive accuracy, fertility, coherence with other things we know, unification, and of course testability." And he thinks of the following practices: "prohibitions against the invention of data, the encouragement of 'innovation and deviance', a non-hierarchical structure, and the encouragement of honesty and reliability" (Stamos 2007: 373). But apart from predictive accuracy and testability (which, for Popper, are one and the same), metaphysics[23] can satisfy all these values and practices. Stamos's proposal therefore amounts to integrating metaphysics into science.

To conclude, if, like Laudan, one thinks that the problem of demarcation between science and non-science is not relevant, then, as far as Darwinism is concerned, one can still formulate a conclusion close to that of Popper: Darwinism is a scientific theory whose specific characteristics make it resemble a certain number of theories traditionally considered as metaphysical. If now, like Popper, one thinks that the problem of the demarcation between science and non-science is relevant, then one can say that the Popperian criterion of demarcation remains relevant because it is central in science (at least as a necessary condition of scientificity). And in this hypothesis, one does not see why this criterion could not be applied to biology.

3.3 Discussion on the Popperian Proposal to Improve Darwinism

In this section, I discuss two criticisms of the Popperian proposal to improve Darwinism, and then develop a third criticism.

A first criticism, essentially developed by Ruse, consists in contesting the reasons that Popper puts forward to justify his attempt to improve Darwinism. Let us recall that Popper puts forward three reasons: Darwinism (in its passive form) does not explain orthogenetic trends, evolution towards "higher" forms of life, and the separation of species during speciation. Overall, according to Ruse, Popper ignores the elements developed within Darwinism to explain these things (Ruse 1977: 651–652). On the first point, in particular, Ruse considers that Popper confuses natural selection and genetic drift: while the latter makes evolution a random walk, the former can produce trends (Ruse 1977: 653).

From one point of view, Ruse's remarks are justified because Popper develops his criticisms of Darwinism very little, probably because he thinks that these criticisms are classical, and therefore widely developed in the literature. From another point of view, however, Ruse neglects to put these criticisms in context. For Popper, Darwinism is not testable. It is therefore not possible to refute it scientifically. It is only possible to consider its explanations as insufficient. Thus, Popper obviously knows that natural selection can, *in principle*, explain orthogenetic trends. But he doubts that natural selection is, *in fact*, sufficient to explain these trends.

A second criticism, developed by many authors, is that, in its broad outlines, Popper's proposal is not original because it repeats an idea already proposed by several thinkers, in particular by Baldwin (Ruse 1977: 654; Watkins 1995: 191–192; Hull 1999: 493–494; Vecchi and Baravalle 2015: 537–538; Bradie 2016: 161). Some of these authors add that, in detail, about the different types of genes (p-genes, s-genes, and a-genes) and the order in which they are modified, Popper's proposal is biologically unsound and unnecessarily complex (Ruse 1977: 655–656; Hull 1999: 494–495; Vecchi and Baravalle 2015: 538).

[22] Stamos draws on several philosophers of science to defend this idea, including Kuhn (1983) and McMullin (1983).

[23] In Popper's sense, and not in the positivist sense of the term.

As I pointed out in section 2.3, in 1982 and 1986 Popper presents his proposal without entering into a discussion of the different types of genes and the order in which they are modified. One can therefore think that this element is not essential.[24]

On originality, Popper's commentators are right to point out that his proposal repeats an idea already formulated. However, they underestimate an important element. According to Popper, the activity of living beings plays *a central role in evolution*, so much so that, for him, there are three fundamental factors in evolution: the activity of organisms, the variability of the genome, and natural selection (see Figure 1 in 2.3). In contrast, for the architects of the Modern Synthesis, the "Baldwin effect"[25] is not central at all: for Simpson and Mayr, this effect is doubtful, if not marginal in evolution (Simpson 1953: 115; Mayr 1963: 610–612); and for Huxley, even if the Baldwin effect is an element to be taken into account, this element is not central in evolution (Huxley 1942: 17, 114, 304, 523–524). Moreover, even today, although there is a renewed interest in the Baldwin effect in biology, we are far from the Popperian proposal. This effect is invoked to explain certain aspects of evolution, notably for the human lineage (Durham 1991; Dennett 1991: 190; Deacon 1997). But it is not considered a central dimension of the whole of evolution. It is therefore difficult to avoid the conclusion that Popper's proposal has some originality.

In reality, this originality is explained by the fact that Popper bases his proposal on two ideas not shared by the defenders of Darwinism. The first is that modern Darwinism *is not enough to explain evolution*, and therefore one or more other major factors must be discovered. The second is that the activity of living beings has *an irreducible teleological dimension*: an irreducible capacity to invent and evaluate new behaviors, at least through sensations of pleasure and pain (Popper 1982a: 39–40). Popper's proposal therefore consists in hypothesizing that this teleological dimension is a major factor in evolution. It thus generalizes the proposal developed by Alister Hardy for the animal world, in *The Living Stream* (1965).[26] In contrast, the defenders of the modern synthesis leave aside, even contest, the teleological dimension of the activity of the living.[27] And among some contemporary defenders of the Baldwin effect, we find the same distrust of teleology.[28]

Table 2 summarizes the basic elements that show how Popper's proposal is original.

[24] In 1974, Popper probably thinks that genetic mutations affecting behavior (preferences and skills) are less likely to be lethal than those affecting anatomy. This is why he imagines that genetic modification in a population tends to follow a certain order: first the p-genes, then the s-genes, and finally the a-genes. But his proposal can be maintained without this order.

[25] This expression was coined by Simpson (1953: 112).

[26] In this book, Hardy makes a critique of modern Darwinism (1965: 153–154, 209). Moreover, he explicitly mentions the "psychic side" of animal life (1965: 262–264). According to him, the teleological activity of animals plays a major role in their evolution (1965: 154, 262). Popper explicitly refers to Hardy (Popper 1982a).

[27] In 2004, Mayr explains that he recently admitted that certain animal behaviors have a teleological dimension (Mayr 2004: 57). But he adds that this teleological dimension is reducible to mechanisms (Mayr 2004: 61).

[28] For some authors, the Baldwin effect is only acceptable if it is conceived as reducible to mechanisms, without anything fundamentally teleological (Downes 2003: 43, 48; Dennett 2003: 71–73).

	Modern Darwinism	Hardy	Popper
Position on Darwinism : + **Position on teleology in the living world:**	Defense of Darwinism + Hypothesis of a reduction of the teleological to the mechanical	Criticism of Darwinism + Hypothesis that the activity of animals is irreducibly teleological	Criticism of Darwinism + Hypothesis that the activity of all living beings is irreducibly teleological
Place of behavioral innovation in evolution:	⬇ Marginal place in evolution	⬇ Central place in the evolution of the animal world	⬇ Central place in the whole evolution

Table 2 On the place of behavioral innovation in evolution. Comparison between Popper, Hardy, and modern Darwinism

A third criticism, this time not inspired by Darwinism, can be addressed to Popper. This criticism concerns the question of *the emergence of the teleological* in the living world. Let us recall that, for Popper, the main merit of Darwinism is to propose a reductionist approach to the mechanisms of evolution, i.e. not to introduce any ad hoc hypothesis – as opposed to theistic, panpsychist, vitalist, or even Lamarckian approaches to evolution. However, in order to explain the existence of irreducibly teleological activities in the living world, Popper makes the hypothesis that this type of activity can somehow emerge from purely mechanical processes. This hypothesis is not supported by any independent reason: it is purely ad hoc. In this respect, the Popperian approach to evolution resembles other non-reductionist approaches.

To defend his emergentist hypothesis, Popper can only claim that this metaphysical position is the one most compatible with the scientific knowledge of our time. Against panpsychism in particular, defended by some evolutionary theorists,[29] Popper asserts that, for contemporary physics, elementary particles do not manifest any memory capacity (Popper 1977: 182).

4 Conclusion

Following the order of the questions addressed in parts 2 and 3, I will conclude this chapter with three points.

First, Popper argues that Darwinism (reduced here to the theory of natural selection) is difficult to test, and his analysis seems sound. The tests proposed by some defenders of Darwinism always have two weaknesses: they are based on unquantified predictions, which makes it difficult to know whether or not a particular fact (real or hypothetical) corresponds to the prediction; and they are insufficiently specific because they do not allow one to decide between Darwinism and some other conceptions of evolution.

Second, Popper deduces that Darwinism is less a scientific theory than a metaphysical research program for science. This assertion presupposes two things: the first is that we can

[29] Among the advocates of a form of panpsychism, Popper mentions two biologists: Rensch (1900–1990) and Waddington (1905–1975) (Popper 1977: 179). Wright (1889–1988) and Haldane (1892–1964) should also be mentioned.

make a clear distinction between science and non-science; the second is that this distinction is essentially based on falsifiability. I have tried to discuss these two presuppositions. The conclusion I propose is that the rejection of a clear demarcation between science and non-science only leads to a reformulation of Popper's position as follows: Darwinism is a scientific theory whose specific characteristics make it resemble a certain number of theories traditionally considered as metaphysical. On the other hand, the acceptance of a clear demarcation between science and non-science leads us back to the Popperian criterion of demarcation, at least as a necessary condition of scientificity. In this hypothesis, and without over-interpreting this criterion metaphysically, one does not see why it could not be applied to biology.

Third, considering that Darwinism hardly explains some aspects of evolution, Popper proposes to replace "passive Darwinism" by "active Darwinism." For the former, evolution is essentially explained by two things: the variability of the genome and natural selection. For the second, there is another factor: the activity of organisms. The originality of Popper's proposal is, if one may say so, to think that the Baldwin effect applies to the whole of the living world, including the humblest organisms. According to him, this proposal is justified by the fact that the activity of organisms is irreducibly teleological. Let us add that, for him, this proposal does not pretend to say the reality of evolution. It only claims to improve Darwinism as a metaphysical research program.

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