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FOUNDATIONS OF BIOLOGY: ON THE PROBLEM OF "PURPOSE" IN BIOLOGY IN RELATION TO OUR ACCEPTANCE OF THE DARWINIAN THEORY OF NATURAL SELECTION

ABSTRACT. For many years, biology was largely descriptive ("natural history"), but with its emergence as a scientific discipline in its own right, a reductionist approach began, which has failed to be matched by adequate understanding of function of cells, organisms and species as whole entities. Every effort was made to "explain" biological phenomena in physico-chemical terms.

It is argued that there is and always has been a clear distinction between life sciences and physical sciences, explicit in the use of the word *bio*logy. If this distinction is real, it implies that biological phenomena can never be *entirely* satisfactorily explained in terms of extant physicochemical laws. One notable manifestation of this is that living organisms appear to – actually do – behave in purposeful ways, and the inanimate universe does not. While this fundamental difference continues to be suppressed, the "purposiveness" (or teleology) which pervades biology remains anathema to almost all scientists (including most biologists) even to the present day. We argue here that it can, however, become a perfectly tenable position when the Theory of Natural Selection is accepted as the main foundation, the essential tenet, of biology that distinguishes it from the realm of physical sciences. In accepting this position, it remains quite legitimate to expect that in many but not all circumstances, extant physical laws (and presumably others still to be discovered) are in no way breached by biological systems, which cannot be otherwise since all organisms are composed of physical material.

KEY WORDS: teleology, purpose, function, cause-effect, natural selection, biology

INTRODUCTION

We would all agree that the parts of living organisms serve purposes or functions. We have lungs so that we can breathe; the purpose of the eyes is to see; the function of the ears is to hear. We might choose to refine these statements in the interests of scientific preci-

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sion (pedantry). For example, rather than "the purpose of the eyes is to see", we might substitute "our eyes, together with the parts of the brain with which they are connected, process and interpret patterns of light, shade and colour". But in making such refinements, we retain at least the sense of "purpose/function" if not the actual word(s). But it is easier in the vernacular to state that the eyes are needed to provide the data-input for the brain, just as the brain is needed to process data-input from the eyes.

If, however, we accept the position – because it seems obvious – that every component part of an organism serves a purpose (we shall say something later about apparent exceptions to this rule, e.g. the notoriously "functionless" human appendix), then it is obvious that biologists should be able to give coherent and explicit accounts and explanations of purposes/functions. Yet biologists seem uncomfortable with the idea that parts of living organisms are somehow "endowed with purpose", especially where by extension we conclude that the organism as a whole is similarly endowed within its context. More often than not biologists seem intent on avoiding this very topic, which non-biologists might consider the most interesting and perhaps the most essential aspect of a proper understanding of organisms. Whitehead [1] gently chided us on this very point:

> Many a scientist has patiently designed experiments for the *purpose* of substantiating his belief that animal operations are motivated by no purposes. He has perhaps spent his spare time in writing articles to prove that human beings are as other animals so that "purpose" is a category irrelevant for the explanation of their bodily activities, his own activities included. Scientists animated by the purpose of proving that they are purposeless constitute an interesting subject for study.

Of course, biologists cannot and do not avoid referring to the matter altogether in their work, but such references tend to be implicit rather than explicit, i.e. they are usually suppressed as far as possible. To choose an illustration from a recent review about protein movements into the cell nucleus (the choice is "random" – we could have chosen almost any cell or molecular biology paper), the authors begin:

> To enter the nucleus, a protein must transit through one of the largest and most complex gateways in the eukaryotic cell, the nuclear pore . . . (which) recognises and imports proteins involved in all walks of nuclear life [2].

The review goes on to describe some (molecular) components of the cell that are involved in nuclear entry, and in a manner typical of modern biological discourse, seeks to show how the chemical properties of these components *cause* them to interact in particular ways and bring about particular *effects* relevant to the movement of certain types of proteins into the nucleus. In other words, the authors seek to provide an account of causes and effects in chemical terms rather than one of biological function. Yet implicit reference to function/purpose is abundantly evident in the quoted passage. In the first sentence we learn that "…(in order) to enter the nucleus", a protein "must" do such-and-such, giving the impression that the proteins are seeking a goal (entry into the nucleus). In the second, function is ascribed first to the nuclear pore, (actively) "recognising" and "importing" the proteins, and second to the proteins themselves, since they are involved in (indeed, responsible for) everything the nucleus does ("all walks of nuclear life").

The innumerable similar examples from the literature we could have cited all implicitly admit "purpose" while concentrating more-or-less exclusively on physicochemical "cause" and "effect". However, we feel that this single illustration from a well respected review suffices to make the point that biologists have, or adopt, an evasive attitude to "purpose".

This attitude is actively inculcated. Too explicit a discussion of purpose renders a scientific article liable to fall foul of peer review. Educators routinely warn students against "teleological arguments" (i.e. arguments or explanations in terms of purpose), actively penalising them in essays and examination scripts. Students quickly learn to eschew explicit mention of biological "purposes". In brief, to twist Whitehead's observation around, we might conclude that biologists whose work is all about "entities endowed with purpose" [3] are trained to be coy about mentioning it, which is a curious state of affairs.

Several philosophers of science have discussed the problematic character of function-statements in biology. Some have thrown real light on the issue [3, 4, 5], while others have cast deeper and more convoluted shadows [6, 7] in that they have presented the problem as intractable or have explored it in ways that biologists cannot relate to their everyday concerns.

We shall make use of such philosophical contributions, without reviewing any in detail or espousing any particular one. Our line of argument in this paper follows that of Mayr [4] and can be traced back to Monod's essay [3]; teleonomic entities, i.e. objects "endowed with purpose", can be understood by virtue of the theory of evolution by natural selection. In this regard, we accept the position of many modern philosophers of biology. But our starting-point is this: *function-statements in biology are problematic because biologists perceive them to be problematic in a way that non-biologists do not* [8]. This could be born of mechanistic materialism, and its tendency towards a reductionist approach, i.e. that biology (life) *is* ultimately reducible to physicochemical explanations [9]. Young [10] fought fervently against this notion that "atomism" could solve problems in biology, when quite the opposite seemed to be called for, i.e. the appreciation that biology had the making of being a great science which could transcend others because it dealt with *organisation*, which cannot be approached from a reductionist viewpoint. But let us therefore ask more specifically why is this so? Should something be done about it? And what can we say or do that will help to alleviate the problem (or at the very least help non-biologists to understand the biologists' "dilemma")?

There is more at stake here than the issue of imperfect communication between the majority of biologists on the one hand and commentators such as Young, Monod, Mayr and Ruse on the other. In medicine and other "applied" disciplines related to biology, the *functions* of an organism's parts are of paramount concern. The attention of practitioners is directed towards the effects of those parts and the consequences of malfunction therein. (For a detailed survey of this matter, see e.g. [11]. In Canguilem's view [12], there are those who examine the norm, the usual, and others whose aim is principally to apply techniques which restore things which are "abnormal" back to that norm, an activity which does not exist in the physical sciences. The "pathologic" is a feature of the world of biology, of the life sciences, with no counterpart in the physical sciences; the concept of the abnormal photon does not exist.) In contrast, molecular and cell biologists, whose concern is the fundamental understanding of how the parts of organisms actually work, adopt the ostensibly mechanistic, reductionist approach we illus-

trated above. They seek to uncover *causes* in the way that physical scientists do. So there seems to be a philosophical gulf not only between the consensus of modern biologists and the consensus of modern philosophers of biology, but also between those who seek to advance biological understanding and those who seek to apply it. Our aim is to begin building bridges from both sides across these philosophical gulfs. Although in the central part of this paper we shall reiterate the account of teleonomy due to Monod [3] and Mayr [4], we shall go on to develop it along novel lines that are likely to seem more relevant to practising biologists. Before we venture on this, however, we want to explore the question of why biologists consider function-statements problematic.

WHY ARE BIOLOGISTS UNCOMFORTABLE ABOUT PURPOSES?

The revolution in Western thought around 1600 AD that we regard as the foundation of modern science is inseparably linked with the writings of Francis Bacon, Galileo Galilei and René Descartes. Jointly and severally, these three philosophers rejected the approach to understanding the natural world that had been created by Aristotle in the 4th Century BC and adopted by the medieval church, and sought to replace it with a purely mechanistic system of thought, explaining every observable and measurable phenomenon in terms of antecedent natural causes. In particular, Galileo and Descartes rejected the idea that objects behave "in order to achieve" a particular state or position, such as their "Natural Place in the Scheme of the Cosmos", which was a staple of Aristotelian teaching. The natural world, the world seen through the eyes of the physicist, does not have purposes; it is a world only of mechanical causes and effects. The physical sciences since Galileo and Descartes have avoided all reference to "purpose" and addressed the world in an exclusively mechanistic language. To eschew "purpose" is scientific; to admit it is Aristotelian. The mechanistic philosophy of the 19th century has persisted into the 20th, with arch-exponents such as Loeb [9] trying to soldier on. His opening of *The Mechanistic Conception of Life* begins with the burning hope that "life, i.e., the sum of all life phenomena, can be unequivocally explained in physicochemical terms." And even more recently from the newly

emergent subdiscipline of biophysics, scientists have wanted to paint out purpose, e.g. Katchalsky [12] describing the living body as a "chemomechanical machine".

It might be argued that biology is sufficiently different from the physical sciences for this simple choice not to hold in quite the same way. We do not want to go into the question here of how "physics-like" biology is – that subject could occupy several essays of this length – but we should at least admit that such arguments are not without force. However, we can legitimately avoid the issue in the present context by simply observing that, as a matter of historical fact, modern biology has achieved spectacular successes over the past 100–150 years by dint of viewing organisms from a physicochemical (particularly chemical) perspective. It is by virtue of having taken an explicitly physical-science approach to the subject that we now understand as much about organisms as we do [8, 13].

However, there is no reason in principle why this fertile perspective should not be treated as complementary to, rather than exclusive of, a more teleological one. A century ago, this complementarity of perspectives was espoused by biologists such as Bohr [14] and Haldane [13], the latter writing:

> No mere physical or chemical account of essential organic processes (of life) could therefore be valid or true to nature.

Two issues arise from the above. The first is that the composition, structure and behaviour of organisms must either be subject to exactly the same laws of nature as the rest of the (non-living) world *and nothing else*, or be the result of these laws *plus something else*. The latter opinion, that the living is distinguished from the non-living by "something else" – traditionally a vital force – is known as "vitalism", and it is fundamentally flawed. For one thing, it reduces to a tautology – the living is distinguished from the non-living by a vital force, which is defined as that which distinguishes the living from the non-living. For another, because the vital force has no observable or testable properties (other than to make things alive), vitalism is an intractable barrier to experimental science. Historically, vitalism has played an important role in the emergence of biology – many of the great names in the subject's past were vitalists – but that role ended with the rise of experimental biology since the

time of Lavoisier and LaPlace, and the steadily accelerating success of the mechanistic physicochemical approach. Modern biologists react to the word "vitalism" much as a 15th Century Spanish Dominican friar reacted to the word "heresy". When challenged as to why they train their students to avoid teleological (purpose-type) arguments, biologists tend to reply that teleological arguments are vitalistic. The fear of vitalism becomes an aversion to any explicit mention of purpose.

The second issue is that teleological statements about function or purpose can and often do reverse the chronology of cause and effect. Consider the following:

(1) Gravity makes an unsupported apple fall downwards

(2) We have lungs so that we can breathe

Statement (1) is a simple mechanistic explanation in physics; what is explained is the falling downwards. A mechanical cause (gravity) acts on an unsupported apple at time **t** so that there is an effect (falling downwards of the apple) at a time later than **t**, i.e. the cause *precedes* the effect. Statement (2) is a teleological argument in everyday biology; what is "explained" is our possession of lungs. The "cause" is being-able-to-breathe. But if breathing is the "teleological cause", and possession of lungs the "effect", then we have a reversal of the expected cause-effect order; for unless we have lungs (effect) at time **t**, then we cannot breathe (cause) at any time subsequent to **t**. This chronology clashes with our intuition and common sense.

One further, quite independent reason for biologists' aversion to statements about purpose and function is that Bacon told us that reliable knowledge can only be constructed inductively, i.e. by careful and judicious generalisation from a large number of particular instances. Yet biologists can rarely avoid reference to purpose, however implicit and "suppressed". There are very good reasons for believing that science does not always, or even usually, proceed by induction in practice, but scientists seem obliged to perpetuate this Baconian myth [16, 17]. They prefer their general statements to *look* as if they are, or could have been, justified by induction: a statement such as (1) above could in principle have been based on a large number of observations of descending apples. But this is

not the case with (2) above. It is obvious that we have not made a series of observations (I have lungs so that I can breathe, you have lungs so that you can breathe, Clytemnestra has lungs so that she can breathe,...) and then generalised them. Rather, we have come to recognise the *general* need for people to breathe, and the *general* possession of lungs to accomplish this purpose; and we can then (if we wish) ascribe the *general* inference to individuals. There is not the remotest possibility here of pretending that our teleological statement (2) is justified by anything resembling the Baconian recipe for doing science. Teleological statements have no inductive justification.

In brief, on four counts biologists are uncomfortable with "purpose": (i) statements about purpose run counter to accepted scientific thought; (ii) they appear vitalistic; (iii) they can appear to reverse cause-effect relationships; and (iv) they cannot be justified inductively. Therefore biologists avoid explicit reference to "purpose". Yet as we saw in the opening of Powers and Forbes review [2], they cannot avoid implicit reference to it. This creates a tension, even a paradox, that pervades modern biological discourse. So long as biologists explicitly eschew "purpose", the paradox remains, and therefore the question is whether it can be resolved.

SEMANTICS, CONNOTATIONS AND PRECISION

Before addressing the central issue, let us consider the words used repeatedly above, such as "purpose", "function", "cause" and "effect", without any explanatory comment or attempt at definition. "Purpose" can be used in at least two distinct, if related, senses. Consider these two statements:

(3) The purpose of mammalian lungs is to enable the mammal to breathe

(4) Clytemnestra's purpose in going to University was to obtain a degree

Statement (3) is more-or-less equivalent to (2), so it is familiar territory. But (4) is not, and we can readily see this if we try substituting the word "purpose" first with "function" and then with "intention" or "goal", and repeating the exercise with (3). In (3),

substitution of "function" for "purpose" does not essentially alter the meaning, but if we use "goal" it produces a bizarre statement, which is not so much false as semantically ill-formed. It is nonsense to ascribe goals or intentions to lungs. In (4), the opposite is true. There is nothing wrong with saying that Clytemnestra has a specific goal or intention, in terms of which we understand her actions. But to say that her "function" is to obtain a degree is, at best, to present her as a member of an unimaginably mechanised and rigid society;[1] at worst it becomes a nonsense.

When we are talking about the "purposes" of *parts* of organisms, such as lungs and eyes, we are talking about "functions" rather than "goals" or "intentions". Whole organisms might have intentions; for instance, our "intention" in writing this essay is to help clarify the "problem of purpose" in order to improve communication and understanding amongst biologists, and between biologists and non-biologists, though we do not see it is necessarily our "function" to do so.

This distinction is sometimes apparently difficult to sustain. Certain political or managerial speeches have been known to ascribe "functions" as distinct from "goals" to individual human beings, an ethically questionable practice (see footnote). On the other hand, in discussing the opening of the Powers and Forbes review [2], we noted that the authors seemed implicitly (though no doubt unintentionally) to ascribe "goals" or "intentions" to protein molecules. In fact – though it would involve too long a discussion to demonstrate this formally – what Powers and Forbes actually said is wholly reducible to function-statements rather than goal-statements. Certain proteins have functions within the nucleus, and the nuclear pore and other components have the function, *inter alia*, of moving these proteins into the nucleus where they are able to function. This is consistent with the position we have taken; our concern, being with the component parts of organisms (including the proteins in the

[1] In the outdated expression of a "functionary", one used to refer precisely to a "person" who had indeed completely subjugated his identity by becoming a part (a totally subservient part) of his master. The cell has a function in the body, but the body has no "function"; a raven is a raven, we cannot wholly and properly describe it in terms of its life activities.

cell nucleus and the devices for putting them there), is with functions not intentions. From now on in this essay, "purpose" = "function".

But if we restrict our use of "purpose" in this way, are we implying any more by it than "effect"? For instance, reverting to our previous example, is there any important difference in meaning between the following?

(3) The purpose (= function) of mammalian lungs is to enable the mammal to breathe

(5) The effect of mammalian lungs is to enable the mammal to breathe

If these two statements are indeed indifferent – as at first sight seems to be the case – then the whole "problem of purpose" vanishes in a puff of semantics, provided we continue to be consistent in this usage. We are back with the kind of safe, uncomplicated mechanistic statement familiar from the physical sciences. In (5), the lungs are the cause, the breathing an effect, and the cause is duly antecedent to the effect, and there appears to be no philosophical difficulty. Unfortunately, this "solution" to the problem is illusory. In contexts such as (3), "purpose" can properly be replaced by "function", but it cannot, despite appearances, be replaced by "effect". Teleological statements about the components of organisms are not equivalent in form to statements such as the one about gravity and falling apples.

To see why this is so, consider a different example. We know that green plants are green because they contain a pigment, chlorophyll, necessary for photosynthesis (the use of the energy of sunlight to catalyse the manufacture of sugars from inorganic materials). A by-product (strictly a waste product) of photosynthesis is oxygen, and all animals need oxygen in order to survive. From these items of common knowledge we can construct illustrations that demonstrate the intractable difference between "function" and "effect" and, indeed, find further limits on our proper application of "purpose" and equivalent terms in biology. Consider the following pair of statements:

(6) The function of chlorophyll is to enable green plants to photosynthesize

(7) The effect of chlorophyll is to enable green plants to photosynthesize

This pair is clearly analogous to statements (3) and (5). Replacing "function" (= "purpose") by "effect" has produced no obvious semantic ambiguity or damage, and once again we are inclined to regard "function" as "effect". But if we write:

(8) The effect of chlorophyll is to make plants green

then we have a statement that is more-or-less unexceptionable as it stands (we might prefer "an effect" to "the effect", and "parts of plants" to "plants", though these are trivial details), but one that is intolerant now to the replacement of "effect" by "function". If we put "function" in (8), we obtain a statement that is amusing in the way that an innocent four year-old child's assertion about the world is amusing. It is quite different from the same replacement of words in (7) to produce (6), or in (5) to produce (3); it yields a statement that no biologist, indeed no adult, would ever make with serious intent.

So why the difference? In what relevant way is (8) different from (5) and (7)? The most obvious possibility, and perhaps the correct one, is that the ability to breathe is *important* to mammals and the ability to photosynthesize is *important* to green plants, for these are matters of survival. Being green (or any other colour) is neither here nor there to a plant. That is to say, when we use the word "function" (or "purpose"), we are talking not merely about an "effect" of the component or part of the organism under discussion, but crucially about something indispensable for survival. With caution, let us now consider the following statements:

(9) The function of the hen's egg-laying is to produce more hens

(10) The function of a hawkmoth's sex pheromones is to attract mates

Both (9) and (10) are acceptable, and in both cases we can replace "function (purpose)" with "effect"; but a sterile hen can survive perfectly well if all her other working parts are in order, and a hawk-moth can live even if she lacks the genes required for the synthesis of sex pheromones. So we cannot say that "function" *simply* means "effect plus requirement for survival". We have to say something

like, "function (purpose) is an effect necessary for the individual either to survive or to reproduce"; and this assertion, with its use of the terms "survive" and "reproduce", immediately evokes in our minds the theory of evolution by natural selection, which focuses on just those concepts. We shall return to this issue later, but the nub of our argument has now been exposed; teleological statements are acceptable in biology, all apparent difficulties notwithstanding, *precisely because we accept the theory of evolution by natural selection*. As we shall show, this theory is our only means of surmounting the difficulties. (Dobzhansky [18] remarked that "nothing makes sense in biology except in the light of evolution." While we still pass comment on the problems of Darwinian theory and speak of NeoDarwinism, the impact of this Theory has been rightly hailed as perhaps *the* greatest concept in the history of scientific endeavour.)

Before delving deeper into this matter, let us take one final illustration from the green plant/photosynthesis example. Suppose we were to say:

(11) The effect of photosynthesis is to replenish atmospheric oxygen

This statement is irreproachable, except that once again we might prefer the indefinite article. But can we now substitute "function" for "effect"? To do so does not generate a nonsense statement, unlike some earlier examples. There is no doubt that replenishment of the atmospheric oxygen is an aspect of photosynthesis that we properly consider important. But important to whom, or what? To ourselves and other animals certainly; we could not survive, still less reproduce, if the oxygen supply were not a consequence of the activities of green plants. What we would actually *intend* by a statement such as:

(11′) The function of photosynthesis is to replenish atmospheric oxygen

would have to do with ourselves, or at least with the global environment, rather than the plants which are doing the work. We would not, in brief, be talking about a requirement for the survival or reproduction of the *plant*; and therefore the use of "function" in (11′) is *incorrect*. This is an important general point; the notion of "survival

value" (that we argue is implicit in function-statements) cannot be transferred to other species. Cases of close species interdependence such as symbiosis, or even commensalism, might be "grey areas" here, but this point would require separate and extensive analysis. We can assert (11), and go on to talk about the general ecological importance of oxygen, but we cannot as biologists accept (11′) as a valid statement.

DARWIN'S THEORY OF NATURAL SELECTION AND THE "PROBLEM OF PURPOSE"

We have glossed "the purpose (function) of part X or organism Y" as "effect of X that improves the chances of survival or reproduction of Y". Other wordings could be chosen, such as "effect of X necessary for the good working of Y", but then it would be desirable to indicate what constitutes "good working". Our wording conveys more or less unequivocally the sense in which we understand purpose/function. Our next task is to justify the claim that, given this understanding of "function", the theory of evolution enables us to interpret it in exclusively mechanistic, non-teleological terms. The central importance of modern evolutionary theory in biology is acknowledged by virtually all commentators [e.g. 3–5, 7, 17, 18]. It is generally agreed that this theory is unlike any theory in the physical sciences in fundamental respects such as its inherently historical character.[2] Certainly it is tempting to try to explain a biological concept alien to physics (function) by reference to a distinctively biological theory (evolution), but we need more substantial reasons than that for asserting our claim. In this section we review these more substantial reasons.

Several excellent accounts of evolutionary theory have been written for the non-specialist [20, 21], and we take their existence as a justification for not going into greater depth about the theory here, except for a couple of points of emphasis. Modern evolutionary theory is a progressively changing amalgam of classical genetics,

[2] So successful has the theory of evolution been in guiding and unifying modern biology that cosmologists are entertaining ideas analogous to natural selection to account for the evolution of the universe(s) [19]. This does not, however, bestow an evolutionary underpinning on mainstream physics. In that regard the physical sciences and the life sciences remain distinct.

population genetics and molecular biology with Darwin's natural selection model; DNA sequencing is playing a dominant and quite spectacular role in new developments. However, it was Darwin's contribution which gave the theory its lasting philosophical character. In biology, it is unrivalled as a unifying concept; indeed, biology is otherwise singularly bereft of general theories and laws of its own; Crick's "central dogma" of biology, discussed in Hunt et al. [22] is perhaps the best example. Equally, it has proved difficult to apply the laws of physical science to living things without many qualifications, provisos and adaptations. Darwin established that some variants of a species are more likely than others to survive and reproduce in a particular environment; in a different environment, an alternative variant might be favoured. Likelihood of survival is crucial because organisms produce more offspring than resources can accommodate. Small differences in adaptation therefore often make for surprisingly large differences between the chances of surviving or dying. Since variations are inherited, the differences in survival chances are translated into the survival of the particular genes involved and their transmission to subsequent generations. These genes encode the parts of the organism whose effects are responsible for the increased chances of survival or reproductive success. We have already argued that "effect of a part responsible for the increased chances of survival or reproductive success of the organism" is the definition of "function" or "purpose" of that part. Thus, it is evolution by natural selection that generates biological purposes/functions

The crucial feature of the theory is that it portrays evolution as an undirected process. Evolution happens because, at any given time and place, certain randomly-generated variants of an organism (type) have a better chance of passing on their genes to later generations than others. It is a typically mechanistic, cause-effect theory, devoid of any "purpose" or "goal", portraying an unscripted history of life, an unbroken but unprogrammed sequence since the origin of the first living cell. In terms of its mechanistic *purposeless* character, it is thoroughly anti-Aristotelian and fully in the tradition of scientific thought springing from the writings of Galileo and Descartes. It tells us that organisms have acquired all their

genetically-determined features by an immensely prolonged and continuing process that is entirely mechanistic and "blind" [18].

This feature is crucial to the completion of our case. Consider any one of the teleological ("function") statements we have used thus far, e.g.:

(3) The function (purpose) of mammalian lungs is to enable mammals to breathe

A reasonable analysis of this statement might be as follows:

(3a) Lungs do enable a mammal to breathe

(3b) Nothing that is not a lung enables a mammal to breathe

(3c) If a mammal does not breathe, its chances of survival (and reproduction) are prejudiced

(3d) Lungs are a result of evolution by natural selection

Statements (3a) and (3b) are elementary facts of anatomy and physiology. (3c) is common knowledge hardly meriting the dignity of the label "physiology", and (3d) is an assertion derived from evolutionary theory. Collectively, (3a), (3b) and (3c) represent our glossing of "function/purpose" as "an effect necessary for the survival and reproduction of the organism concerned", and the original statement (3) summarises their conjunction. The addition of (3d) assimilates the "necessary for survival and reproduction" element into an existing theory that is itself wholly mechanistic and purposeless. Thus, by conjoining all four subsidiary statements, we have a translation of "function/purpose" wholly and exclusively into mechanistic, cause-effect, purposeless, non-teleological language.

We can perform the same exercise on any other function-statement about an organism component. Thus:

(6) The function of chlorophyll is to enable green plants to photosynthesise

(6a) = Chlorophyll does enable green plants to photosynthesise

(6b) + Nothing that is not chlorophyll enables a green plant to photosynthesise

(6c) + If a green plant does not photosynthesise its chances of survival and reproduction are prejudiced

(6d) + Chlorophyll is a result of evolution by natural selection

or:

(10) The function of a hawkmoth's sex pheromone is to attract mates

(10a) = Sex pheromone does attract mates

(10b) + Nothing that is not sex pheromone is sufficient to attract mates

(10c) + If mates are not attracted, a hawkmoth's chances of reproduction areprejudiced

(10d) + Sex pheromones are results of evolution by natural selection

There are subtle differences in the last example, but the form of the argument is unchanged and, most important, the wholly mechanistic and purposeless character of the analysis remains intact.

The "disappearance" of function/purpose in this analysis, the substitution of a teleological proposition by a sequence of mechanistic propositions, might initially seem disturbing. Has the sense of purpose really disappeared or does it still lurk covertly amongst the components of our analysis? Or was it ever there in the first place – was its appearance illusory? In fact, neither of these is the case. What we have shown, what Monod [3] and Mayr [4] and others have indicated, is that it is indeed possible to "translate" genuinely teleological propositions such a (3), (6) and (10) into genuinely mechanistic ones *without any loss of meaning*. This is really no more remarkable than (say) the translation of the quality "blue" into mechanistic statements, which is not considered problematic. The statement "X is blue" can be analysed without loss of meaning into "X emits/reflects electromagnetic radiation preponderantly around 400 nm" + "the retina contains receptors that are stimulated by radiation of this wavelength" + "the brain interprets stimulation of these receptors as the 'experience of blue' ". This analysis moves the blueness from the object X to the activity of the brain of the perceiver. But it does not make the statement "X is blue" any less valid or any less useful – we can still, for example, relate or subcategorise X-like objects according to whether or not they are blue – it just makes

scientific sense of it. Similarly, the analysis of function-statements we have discussed does not make function-statements less valid or useful; it just makes scientific sense of them.

This capacity for glossing of function/purpose-statements in wholly purpose-free terms should, in our view, resolve the difficulties that biologists tend to find in such statements. The analysis shows that attributions of "function/purpose", so long as they are biologically valid (*cf.* discussion of (11) and (11′) above), are not, contrary to appearances, incompatible with the Galileo-Descartes tradition of scientific thought. The analysis shows that the bogeyman of vitalism is nowhere to be found when proper care is taken with the logic. Because of evolutionary theory, and specifically Darwin's contribution, there is after all no real reversal of cause-effect relationship. And because evolutionary theory supports by deductive inference *general* statements about species (or at least populations) rather than individual organisms and their parts, we can understand why function-statements cannot be made to fit an inductive-reasoning model, i.e. they are inherently general.

Even if evolutionary theory was not the backbone of biological understanding for other reasons, such as its unique capacity to account scientifically for the *unity* underlying the development of the extraordinary diversity of life, the essential role it seems to play in making biological function-statements scientifically acceptable would make it so. Our discussion suggests that there is, after all, no real conflict between biologists and non-biologists on the "problem of purpose"; it is a problem that biologists can consider solved. However, biologists continue to behave as if there were a real problem, as though the reasoning that we have set out here would not be *tacitly* understood by their peers. Perhaps they would be more comfortable if they could be persuaded that function-statements can in certain respects have practical scientific value and are in these respects irreplaceable. We argue this case in the final section.

'FUNCTIONLESS COMPONENTS'

Our introduction alluded to the awkward case of the apparently "functionless" parts of organisms; we cited the human appendix

as one such example. This is in fact a poor example, since the appendix is a significant piece of lymphoid tissue with a clear (if not unique or distinctive) function in the immune response. But there are less equivocal instances of "maladaptation" in the biological world, which merit attention in this context. Consider the following statement:

(12) The function of the teeth and digestive system of the giant panda is to enable the animal to survive as a carnivore

What justifies (12) is the *design* of the panda's teeth and gut compared to those of other mammalian herbivores and carnivores. The panda has typically carnivore teeth, with large sharp canines and short incisors, and a far shorter intestine relative to body size than is found in herbivores. The fact that the giant panda survives *very inefficiently* on a diet of bamboo indicates that it has – for uncertain reasons – adopted a mode of life for which it is not primarily adapted, i.e. the relevant parts of the panda are more appropriate for a function other than that for which they are actually used. The implicit unspoken part of this argument is that the ancestors of the giant panda were indeed carnivores [23]. They were appropriately "equipped" by evolution.

But there are standard objections to this sort of claim. First, speculations about an evolutionary past (unsupported by unequivocal evidence) are so much imaginative story-telling, and not science at all. Second, such statements as (12) are based on trends rather than "laws" of nature – a *pattern* typically of carnivores than of herbivores in this case – and extrapolation of trends is rarely justifiable. Thus, it might be inferred that (12) is scientifically ill-founded. This illustrates the dangers that doubters will invariably find in function-statements.

To such objections there is a convincing answer. If, as we suppose, the panda is evolutionarily "designed" as a carnivore, then this "design" must apply to all body parts connected with nutrition, not just teeth and intestine. The livers of carnivores have much higher levels of enzymes that metabolise amino acids than the livers of herbivores (an adaptation to the different protein contents of the diets). So, for example, the activity of the liver enzyme arginase is about six times higher in the cat than the rabbit. On this basis,

we can predict that the levels of such an enzyme in the liver of the giant panda will be more like that in the cat than the rabbit. This is an experimentally testable prediction, one that has not, as far as we know, been investigated. The ability to make specific testable predictions is the hallmark of genuine science, rather than of story-telling and speculation. It follows that function-statements, provided they are biologically valid (as we have argued), are capable of generating testable predictions *that could not otherwise be made*. This accords to such statements a role in science that would be lost if we were denied the right to make them.

We believe that, at least in principle, all examples of "function-less" parts in biology can and should be handled in this way, as illustrated with statement (12). But more importantly, perhaps, our consideration of this issue has added one final twist to our consideration of the "problem of purpose". We had already argued that function-statements are scientifically unproblematic, despite suspicions to the contrary, and therefore are acceptable in principle in biological discourse. In this final section, we have given reason to suppose that they are not merely unproblematic, but have (or can have) a positive and irreplaceable scientific role. Perhaps, therefore, we should conclude that function-statements are not merely acceptable in biology, but are *indispensable* in their way to its continued progress. Earlier in this essay we suggested that there is no reason in principle why the teleological and mechanistic perspectives should not be treated as complementary, as Bohr [14] and Haldane [15] did. We would now like to reiterate this more strongly, i.e. that there is every good reason in principle why the two perspectives *should* be treated as complementary.

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