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Evolutionary Change and Lawlikeness

Beatty on Biological Generalizations

Martin Carrier
Department of Philosophy, Universität Heidelberg

1. Beatty's Position

In his very interesting and noteworthy paper "The Evolutionary Contingency Thesis," John Beatty claims that there are no specifically biological laws. All biologically relevant generalizations either are laws of the physical sciences or else critically depend on the historically contingent results of the evolutionary process. This disciplinary division of labor is explicated on the example of the mechanism of respiration in cells. This so-called "Krebs cycle" is in itself just a sequence of chemical reactions. As such it constitutes an instantiation of the common energetic constraints and molecular mechanisms involved in chemical reactions in general. In this sense the Krebs cycle represents a purely chemical generalization. However, the fact that the cycle is prevalent in biological cells is not a matter of chemistry, but of evolutionary biology. Its predominance among living creatures is a product of evolution. All generalizations about cell respiration thus refer to a specific result of evolution. The same holds with respect to other distinctively biological generalizations such as Mendel's laws of inheritance.

All these generalizations merely describe specific outcomes of the process of evolution. They are evolutionarily *contingent* in that they are brought about by the agents of evolutionary change. The contingent nature of these generalizations is exhibited by the fact that they do not hold universally but are restricted by the presence of appropriate circumstances. They are restricted to those circumstances, namely, which favored the development of the corresponding trait. This restricted validity is highlighted by the appearance of exceptions. Not every cell respiration proceeds by means of the Krebs cycle, and not all processes of inheritance obey Mendel's laws.

As a consequence, these generalizations are not lawlike; they do not support counterfactuals. It is not justified to say: If this entity were a respirating cell, then it would operate using the Krebs cycle. The inference to non-lawlikeness is reinforced by the "highly contingent" nature of evolutionary change: Even if the environmental conditions are kept unchanged, no definite product of evolution is bound to develop. Identical environmental initial conditions could have led up to a different evolutionary result. Beatty takes this feature to be the reason for the lack of lawlikeness. Since there is no fixed evolutionary path, no biological generalization is exempt from exceptions. Consequently, none of them is capable of supporting counterfactuals. Beatty's claim is that all distinctively biological generalizations are highly contingent in this sense and that, consequently, there are no biological laws.

2. Outline of the Comment

Beatty does explicitly not intend his description to provide a criterion of demarcation between biology and the physical sciences. He is perfectly ready to admit that the laws of physics and chemistry likewise suffer from high-level contingency. He is thus prepared to concede that there are no laws of nature at all in the proper sense. There are, in any event, no laws of biology (p. 52 fn. 8).

I follow Beatty in taking the capacity to support counterfactuals as the distinctive criterion of lawlikeness (p. 53, fn 9), but I contend that there are specifically biological laws. I admit that generalizations about the traits of species and higher-level taxa do not qualify as laws. But not all biological generalizations are of this kind. Moreover, contingency and high-level contingency are not sufficient to deprive biological generalizations of their lawlikeness. There are analogs to these features in the physical sciences, and the corresponding regularities are still widely—and in my view rightly—regarded as laws. Consequently, the biological generalizations in question should count as laws as well.

Accordingly, I quite agree with Beatty that the notion of a law is not a good criterion for separating the physical sciences from biology. The boundary between the two branches cannot be drawn neatly using this notion. However, whereas Beatty would conclude that the notion of a law of nature has lost its point and that laws as usually conceived do not exist, I advocate the reverse conclusion, namely, that biology is more law-oriented than Beatty's account suggests.

I shall try to support this claim in two steps. First, I will look into the reasons, as advanced by Beatty, for the non-lawlikeness of biological generalizations. My claim is that these reasons are insufficient to buttress his conclusion. Second, I shall try to defend the view that there are indeed biological laws that govern the evolutionary process.

3. The Argument from Simple Contingency

Beatty's argument from contingency comes in two stages. The first is concerned with the dependence of biological generalizations on the circumstances in general, the second addresses the failure of the circumstances to determine unambiguously the outcome. In this section I look into the problem of dependence in general (or "simple contingency"); in the following section I turn to the ambiguity problem (or "high-level contingency").

Beatty's argument from simple contingency runs as follows. Laws are required to support counterfactuals and thus to confer a sort of necessity on the features they capture. Biological generalizations deal with the characteristics of species or higher-level taxa. These generalizations are the result of the action of evolutionary forces. However, the results are crucially dependent on the environmental circumstances in which they emerge. If the conditions had been different, the products of evolution would have been different also. All warm-blooded vertebrates have four limbs. Well, it just happens to be the case; it could easily have been otherwise. Analogously, the near universality of the genetic code is just a frozen accident. There is nothing necessary about the circumstances that favored the corresponding trait, and this is why the pertinent generalization lacks lawlikeness (pp. 52, 61).

I agree that most (and perhaps all) generalizations about species do not qualify as laws. Species do not form natural kinds.[1] Admittedly, the occurrence of a black swan did not violate a law of nature. Likewise, non-Mendelian gene transmission does not involve an overturn of the order of nature. But for what reason? In my view, the reasons advanced by Beatty are insufficient for establishing non-lawlikeness. I'm going to argue that the laws of physics are likewise afflicted with both contingency and high-level contingency without thereby ceasing to be laws. As indicated earlier, I will first focus on simple contingency and then turn to high-level contingency in the next section.

It is a pervasive feature of all scientific laws that the concrete results achieved on their basis heavily depend on the boundary conditions present and the initial conditions chosen. Let's consider some cases of increasing complexity. First, when you let a stone drop vertically to the ground, it lands in front of your feet; when you throw it away, it smashes your neighbor's window. In spite of their remarkable difference both outcomes are captured by the laws of mechanics. This is possible because the initial conditions are different in both cases. Dependence of the end-states on the initial conditions detracts nothing from the lawlikeness of the generalizations involved. They still support counterfactuals.

Understood a trifle more strongly, dependence on the circumstances means, second, that a generalization does not hold universally but is restricted to specific situations. All statements about aerobic energy processing and about gene transmission would be empty and entirely pointless if the corresponding mechanisms had not come into existence. But consider Fourier's law of heat conduction. This law would obviously be empty if the universe actually were in a state of thermal equilibrium. No temperature differences, no heat conduction. Is Fourier's law disqualified as a law for this reason? This would surely be an odd contention.

In a yet stronger sense the dependence can be thought as expressing, third, the fact that biological generalizations depend on circumstances which could easily have been otherwise and, as

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[1] A possible exception may arise from the fact that some variants of a species may simply be inviable. The viability of these variants would be precluded by chemical laws, and the species would thus exhibit the corresponding traits lawfully (see Kitcher 1984, pp. 312–313).

a matter of fact, have been otherwise at some place some time. The prevalence of the Krebs cycle is not universal since in the course of evolution deviant local factors have shown up. Analogously, the applicability of the Hardy-Weinberg law hinges on conditions such as the independent transmission of alleles, and these conditions are not always fulfilled (p. 51). As a consequence, recourse to domain separation is necessary for an adequate description. We have to apply different generalizations about cell respiration or inheritance depending on the organisms we are dealing with.

But this is not so different from the physical sciences. Not all physical laws are universally applicable; some are restricted to quite specific circumstances. The state of affairs they are intended to capture may be very contingent indeed. Think of the account of the complex chain of intertwined chemical reactions which will eventually leave us with a depleted ozone layer. These generalizations just happen to apply to the earth's upper atmosphere. If we had acted differently in the past, these generalizations would be empty. Another case in point is high-temperature superconductivity. The development of an account of this phenomenon constitutes one of the foremost contemporary challenges for physical theory. The scope of this venture is evidently rather limited. That is, the applicability of the future theory obviously hinges on the historically contingent production of the object it is supposed to hold for. Moreover, there is a kind of domain separation involved here. It has become clear that the received BCS theory of superconductivity only applies to temperatures close to absolute zero and thus fails to capture the phenomenon in question. High- and low-level superconductivity thus most probably represent phenomena of different kinds which are to be explained by different accounts. I take this instance to be in close analogy to cases of biological domain splitting such as the distinction between Mendelian and non-Mendelian gene transmission.

Fourth, a generalization may be contingent in that influences of different kinds are operative at the same time. Beatty presents Bergmann's rule as an example of an exception-ridden generalization which, one supposes, cannot be considered lawlike for this reason (p. 57). Let's ask how these exceptions come about. Bergmann's rule states that the cooler the climate in which a variant of a warm-blooded species lives, the larger this variant grows. Given the framework of evolutionary theory, this rule follows from geometry and thermodynamics. The larger a body is, the smaller is its surface-volume ratio, with the result that heat dissipation is relatively diminished. Thus it appears that an organism obeying the rule has an energetic advantage over its deviant rival, which in turn contributes to its increased fitness value.

How is it possible that such a physics-based rule can have exceptions? The reason is that a proviso or *ceteris-paribus* clause is implicitly appended to it, and this clause need not be satisfied. It is perfectly possible that additional influences are operative that override the energetic advantage. For instance, the increased body size necessitates increased food supply and goes along with enhanced visibility for predators; moreover, larger animals have a hard time finding a suitable refuge. So, the adaptive advantage may be outweighed by unwholesome side-effects which tend to reduce the organism's fitness. Which result actually turns up thus depends on the circumstances realized.

But this feature is in no way distinctive of biology. Consider the law of free fall: All bodies near the earth's surface fall with a constant acceleration. Right? Quite wrong. Every parachutist constitutes an exception. Does he also constitute a violation? Not at all. For this law likewise holds under the proviso that no forces other than gravity are operative. Air friction or an eventual electric charge of the body represent such possible additional influences. And when competing influences are in play, more than one law is needed to account for their combined effect.

Bergmann's rule addresses only one of the relevant factors and is thus bound to have exceptions. The conceptual situation is akin to the one in the parachutist-case. It only brings to light that the superposition or interaction of the various influences present has to be taken into account more thoroughly. The mere fact that various selection pressures or that selection and drift act in competition is not detrimental to the lawlikeness of any one of the laws involved. Otherwise one would end up with the conclusion by analogy that the law of free fall is violated with a vengeance and in no way qualifies as a law. I take this conclusion to be self-defeating.

Fifth and finally, a law may be contingent in the sense that it happens not to be instantiated at all. Consider the Hardy-Weinberg law. Provided that no mutation, no selection, and no migration occurs, the gene frequencies remain constant. But as a matter of fact, these influences occur universally so that there are no instances for which the law actually holds. But this peculiarity is in no way sufficient to deny it lawlike status. For the same is true of Newton's law of inertia. It follows from Newtonian mechanics that there is no entirely force-free body in the whole universe. Both laws constitute approximations or idealizations whose appropriateness derives from their integration into a body of theory. It is the theory in its entirety that manages to cope with the real-life cases. In virtue of this integration the law of inertia indeed supports counterfactuals. The Hardy-Weinberg law likewise plays an essential role in a number of biological explanations (mostly in population genetics).[2] Consequently, I see no reason to deny it counterfactual force.

Dependence of the ensuing results on the circumstances present is thus not sufficient for establishing non-lawlikeness. It is quite unsurprising that in different environments different species evolve and that, consequently, any generalization about one of these species ceases to be instantiated if the circumstances had been otherwise. Dependence on the initial and boundary conditions, as they happen to be realized, is a pervasive characteristic of physics also.

I admit, however, that regarding evolutionary biology the advice to take all relevant factors into account is much more easily outlined than actually followed. The problem seems to be that in biology it is much more difficult than in physics to approximate empirically the undistorted state. The relevant factors are more heavily intertwined and less easily disentangled. It is difficult to attribute unambiguously a particular trait to a particular kind of selection pressure. But this difference is a matter of degree, not a matter of principle. The combination of several influences constitutes an ubiquitous feature in physics as well. The conceptual situation is thus similar in both disciplines.

4. The Argument from High-level Contingency

Beatty's claim is not merely that biological generalizations are characterized by simple contingency; rather, the decisive blow against lawlikeness is said to stem from the fact that biological generalizations are *highly* contingent. By this he intends that "evolution can lead to different outcomes from the same

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[2] The explanation of heterozygous superiority briefly touched upon below constitutes an example.

starting point, even when the same selection pressures are operating" (p. 57). That is, in spite of the complete equality of the initial and boundary conditions, different results may emerge. Beatty attributes this feature to two chief sources. One source is the intrusion of chance events into the evolutionary process, the other one is functional equivalence. Functional equivalence means that different mechanisms may confer the same adaptive advantage on an organism. Adaptation to a cooler climate need not be achieved through increased body size; it might as well be reached by developing a thick layer of fur.

The possibility of different, but equally effective, solutions to the same adaptive problem, along with the occurrence of random changes in the evolutionary process, opens up a wide range of options for the development of physiological mechanisms. And this is what is indeed encountered in nature. Various sorts of orchids developed different mechanisms so as to cope with a common problem, namely, the fertilization by insects (pp. 58–59).

The point of high-level contingency thus is that there are different routes to the same fitness value and that one of these routes is ultimately singled out through chance events. The salient aspect thus apparently is that due to the intrusion of random variations every account of the process of evolution is bound to be non-predictive. We can reconstruct and explain with hindsight the stages that led up to the present state of affairs, but by no means can we predict in advance how species will be developing in the future. No one could possibly have anticipated that giraffes would develop long necks and that humans would eventually be proud of their tremendous IQ-values.

Quite all right. But I am at a loss to understand how this feature might be responsible for the missing lawlikeness of the generalizations involved. The argument turns on the non-predictive character of evolutionary explanations. But what does this peculiarity demonstrate? Some decades ago, we learned the hard way that the quantum world is likewise littered with chance events that render impossible any predictive account of quantum phenomena. Quantum states that are initially alike in every quantum mechanical respect can be followed by quantum mechanically quite different states. When a beam of equally prepared silver atoms is sent through a Stern-Gerlach apparatus nobody can tell which atom will land in the spin-up and which in the spin-down channel. That is, no one is able to predict which one of the alternative possible states a given particle will assume. So, by analogy, we are forced to conclude that the laws of quantum mechanics are in reality no laws at all.

One might respond that there is an important disanalogy between evolutionary biology and quantum mechanics. Quantum mechanics actually is able to predict something in advance, namely, averages and relative frequencies of measuring values. But even statistical generalizations of this sort appear unattainable in evolutionary biology. Even probabilistically qualified predictions seem to be out of the question. After all, who would dare to ascribe probability values to possible alternative developmental paths of giraffes?

Still, there are predictively relevant generalizations in evolutionary biology. These generalizations are framed on a particular conceptual level—and this is why they easily escape notice. They are framed, namely, using *supervenient concepts*. A concept s supervenes on a number of different concepts p, if every distinction on the s-level is accompanied by a distinction on the p-level, but not vice versa. That is: $\Delta s \rightarrow \Delta p$; but not: $\Delta p \rightarrow \Delta s$. The concept of fitness constitutes an example. Fitness supervenes on the particular physical characteristics of an organism. Organisms can only differ in fitness if they also differ in at least one physical trait; but not every physical difference entails a difference in fitness too. For instance, a fitter zebra may be one with longer legs and the concomitant capacity to run faster. Physically identical zebras are identical in fitness also. The salient point of supervenience is that nothing is implied about which physical characteristics contribute to a change in the corresponding organism's fitness. Whereas a zebra may benefit from longer legs, the fitness of rats may be increased by the acquisition of resistance to a certain brand of poison. That is, fitness is realized differently in different species (or in the same species under different environmental conditions). Evolutionary biology makes ample use of supervenient concepts. Another example is courting behavior. Courting among elephants is evidently physically different from courting among catfish.

Elliott Sober has drawn attention to the fact that the capacity of multiple, different realizations makes supervenient concepts suitable for entering into laws of a specific type—laws, that is, dealing with properties which are more abstract than the concrete physical characteristics of particular species. Consider the example of fitness. By assigning appropriately rank-ordered fitness values to varieties of a species or to various combinations of alleles it is possible to derive consequences about the relative sizes of populations or about the relative frequencies of genotypes. The paradigm instance is the derivation of heterozygous superiority of sickle cell genes in malaria regions. A specific allele causes a fatal disease when it occurs in pairs; but conjoined to a different allele it confers resistance to malaria. On the basis of the Hardy-Weinberg law and resorting to an appropriate rank-order of fitness values, one derives, and is consequently able to predict, that the frequency of the fatal gene approaches a fixed limiting value.

Analogously, the temporal development of the comparative size of predator and prey populations can be analyzed. This is achieved in the framework of the so-called Lotka-Volterra model, and one of the results obtained is that regular oscillations of the number of animals around a fixed average value will turn up. On that basis it can be predicted how specific interventions in the ecological system will affect the respective numbers.

The point is that these lawful generalizations in no way refer to the physical particulars of the situation at issue. It is completely irrelevant what the reason for the increased heterozygous fitness is and by what physical means a predator manages to catch its prey. These laws thus apply to a variety of physically distinct cases. They express features that are quite differently realized physically. For this reason supervenient concepts are apt to capture general traits inaccessible on the purely physical level, and this capacity constitutes the basis of the explanatory usefulness of these concepts (cf. Sober 1984, pp. 38–40, 48–51; Richardson and Burian 1992).

It is true, it is not always easy to assign fitness values in a justified manner in concrete instances. But this is not the point. The role of regularities using supervenient concepts is analogous to the role the Newtonian equation of motion plays in mechanics. If the forces are given—whatever their origin and nature may be—then we can determine the motions of the bodies involved. Analogously, if comparative values of fitness are assumed—whatever their physiological basis may be—then we can determine the gene frequencies and the population sizes involved.

I conclude that there is indeed a specific type of biological concepts that opens up the avenue to a specific type of biological law. These laws make use of supervenient concepts and refer to traits that are differently instantiated among different species.

Supervenient concepts lead us out of the jungle of alternative physical realizations of an adaptive advantage by focusing on those aspects that all these alternatives have in common and by following out the consequences. Laws relating such concepts thus constitute the sought-for analogy to the statistical laws of quantum mechanics in that they relieve us of the need to address the contingent particulars of specific single cases. Moreover these supervenient laws certainly possess at least as much predictive and counterfactual force as quantum mechanical laws. I see no reason not to regard them as distinctively biological laws.

5. Evolution as a Law-governed Process

However it is not these generalizations alone that qualify as lawlike. Rather, the Darwinian theory of evolution by natural selection circumscribes a law-governed mechanism as well. After all, this theory constitutes the background for most of the laws or generalizations hitherto addressed. The theory states that evolution arises from differential reproductive success which is in turn determined by the respective organisms' fitness. Evolutionary change is not brought about by deliberate adaptation of individuals; it rather arises from reproduction with variations and subsequent selection. This sketched mechanism is admittedly quite imprecise, and it can only be made precise by filling in the messy contingent details. Put in concrete terms, the evolutionary story runs quite differently in different cases. As already indicated, the reproductive success of a fruitfly hinges on factors entirely distinct from those fixing the reproductive success of a rabbit.

But compare this situation to the character of the fundamental laws of physics such as Newton's equation of motion, $F = ma$, or Schrödinger's equation, $H\Psi = E\Psi$. What do these venerable laws of nature really tell us? If considered in their austere succinctness they tell us next to nothing. These equations only acquire physical significance if the contingent details of the respective situation are filled in. Only if particular initial and boundary conditions are brought to bear in addition, do these laws enable us to derive concrete accounts of specific phenomena. In fact, depending on the situation under consideration these equations assume a quite different shape. The uninitiated won't even recognize that they are presented with variants of the same equation. In physics also, the concrete story essentially turns on the messy contingent details.

If this analogy is granted we can understand why Beatty failed to identify any lawlike regularity in biology. He was looking in the wrong place. Characteristics of species are ill-chosen candidates for biological laws. It is not the actual end-product of evolution that exhibits lawlike relations but rather the dynamics of evolutionary change. Consider the following analogy from celestial mechanics. The analogy is supposed to show that it is perfectly possible to miss lawlike regularities actually inherent in a system by focusing on the wrong kinds of quantities—by focusing, namely, on the system's present state rather than its dynamics of change.

Let's ask whether the solar system is governed by any laws of nature. If we concentrate on that system's present state the question comes down to asking whether there are any true lawlike generalizations about planets. It is quite easy to come up with a negative answer. After all, it is not true, for instance, that all planets possess satellites or rings or a magnetic field or that they rotate in the same sense and so on and so forth. Their distances from the sun do not instantiate a regularity, and their positions at a given time depend essentially on the initial and boundary conditions realized (such as the mass values and positions of the sun and the other planets). The present state of the solar system is thus a contingent product of its formation and development. All generalizations about planets are contingent in that they are produced by environmental circumstances that were accidentally realized in the solar system's formative period.

In addition, there is something akin to high-level contingency. Namely, as it became clear some years ago, the planetary motions in the solar system are indeed chaotic. The result is that planetary configurations which are indiscernible initially in every empirical respect will in the long run lead up to quite different configurations. An epistemic, though not ontological, chance element is present here.

The conclusion suggested by this scenario is that there are no laws governing the solar system. But this is evidently wrong. The laws of Newtonian mechanics are precisely such laws. The solar system constituted the paradigm of law-governed behavior for centuries. But why did these laws not appear in the just-given analysis? Because the approach for identifying these laws was misguided. It was asked whether there are any laws characterizing the present state of the planets. The right question would have been if there are any laws governing the *changes* of the planetary states. It is the alteration of states or the dynamics of change which exhibits a lawlike pattern. These laws were missed by addressing an inappropriate level of theorizing.

What I want to suggest is that Darwinian theory plays a role in evolutionary biology that is analogous to the one Newtonian theory plays in celestial mechanics. It provides the mechanism of change; it specifies the law-governed processes that determine how species develop and adapt in a possibly changing environment.

The process of reproduction with variations and subsequent selection circumscribes a law-governed mechanism. The law-governed character of this mechanism is evidenced by the fact that it is now used as a technical tool for designing molecules suited for a given purpose. This is achieved by the following three-step process. First, a sample of heterogeneous DNA is produced by deliberately introducing variations in a sample of like DNA molecules. Second, these variegated molecules are multiplied using appropriate enzymes. Third, the molecules fit to perform the intended function are selected. By combining differently designed functional molecules with the DNA variants (which are needed for the reproductive step), this process can be employed for the purposive engineering of new macromolecules. Directed molecular evolution has become a technically applied procedure (see Joyce 1992). I wonder if this technical use would be possible if the underlying mechanism were not law-governed and were not capable of supporting counterfactuals.

True, it would be odd to regard natural selection as a law in itself. But in the physical sciences there are analogous instances of law-governed mechanisms that hardly qualify as laws in themselves. Consider chemical bond as an example. There are two principal mechanisms for bringing about the combination of atoms, namely, covalent and ionic bonds. It seems inappropriate to regard them as full-fledged laws of nature in their own right. Rather, they constitute theoretical mechanisms which derive from the application of such laws to specific circumstances; that is, they represent theoretical models. Any account of a particular chemical compound requires invocation of various details about the atomic shells involved. Moreover, apart from degenerate instances, both mechanisms have to be resorted to in order to explain a given compound. The applicability of both mechanisms to particular cases is a matter of degree. According to Beatty, problems of the extent of applicability of distinct models and of their relative significance are characteristic of evolutionary biology and related disciplines (pp. 66–67). In light of the example just given this seems not to be the case. I conclude that evolutionary biology is not so exceptional in its methodological features as Beatty would have us to believe.

6. Conclusion

I am basically in agreement with Beatty's portrait of evolutionary biology. In particular, I agree with his assessment that generalizations about the characteristics of species do not qualify as laws of nature. However, the reasons advanced by Beatty fail to establish the non-existence of biological laws. Contingency and high-level contingency occur in physical generalizations as well without depriving the latter of their capacity to support counterfactuals. Accordingly, what Beatty has given us cannot be the whole truth.

Second, and more positively, I claim that distinctively biological laws do exist. These laws employ supervenient concepts and abstract from the multifarious particulars of the world of life. Furthermore, Darwin's theory of natural selection, sufficiently modernized of course, provides us with a lawful mechanism of evolutionary change.

It is true, application of all these biological laws to specific cases is a delicate affair, and the actual results obtained depend on the contingent, or even highly contingent, circumstances. But the same holds true of many laws of physics. I admit, one could respond by contending that in reality there are no laws of nature and that, consequently, most of us have fundamentally wrong ideas about what science is all about. Actually, as indicated earlier, Beatty is prepared to embrace a conclusion of the kind. But in light of the fact that the methodological characteristics expounded by Beatty do not bring unmanageable difficulties in their train, as evidenced by their analogs in the physical sciences, this conclusion appears overly dramatic.

It would be foolish to maintain that evolutionary biology is akin to the physical sciences in every methodological respect. I do not advance anything of the kind. One difference is certainly represented by the tremendous amount of bare facticity figuring in biology. Facts that are theoretically unaccounted for and have thus to be accepted as being simply given are drawn upon much more in biology than in the physical sciences; much more than even in those branches of the physical sciences that exhibit strong affiliations to natural history such as astrophysics. In the physical sciences a much larger amount of facts can be derived theoretically; laws pervade them to a much greater extent than biology. But this is a matter of degree, not of principle. If, however, the question is stripped to the all-or-nothing affair of the mere existence of biological laws, then, I maintain, biology and the physical sciences are in the same ballpark. They both contain laws.

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