The Role of Science in the Avenues of Understanding and Appreciating Nature*

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Summary. Scientific explanation is not a 'tower' in which one layer explains or completely accounts for another. It is a network of mutually informing concepts and languages. The language of physics describes things and processes which can *support* the things and processes described by biology. Biology meanwhile has its own coherent discourse which is not rendered redundant, nor even fully explained, by the physical processes which support it. In order to show that this is not a contradiction, I examine the role of symmetry principles in physics where similar statements can be made. Next I elucidate a logical fallacy (the 'Babel fallacy') which is often at work when people make unsupported claims about the scope of a given physical model, and I argue for the reasonableness of treating human persons as subjects and moral beings. But in our schools the impression is given that science seeks to and could replace the languages of justice, mercy and moral insight by a machine-like model of all that happens. This is a false vision of science. A true vision places it correctly in the landscape of discourse, and offers a more liberating, humane and coherent picture of the whole setting of human life. We now have an educational task, and an opportunity, to teach this. It is a welcome part of a more creative and less exploitative outlook on the whole natural world and our place in it.

> How wonderful is the certainty that each human life is not adrift in the midst of hopeless chaos, in a world ruled by pure chance or endlessly recurring cycles!
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> *Laudato Si'*; Pope Francis

This paper explores the nature and role of science, and introduces some proposals for education. Much of the discussion is set out at greater length in *Science and Humanity*.[Steane, 2018] The present publication gives me an opportunity to summarize this; readers can then explore the longer version or not, as they choose. In the present essay I shall draw out lessons which are relevant to the educational possibilities indicated by the encyclical *Laudato Si'* of Pope Francis.

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My own scientific background lies mainly in areas of quantum information and quantum computing, including experimental and theoretical work, and I have also done some work in relativity (classical electrodynamics) and thermal physics. So I write as a physicist rather than a philosopher by training. But this long experience with areas of physics which I have also taught, and for which I have written textbooks, gives me expertise in the way scientific explanation functions in those areas, and I think a general knowledge of other areas of science such as chemistry and evolutionary biology is sufficient to see that similar lessons apply there.

1 The structure of science

The first point I wish to make concerns the structure of scientific explanation. It is that this structure is not like a tower in which each layer explains the one above it, but rather it is a network in which there are multiple areas of discourse, with two-way, not one-way, links between them. For example, it is not true to say that physics explains chemistry. The relationship between these two discourses is of another kind, in which there is a two-way furnishing of information and illumination, as I will set out more fully in a moment.[1] I am not the first to say this; in fact I will be presenting mainstream ideas in the philosophy of science, but it is notable how much they need to be reasserted in the current social and educational climate, since many people are quite misled about this.[2]

The relationship between biology and physics is not amenable to thorough statement in any brief phrase, but a fair summary statement is as follows:

$$\text{Physics} \quad \underset{\text{supports}}{\overset{\text{enarches}}{\overleftarrow{\underrightarrow{\quad}}}} \quad \text{Biology}$$

Here "supports" is a shorthand for "can physically embody an expression of" and "enarches" is a shorthand for "exhibits structures and behaviours that make sense in their own terms and are possible within the framework of". Hence the above diagrammatic statement should be read:

> Physics (the members and patterns of the particle- and field- constituents of physical things) can physically embody an expression of biology; Biology (the members and patterns of the congregation of living things) exhibits structures and behaviours that make sense in their own terms and are possible within the framework of physics.

It is not the case that either explains the other. Rather, there is this reciprocal relationship. So far I have merely asserted this; I shall argue it in the following,

[1] To one who says "given physics, chemistry will follow" we may reply "given chemistry, physics must be of a certain kind."

[2] The protagonist Joe Rose of Ian McEwan's novel *Enduring Love* illustrates this phenomenon quite well.[McEwan, 1997] He is eloquent concerning various aspects of physics and biology, but quite unaware of the illogical nature of his reasoning from them.

chiefly by furnishing examples which explicate what is being said.

In order to explain more fully the term ‘enarches’ which I have coined here, let us consider the case of an ordinary stone arch, of the type to be found in many bridges, doorways and buildings. If an arch is composed of stones and mortar, and there is nothing else present, then one might wish to say that the properties and nature of such an arch are fully accounted-for and explained by the nature of stones and mortar. Once we have set out the material properties of the individual stones, and their geometric locations relative to one another, and the mortar, there is nothing further in the arch, so, it might appear, we have thoroughly explained the arch. But it is not so. For, the arch might have been made of another material such as wood or steel. What is important to its nature—the fact that it distributes force a certain way and consequently is a strong shape under compressive loading from above—is not completely captured by the analysis of the parts. An arch has global properties that concern its overall shape; until one has discerned those properties one has not understood an arch. Consequently if the description in terms of stones and mortar does not employ that global geometric language then it has singularly failed to amount to an explanation.

Even if all arches in the physical cosmos happened to be made of stone, it would still be incorrect to say that arches are explained by stones.

This is a simple enough point; a child at high school could quickly appreciate it, but it is largely omitted from the training we offer our young people in their general education.

Let’s now explore a similar but more subtle theme in fundamental physics. In the foundations of physics it is found that *symmetry principles* play a large role. Much of the progress in particle physics and quantum field theory of the past fifty years can be seen as a sequence of triumphs of reasoning from symmetry. The term *symmetry* here refers generically to a case where some transformation is introduced, such as a reflection or rotation or translation, but the object or process under study does not change: it is said to be *symmetric*, or to possess symmetry, under the given transformation. The technical names for some examples of this are *translational invariance*, *Lorentz covariance*, *parity invariance* and *charge conjugation invariance*. The laws of thermodynamics are of a similar character. To be precise, the first law of thermodynamics concerns a statement about energy which can be obtained by arguing from symmetry, and the second law concerns a certain kind of non-symmetry.

In order to appreciate the flavour of reasoning from symmetry, let’s consider an example: the working of a car engine. It is observed that the engine inside some given car works correctly as the car is driven around. The functioning of the engine does not depend on the location of the car—it will work just as well in China as it does in Paris. This is an example of *translational symmetry*. The functioning of the engine is unchanged or preserved under the action of a *translation*—a displacement in space.

Now we can also examine an internal combustion engine from another point of view. We can treat it in terms of physical processes such as the chemistry of the fuel–oxygen mixture; the expansion of hot gas; Newton’s second law of motion (rate of change of momentum is equal to force) applied to the pistons, and so on. In this detailed discussion one might find that one never made direct appeal to the concept of translational invariance. So, then, would it be correct to say that the principle of translational invariance here has no explanatory role to offer; is it simply some sort of superfluous decoration?

The answer from physics is unambiguous: the symmetry principle here plays an important role because it constrains and illuminates the very ideas that are invoked in the description based on cause and effect and equations of motion. Only certain types of equations can succeed in describing isolated systems and this is a deep insight which is applicable to all sorts of physical systems, not just engines. Furthermore, reasoning from symmetry survives the transition from classical (Newtonian) physics to quantum physics. This shows that such reasoning is not merely a derived set of ideas that follows from the equations of classical physics. The language of symmetry is a self-consistent language in and of itself, like a high-level language in computer programming, which cannot be reduced to the equations which describe physical stuff at the microscopic level.

I could multiply examples. Lorentz covariance is the technical name for the symmetry associated with relative motion which underlies Einstein's special theory of relativity. The equations of electromagnetism called Maxwell's equations respect this symmetry, for example. This is an interesting example because if someone were to claim that Maxwell's equations are themselves sufficient and one does not need to appeal to Lorentz covariance in order to understand electromagnetic phenomena, then we may reply that Maxwell's equations are themselves *derivable from* Lorentz covariance plus a few notions of what a simple field theory can be. Therefore, far from adding nothing, the symmetry principle here furnishes almost everything! In truth there is no outright 'victor' in this wrestling match; neither side does all the work of explaining or giving insight. The relationship is one in which the electromagnetic phenomena support the symmetry principle, and the symmetry principle enarches the phenomena. Thus already, within the foundations of physics, a purely reductionist approach is not the whole story. The notion that "all the explanatory arrows point downwards" as Steven Weinberg put it, is not quite right. The situation is more rich than that. The concepts and discourse involved in symmetry arguments do not sit at the bottom of a stack of ideas; rather they interact with the equations of physics in a subtle logical dynamic, giving deeper insight into what the equations are, and into what kind of equations one might expect.

The reader may now begin to have a clearer grasp of my earlier assertion that physics does not explain chemistry. It is not that chemical processes fail to respect physical principles; it is simply that physical principles such as Schrödinger's equation are incapable of framing an insightful discourse about much that goes on in networks of chemical reactions.[3] Also, much of chemistry

[3]Consider, for example, the phenomenon of self-organized criticality in chemical networks. The main features of the global behaviour are determined by the nature of the network connectivity. The observation that Schrödinger's equation describes the motions is true but irrelevant to many of the questions that arise. This is comparable to one who asks whether

is independent of many of the details of the motions of particles, somewhat as high-level computer functions can be supported by a number of different hardware designs. An example of this is the way that the laws of thermodynamics are themselves sufficient to establish results such as the Clausius Clapeyron equation and the van 't Hoff equation, without regard to the details of atomic physics. All that is needed is a collection of more global ideas such as energy and entropy. And those global ideas remain applicable whether atoms are Newtonian particles or quantum field excitations (this is a brief statement of a point made with technical precision in the appendix of [Steane, 2018]).

When we come to biology, similar points can be made. Professional biologists have been able to make much progress in their chosen area without the need to have any training at all in quantum field theory. This illustrates the fact that biology has a coherent discourse of its own, one that does not require the details of microphysics in order to make sense. It makes sense already. This is not to deny that biological things are also physical things, nor would I suggest that biological things somehow circumvent basic patterns of behaviour that are revealed by the study of physics—patterns such as the conservation of energy and momentum, and the increase of entropy. But biology stands to physics somewhat as an arch to stones, or as a collection of symmetry principles to a collection of equations. This is an analogy, not a precisely delineated correspondence. I claim merely that it is a valid and insightful analogy.

It is interesting to note the way in which the term 'fundamental' is used in the physics community. This term is often applied to discourse such as quantum field theory and general relativity, but not to discourse such as the laws of thermodynamics. It is said that microphysics is 'fundamental' and thermodynamics is not. In this way it is implied that the microphysics says 'what is really going on' and thermodynamics (the laws of large-scale energy and entropy movements) is merely an approximate way of expressing some of the results. But this way of speaking is not a matter of mathematical derivation. It is not forced on us by the data. It is a human choice. We can if we like assert that the first and second laws of thermodynamics get the appellation (or the accolade) 'fundamental' and then, when we seek to discover and elaborate descriptions of microphysics, one of the tests they have to pass is that they support behaviour that respects the principles of thermodynamics in the appropriate limit. In this way the laws of large-scale energy and entropy movements play a role like that of symmetry principles: they enarch microphysics and have equal right to the appellation 'fundamental'.

I am not hereby proposing that we change the way such terminology is used in physics. Terminology offers a useful shorthand that helps people to exchange ideas rapidly. All I am suggesting is that in our effort to get a true appreciation of how scientific descriptions work we should not allow the adjectives to drive the argument.

a computer is running a spreadsheet or a video and is told that it is running logic gates.

2 The Babel fallacy

In the previous section I discussed the nature of scientific explanation, and in particular the way it invokes multiple languages which mutually inform one another without replacing one another. Now I wish to describe a failure in logic—a fallacy—which is often on show in discussions of science, but which is not always recognized as a fallacy.

Science involves model-making. We construct a model, which is a set of ideas and relationships, and make the hypothesis that the model captures significant elements of the behaviour of some entities in the natural world. For example, Newton's theory of motion and of gravitation can act as a model for the large-scale motions of planets in the solar system; certain simple ideas about fish can act as a model which reproduces the typical behaviour of a shoal of fish; some models of neurons capture observations about the behaviour of brains, and so on. It can happen that someone suspects that a model will be able to account for some given phenomenon, and they are mistaken. Such a mistake is understandable enough and does not amount to an error of logic; it is just a conjecture that turns out to be wrong. However, what does amount to a failure of logic is when conjectures of this kind masquerade as truth or knowledge.

An example is the conjecture, widely made by mathematicians at the turn of the twentieth century, that it would be possible to demonstrate by logical analysis the internal consistency of mathematics. As a conjecture, this can stand. It is in fact untrue but if it is presented merely as a conjecture then its truth is not being claimed so no fallacy is committed. But what if someone were to claim that the tools of logic are in fact adequate to prove the consistency of mathematics? (They might argue that those tools are very powerful and 'therefore' one need not doubt that such a proof would be within their scope.) Such a person would be committing a fallacy. I call it the *Babel fallacy.*

> **Definition.** *The Babel fallacy* = the claim that a given low-level treatment or language is adequate to support a given high-level collective phenomenon or language when this has not been explicitly demonstrated.

In the mathematical example the low-level language is the internal logical rules that apply to arithmetic, and the high-level language is the meta-claims that are being made about the nature of arithmetic as a whole. Gödel showed that the former do not in fact suffice to establish the latter. The claim that they would suffice would therefore be untrue. The Babel fallacy is not merely to assert an untruth, however. It consists in a particular kind of untruth. It consists in asserting that one possesses knowledge one does not have, in the area of the capacity of languages and models to represent or support types of behaviour.

If we did not have Gödel's work, and had never developed the argument named after him, then to claim that logical analysis will, eventually, be able to prove that mathematics is internally consistent would still be to commit a fallacy. I wish to give it a name because it is a particular kind of mistake, one involving *a refusal to admit the possible limitations of the power of a language or way of proceeding.*

An example of the Babel fallacy in current affairs has occurred in economics. Economic decisions were taken on the basis of some simple model of the economic behaviour of people and corporations, in the belief that the model captured that behaviour sufficiently well to support sound investment decisions. But it turned out that some of these models were inadequate, and financial disaster ensued. The fallacy was to suppose that the simple model was adequate to account for the complex motivations of economic agents.

A more precise but more technical example of the Babel fallacy occurs in the analysis of linguistics furnished by the Chomsky hierarchy or Chomsky–Schützenberger hierarchy. This hierarchy consists of a sequence of types of grammar applied to symbols, which leads to a sequence of types of language. The Babel fallacy in this area would be to make the claim that a given language can be produced by a grammar of some given level, without providing an explicit demonstration.

An example in science occurred when commentators at the end of the nineteenth century supposed that the understanding of physics was nearly complete; Newtonian physics and classical field theory would suffice. It turned out that such claims were utterly mistaken: the quantum revolution was needed.

We can now examine the way the Babel fallacy typically operates, using the example of liquid helium. Suppose we have a sample of helium gas at ordinary temperature and pressure (one atmosphere) and we begin to cool it down at constant pressure. In view of the fact that helium gas is no more and no less than a collection of atoms, someone may make the claim that they know what will happen: the gas will condense into a liquid, because that is what collections of atoms do when they are cooled. The experiment is done and it is found that the gas does indeed condense into liquid helium. So now we propose to cool it down some more. "I know what will happen," our friend may say, "it is a collection of atoms, and that is all. Therefore it will solidify." This time our friend's statement proves to be wrong. The liquid does not solidify; in fact it becomes if anything more liquid, in that it becomes free of viscosity—a superfluid. The point I wish to highlight is that the error made by the friend here was not to assert that helium is made of atoms. The error was to assume that one already knew all about what atoms are.

A similar situation arises when we consider a living thing such as a dolphin or a crow or a monkey or a human being. "It is a collection of cells, and that is all," someone may say. But what is being hidden underneath that phrase 'and that is all'? If it means merely that there is nothing further in addition to the cells, well and good. But if it is being used to signal that the speaker already knows all about what cells are, and what they are capable of when congregated in highly structured groups, then a fallacy is being committed. Nobody currently alive has that knowledge. For all we know, structured collections of cells may require for their adequate description whole new types of language, just as proved to be the case in the area of liquids, solids and classical and quantum physics.

Related to this are the claims currently being made in the area of artificial intelligence. Machine learning and artificial intelligence is proving to be a powerful tool. It is likely to revolutionize many areas of medicine and commerce and will have a large impact on society for good or ill. One hesitates to suggest limits on what it might be possible for processing based on boolean logic to do. But through the work of Gödel and Turing we already know that there are subtle limits on the power of automated logical processing. It is not yet clear whether, in the type of insights that humans gain when they develop new ideas (such as new insights into mathematics), another type of processing may be happening, as Penrose has pointed out.[Penrose, 1989, Penrose, 1994]

3 On the validity of moral philosophy

In this section I wish to bring together the discussion of the structure of science and the discussion of the Babel fallacy in order to assert the simple point that moral philosophy is valid. By 'moral philosophy' here I mean the set of discussions and urges that surround the notion that there are things that one *ought* to do and things that one *ought not* to do. It includes concepts of justice and fairness and asserts that human life is in many respects moral or immoral as opposed to amoral, and furthermore this is not just a convenient way of speaking or an illusion, but gets at the truth of human behaviour.

I will argue that we have no good reason to say that questions about the moral rightness or wrongness of actions are without meaning, or do not grapple correctly with human behaviour, being merely a kind of illusion thrown up by our brains. On the contrary, we have every reason to think that our sense of *ought*, and of justice, is giving us good (though imperfect) insight into a world of meaning.

This needs to be stated because sometimes people adopt an illogical syllogism along the lines: "human beings are made of cells and molecules; cells and molecules are in turn entities following laws of chemistry and of physics; therefore moral philosophy is irrelevant to the behaviour of human beings." This is an attitude that assumes that human beings, along with all other elements of the natural world, are automatons. A philosopher will not find it difficult to point out that the above argument does not hold good and the conclusion does not follow from the premises. But the argument is at work, not fully thought-through, in the minds of many modern people, because they think it is a scientific argument, or what science teaches.

For the sake of clarity, first let's dismiss the argument. It fails on two counts. First, it commits the Babel fallacy because it rests on an assumption that the speaker knows the nature of cells and molecules sufficiently well to be able to claim that the language of moral philosophy does not apply. But nobody has that knowledge. Secondly, it ignores the two-way and network-like structure of scientific insight and explanation. The high-level language offered by moral philosophy is a valid language in and of itself and can enarch the descriptions offered by the cell biology without being contradicted by them.

Notwithstanding this, some may wish to say that they believe it to be the case that human beings are automatons, along with everything else in the natural world. By an *automaton* I mean a physical thing whose behaviour is wholly the outcome of the combination of impersonal forces acting upon and within it, with possibly a random element.

Those who think the whole world and everything in it is the outworking of impersonal forces are making a guess, a conjecture. I prefer to make another guess. Either of these guesses is consistent with everything that has ever been discovered about the patterns of nature. The first guess—the automaton world—proves to be very insightful when it comes to describing all those aspects of the world which do not require one to recognize another as a *subject* and not just an object. Here by a *subject* I mean a semi-independent source of meaningful novelty. In view of this success of the automaton model, one might be inclined to treat everything as objects and not subjects, because one thinks that this is what science invites us to do. But science makes no such invitation. Recall that I use the word *subject* to mean one deserving recognition as a semi-independent centre of meaningful novelty, as opposed to an automaton. The conjecture that the world has in it subjects and not just objects is entirely in keeping with the rich variety of discourses and languages that we find in the way science operates. This is not a proof but a strong hint that the languages developed in the arts and humanities—the languages of moral philosophy and of aesthetic and poetic insight, for example—will prove to be every bit as truthful as any other attempt to see, describe and understand what goes on in the world. On this view, when a parent urges a child not to torture a cat, for example, then what is happening is not a shared delusion in which matters of convenience are framed in a language of morality which in fact has no basis in truth. Rather, what is happening is that the parent is urging the child to nourish the sense for moral truth that they already possess.

The types of discourse that science deals in do not themselves furnish the types of discourse encountered in the arts and humanities, but they give us every reason to expect that higher-level discourses will be valid. In particular, when it comes to the inner experience of what it is to be a person and to recognize other people as subjects, not just objects, the working assumption that we are not automatons resonates. It makes sense. It is a reasonable thing to assume unless a convincing amount of evidence should accumulate against it.

Some will argue that the success of physics—the precision and wide reach of the arguments it invokes—amounts to evidence that the world and everything in it is indeed a huge machine. On this argument, conscious experience is simply what the machine generates as part of its working. Such an argument commits the Babel fallacy. In fact it is entirely possible that the patterns which truly describe sufficiently complex and sensitive things, such as human beings, are not fully captured by the way we currently approach particle physics and quantum field theory: they might not be completely algorithmic, in which case further elaboration of algorithmic descriptions will not suffice.

It is equally possible that human beings are not correctly described as objects merely; they may be subjects and centres of genuine novelty. This is certainly how I, in common with most sane people, think they should be treated. The evidence from physics is far from overturning this. Indeed, the evidence from physics is that reductionist descriptions are incapable of expressing in full the nature of composite quantum systems, and also non-linear systems involving feedback can exhibit exquisite sensitivity to initial conditions, in such a way that if there were further principles at work in the way brains behave (as I suspect) then they could operate on top of the framework described by contemporary physics without running counter to its patterns, while not being fully captured by those patterns.[Polkinghorne, 1996, Polkinghorne, 1991, Polkinghorne, 1999, Penrose, 1989]

3.1 On determinism and reductionism

The evidence I am appealing to here is from the study of the behaviour of non-linear systems which goes by the name of 'chaos' or 'deterministic chaos'. It is important to note the sense in which the word 'deterministic' is used here. It does not imply that chaotic behaviour is in fact deterministic, only that it may be. Also, the behaviour under study is not completely chaotic; far from it.

'Determinism' denotes a case where all future states of affairs are in one-to-one correspondence with past states of affairs. It means that, given a specification of the state of a physical system at one time, and given a set of physical influences on the system, then one and only one state can obtain at some later time. The phrase 'deterministic chaos' is a reference to the fact that under such conditions very sensitive and complex behaviour can result. But one should note that this does not amount to knowledge that the behaviour of some non-linear system is in fact deterministic. It means simply that a deterministic *model* can capture significant features of the behaviour. But those same features can also be captured by a non-deterministic model. The important point here is that empirical observations are not able to tell which type of model is the right one. This is owing to the extreme sensitivity. Tiny influences are sufficient to change the outcomes of processes of extreme sensitivity, and there is a limit to the degree to which the conditions of an experiment can be reproduced. In such cases the experimental result will vary from one realization to another, and we cannot tell whether that variation reflects a variation in the initial conditions (with a deterministic outcome), or whether it is the result of inherent non-determinism in the nature of the physical world.

Deterministic models are useful and highly accurate in many areas of physical behaviour, and therefore they are widely adopted and employed. It does not follow that the whole physical world is deterministic. It may be, or it may not. As Gisin has argued, the very notion of a state or an influence which is defined sufficiently well to make the universe predictable is itself questionable.[Gisin, 2017]

A second observation about physics is also relevant to the question of what type of language correctly expresses human capacities. This is the observation that *reductionism* is somewhat qualified by modern physics. It is not overturned completely; it is modified or qualified a little. This is a reference to the aspect of composite quantum systems which is called *quantum entanglement*. This involves states of collectives of matter which cannot be expressed by any description which seeks to assign properties individually to the constituents. The superfluid state of liquid helium has this character, for example. One should be careful in deciding what it is and is not warranted to deduce from this. It is an area where our understanding is incomplete but in view of the significance of any limit to reductionism it is an important consideration.

Note, I do not make the claim that I know quantum entanglement to be relevant to the processes in and between neurons which support the way humans arrive at decisions. I do not know that. But I do know that quantum entanglement demonstrates that the physical world is not correctly understood as a collection of individually definable subsystems ('particles jostling in the void'). It is more subtle than that.

3.2 On the origins of moral insight

When a human being utters a sentence such as "two plus two equals four" they are not merely uttering some meaningless noise. They are communicating a simple truth about number, in a language which they have in common with other people. If biological evolution had gone differently, would it be the case that humans would say (after translating into English as we use it) "two plus two equals five?" Of course not. Either we understand mathematics and think that two plus two equals four, or else we have no idea what the words even mean. Our mathematical and reasoning capacity is not an arbitrary offshoot of a propensity to propagate genes; it is a capacity to employ a meaningful language, one that is entirely independent of the processes of evolutionary biology. The ability to grasp and employ this language is not independent of biology, but the language itself is. To say that two plus two is equal to four succeeds as part of a biological reproductive strategy not because it beguiles oneself or another with invented delusion, but because it is part of a capacity to grasp logical truth, and to share a coherent language in common with members of a community. It is that capacity which is a useful one in evolutionary terms, not the rules of logic. The rules of logic simply are what they are and evolution cannot do anything about them nor influence them in any way.

Similar assertions can be made about moral reasoning. The mere fact that our moral capacity is a feature of a body—the human body—that came about by a long process of development (Darwinian evolution) does not invalidate that capacity. Our eyes too came about through a long steady process; that does not mean they cannot see. That would be the exact opposite of the reasonable conclusion! The same goes for our moral capacity. There is every reason to think that it is a capacity furnishing insight into a coherent collection of principles that deserve our respect. When we say that nurture is better than torture we are not merely beguiling ourself or another with invented delusion. We are enunciating a moral truth, and sharing a capacity to employ this language in common with members of a community. That capacity furnishes evolutionary benefit, but the patterns of what is good and just and what is not are entirely independent of any process of natural selection.

Of course our moral capacity is much more subtle than our eyesight, and we are capable both of deluding ourselves and of being blind to injustice. But the important point is that such blindness is blindness to a reality, an absolute truth, not an unreality or a mere construct convenient to some.

The alert reader will recognise that in the previous paragraphs I asserted the absolute status of moral truths without providing a proof. It is not my intention to offer such a proof (I think it probably cannot be done). It is my intention only to show that this position is open to us and is a reasonable position that does not contradict the rest of our knowledge, and indeed is positively coherent with the rest of our knowledge. It is consistent with evolutionary biology, and resonates with our lived experience. It does not mean that one thinks moral truths are easy to identify or to state; they are usually complex and subtle. They involve the sense that education is better than propaganda, and that the powers of the state over the individual should be limited, and things like that. But to have a crude example, I think it is an absolute moral truth that in ordinary circumstances inhabitants of one country ought not to abduct and force into slavery the inhabitants of another country, and furthermore if there are any circumstances where it might be moral to do that then they are so extraordinary that I cannot currently conceive of them.

One of the basic moral principles, it seems to me, is that entities that show signs of being subjects not just objects deserve recognition as such.

4 The possibility of purpose in evolutionary biology

In this section I wish to overturn an argument made by Richard Dawkins in his books *The Selfish Gene* and *The Blind Watchmaker*. In those books Dawkins promotes the view that evolutionary biology has no guide and consequently cannot serve any purpose, being merely an outcome of the action of purposeless forces and randomness. To be precise, Dawkins suggests that there is a purpose after all, namely to promote the replication of genes, but this might be merely a metaphor (the books are not quite clear on how far he wishes to press the notion that living things genuinely or primarily serve the purpose of gene survival). If one considers that the mere replication of certain molecules does not really amount to an end worthy of the name of 'purpose' then one concludes that there is no purpose.

I think what drives the argument in these books, especially *The Blind Watchmaker*, is the belief that the only type of argument or reasoning that can be regarded as adequate, when describing the production of complex things such as living animals, is one in which the complex entities are the outcome of the juxtaposition of simpler entities. He especially wants to avoid invoking an entity more complex still in order to explain the origin of any given thing, because that would not amount to an explanation—it would simply make matters worse, from an explanatory point of view.

I think that Dawkins is largely right on this point about explanatory power, but he overlooks a further possibility, and he is mistaken about the overall nature of biological evolution and the fact that it may serve a purpose.

I will argue the second point first, on the nature and possible purpose of biological evolution. To be clear, I wish to deny the following widely-made claim: "Evolution is blind, not guided or part of a design, and as such has no goal or purpose. It is just a (more or less) random sequence of mutations and environmental influences." If it were true that evolution had no guide, and that its outcomes were largely random, then it would follow that it can serve no purpose (except possibly the production of random outcomes). But in fact evolution is strongly guided by the nature of what can be and what cannot be. It is deeply constrained by many facts about mathematics, physics, engineering, social science and moral philosophy. Consider, for example, the fact that the trunks of most trees have an approximately circular cross-section, not square nor star-shaped nor triangular nor highly elliptical. Then notice that this same approximate circular cross-section is found in the bones and arteries of mammals, and in the antennae of insects and the stalks of flowers. Is this all a massive coincidence? Of course not. It is because the circular cylinder is a strong shape for a given quantity of resources required to form it. It makes efficient use of materials. Random mutation and natural selection do not stipulate this; it is a fact about geometry and the properties of solid matter. What random mutation and natural selection cannot fail to do is respect this fact. So the outcomes are not random after all. They are round.

Once one has noticed this, it becomes easy to find huge numbers of other examples. One immediately discovers that the biosphere is far from random and far from an outcome of mere force combined with a random element. Rather, it is an expression of a rich collection of truths about how life can be lived. It expresses the truth that heavy things require strong muscles, that light sensors must be sensitive to light, and that an arch is an efficient load-bearing structure, for example. It expresses the truth that tit-for-tat is a successful simple strategy in communal living, and the fact that sensing and adaptability are required to survive in a changing environment. Such truths are almost self-evident, they amount to tautologies. Darwinian evolution could not fail to respect them, and consequently Darwinian evolution is highly constrained, through and through, right up to the social rules that are at work in populations of social mammals such as whales, elephants and apes. I wish to emphasize that these patterns do indeed extend as far as social behaviour. An elephant with a defective cognitive faculty, for example, such that it cannot recognize that other elephants are like itself, will not be able to negotiate the social etiquette amongst elephants and consequently may be excluded from the group, or will disrupt the group. This is not a random outcome; it is an aspect of what social behaviour involves.

Darwinian evolution is correctly seen as an exploratory mechanism which explores, more and more completely over time, a rich landscape of truths which are laid down in the very way that things can be. A fish that conserves energy can be; a fish that does not conserve energy cannot be. A social animal with a cognitive faculty can be; a social animal with no cognitive faculty cannot be. A fair division of labour without slavery can be; a fair division of labour with slavery cannot be. A rich person who finds it hard to enter into life at its most meaningful and humane can be; a rich person who finds it easy to do this cannot be. All these outcomes are unavoidable once the complexity of the biosphere acquires the potential to express them.

In view of the fact that the overall situation here is not random, it follows that the process can have an end, a purpose, other than mere randomness. It does not follow that it *must* have a purpose, nor that we know the purpose if there is one, but it makes it logical and reasonable to say that Darwinian biological evolution can serve a purpose.

Let us now return to Dawkins' point about explanatory power: the incorrectness of appealing to a complex in order to explain a simple. For example, we do not say that Earth orbits the Sun because the Sun likes to have the Earth nearby and the Earth does not want to disappoint her. That does not amount to an explanation because it renders the situation less well understood; we immediately need to enquire how the Sun could have wishes and the Earth volition. Similarly, if one considers that the word 'God' refers to a complex and powerful entity conjectured by some to steer events, then it does not contribute to explanation to assert that this 'God' is the cause of something such as the origin of life or a new species or a healing or a disaster. In order to be reasonable, and to earn the attention of reasonable people, religious language has to be more careful than this. We have to remind ourselves that in God we approach not another entity to be added to the sum of things in the cosmos, but one whose influence is more like the sum-total of all those constraints we contemplated just now—the constraints of truth, and of what it is to *be*, to have existence, especially existence as a subject not just an object, and to have moral dignity. This includes not just the constraints implicit in the capacity to have some simple physical existence (even a rock respects those) but also the constraints of love. The anthropomorphic images invoked by many ordinary people as they seek to express a sense of recognition of God should not be scorned, since they often represent a willingness to respond to the truth of things as deeply as we can, but neither should they be embraced too fully.

5 Education

The main purpose of this paper is educational. I am not so much presenting original research as aiming to make more widely known things that are part of the ordinary discourse in philosophical and theological communities but less known outside those communities. In particular I wish to clarify what is the nature of scientific explanation by introducing sharp images and pithy names such as the *Babel fallacy* and *enarch*. Part of our duty is to bequeath to the next generation a sound grasp of how scientific explanation operates and what contribution it makes to wider understanding. I think this is not very well done at present in our schools.

5.1 The Embodiment Principle

Science is often seen as a discipline that lacks patience with personal categories and seeks to describe everything in impersonal, amoral language, and it is implied that this will eventually supersede the approaches adopted in other disciplines such as the study of human language and literature, history, art, philosophy and theology. This perception is misleading and incorrect. As I have discussed above, the structure of scientific explanation in fact involves a network of mutually informing ideas. In order to offer to our children, and each other, a more accurate basic vision of science I would like to recommend the following summary statement which I dub the *Embodiment Principle*:

> **The Embodiment Principle.** Science is about building up an insightful picture in which the underlying microscopic dynamics do not replace, nor do they explain, the most significant larger principles, but rather they give examples of how those larger principles come to be physically embodied in particular cases. The lower level and higher level principles are in a reciprocal relationship of mutual consistency in which each illuminates the other.

This statement is intended to express correctly the relationship between disciplines such as physics and chemistry, physics and biology, chemistry and biology, and all the other partners in scientific discourse. It should be understood as a way to summarise the picture which I have discussed in section 1 of this paper, and at greater length in [Steane, 2018]. I recommend it as a statement which could be introduced as the main theme of a science lesson for 16-year-old school pupils. The lesson would look at examples and the pupils would be expected to answer a question in this area in their end-of-year examinations. The phrase 'nor do they explain' is an important part of the statement and I have not, in this paper, done enough to establish that phrase fully. But the reader may like to reflect on the fact that Newtonian mechanics, and quantum mechanics, do not explain translational symmetry so much as embody it, and the behaviour of logic gates in a computer does not explain the *Java* programming language even when the computer is running a program written in that language.

5.2 Biological Evolution

When we educate our young people on the subject of biological evolution we should promote a balanced perspective which sees both the openness of evolution and the sense in which it is nonetheless guided by sheer ontology (it can only produce things that can be). The role of openness and improvisation in evolution should be celebrated, not disdained. It should not be improperly coloured through the use of tendentious adjectives such as 'blind'. We should give to our children a sense of the positive role of chance (another word for openness) in the realisation of positive outcomes in evolution, while acknowledging the role that such openness also plays in disease and death.

Repudiation of literalist readings of the Bible (the "answers in Genesis" form of creationism) is probably best done by teaching how literature is correctly handled and respected. However, showing that the science is unthreatening also has a role to play.

Drama and poetry, art, and hymn-writing should endeavour to celebrate all aspects of science, just as they celebrate our direct experiences of the natural world. It takes skill to do this appropriately, but it is a mistake to fail to do it, because to fall silent is itself a statement that implies a lack of interest and appreciation. The legacy of St Francis of Assisi includes that one takes a deep interest in the world around us, and sees it first for what it is in and of itself, not as a means for our gratification, nor to be exploited in other ways. We abuse our role both when we see the whole world as mere object, and also when we prefer fantasy stories to the true nature of things, as for example when people practice 'alternative medicine' or 'faith healing'.

5.3 Our place in the landscape

It is a widespread experience that faith in God re-connects one to the natural world in a more full way. The world is encountered in the type of reverence and wonder that was expressed by Saint Francis, and one experiences the sense of ones place in the landscape which is a feature of Celtic Christianity. In his thoughtful and intelligent book, *Soil and Soul*, Alastair McIntosh has shown how this can impact on political and economic decisions in a positive, humane way.[McIntosh, 2001] As Pope Francis expounds in *Laudato Si'*, this is also the Biblical witness:

> "The biblical texts are to be read in their context, with an appropriate hermeneutic, recognizing that they tell us to "till and keep" the garden of the world (cf. Gen 2:15). "Tilling" refers to cultivating, ploughing or working, while "keeping" means caring, protecting, overseeing and preserving. This implies a relationship of mutual responsibility between human beings and nature.

Further deliberation on the pattern of communal life in ancient Israel leads him to the conclusion, "Clearly, the Bible has no place for a tyrannical anthropocentrism unconcerned for other creatures." Strikingly, the notion of land ownership, with all the injustice and dubious moral positions that get bound up with it, was explicitly qualified in ancient Israel: "The land shall not be sold in perpetuity, for the land is mine; for you are strangers and sojourners with me" (Lev 25:23). This is not to suggest that land ownership legislation should be abolished at a stroke, but it may act as a constant reminder that the notion that one person or group has complete ownership rights over a piece of the Earth (a forest, an oil well, a plot of land) is deeply compromised.

The vision of science that I want to recommend for education is urged in this paper mainly because I think it is a truthful vision. But I think also that it is a significant, humane and creative vision. How wonderful to be able to teach the next generation to respect others on the basis that our recognition that others deserve it is an authentic sensitivity to what is the case, rather than a deluding and controlling passion instilled in some of us by molecular chemistry with no basis in truth except the truths of chemistry! When we find that science is not positioned to overturn or undermine all other forms of sensitivity to the natural world, then we can be receptive to what both science and those other forms have to offer. For example, when we contemplate the death of the world's last surviving male northern white rhino, there are a range of attitudes and reactions involved, not all of them expressible in purely analytical language. We need poetry as well. We need to recognize the somewhat undefinable yet authentic sense of connection to other species that we experience. Science is an important partner here—not least in obliterating false beliefs about the healing powers of rhino horn—but it is not the whole story nor the only language in which we must learn to speak. If we recognize that through poetry, literature, jurisprudence, history, and song we do not just entertain each other, but also grapple with truth, then we become open to appreciating the natural world more richly, and we see science as a partner in a larger enterprise. That larger enterprise is one of recognizing, respecting and, where appropriate, celebrating the nature of things we find out about, rather than a way to capture them and take them into our internal mental possession.

Once it is located correctly in the structure of knowledge and understanding, science is both welcome and important. It is fully at home in, and part of, the Kingdom of God. Those who see it that way have the welcome opportunity to present science correctly to the wider community, and this will be a valuable service. They can recommend a nourishing and fulfilling vision of science in partnership with humanity, in which it is not made to exercise a hegemony over all other avenues of understanding, nor is it distorted into the role of supporter of a machine-like and amoral paradigm for all that it touches. Rather we can correctly recognise the multiform nature of true understanding, while being honest enough to allow mistakes to be corrected wherever they are found. I think an educational change along these lines can be part of the *transformative change* whose urgency is spoken of in the summary of the United Nations' IPBES Global Assessment report given in Paris 2019.[Bridgewater et al., 2019]

I shall by finish by mentioning that, in common with many of us, I consider the environmental crisis to be one of the primary moral issues of our time. I think the evidence of diminishing biodiversity is especially concerning, and represents a form of impoverishment of our grandchildren and the planet that we are duty-bound to try to mitigate, now that it has been identified. In particular, economic measures need to be reconfigured so that they represent the true value and cost of human choices, and so that the cost is shared equably. At present too much of it is loaded onto future generations and onto the poorest among us. I think a sense of our identity as fundamentally loved children of God can help diminish the thirst for ever more consumption, in favour of an appreciation of the good things we already have around us. It can also enable us to avoid fatalism and seek better practices in good hope, ready to believe that the small difference that each of us can make is a valuable difference and worth the making.

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