

The Lagoon How Aristotle invented science

Armand Marie Leroi (Penguin Books 2014)

7 There is a sense in which his philosophy is biology—in which he devised his ontology and epistemology just to explain how animals work. Ask Aristotle: what, fundamentally, exists? He would not say—as a modern biologist might —‘go ask a physicist’; he’d point to a cuttlefish and saythat.

18 IT’s NOT THAT there wasn’t any science—or at least natural philosophy—before Aristotle... The Greeks called them physiologi, literally ‘those who give an account of nature’. Many were bold theoreticians.

20 It may seem that all Aristotle needed to do to become a scientist was to broker a marriage between the questing, querulous physiologi and the dourly empirical medics. Which is what he did. That he managed it, however, is a tribute to the power of his mind.

22 By the time the teenaged Aristotle arrived at Athens to sit at Plato’s feet, the tradition of natural philosophy, no more than two centuries old, was dead. Literally so: Democritus of Abdera, the last and greatest of the physiologi, had diedjust a few years earlier.

Disillusioned by the physiologi’s singular lack of interest in discussing why the universe was good, Socrates turned away from the study of the natural world.

26 Then, too, if Plato’s science is barely distinguishable from theology so, to judge by the pronouncements of some physicists, is modern science: ‘If we discover a complete theory, it would be the ultimate triumph of human reason—for then we should know the mind of God.’ Plato? No, Hawking. The comparison doesn’t save Plato.

27 Aristotle would turn his back on his teacher’s idealism and see the world, our world, for what it is: a thing that is beautiful and so worth studying in its own right. He would approach it with the humility and seriousness that it deserves. He would observe it with care and be unafraid to dirty his hands doing so. He would become the first true scientist. That he made of himself this after having been taught by one of the most persuasive intellects of all time—that is the mystery of Aristotle.

38 To be sure, Aristotle never called himself a ‘scientist’, but he did have a term for ‘natural science’—physike episteme, literally the ‘study of nature’.

39 Aristotle does not mean ‘know’ just in the sense of ‘understand’; he also means ‘perceive’. ... For Aristotle goes on to argue that ‘knowing’ in the sense of ‘perceiving’ is the foundation of ‘knowing’ in the sense of ‘understanding’—indeed, is a requirement for wisdom.

40 Brute empiricism of that sort is useful, says Aristotle, but really not that admirable. ...

Aristotle is launching a **new kind of philosophy**: one that is neither concerned with the search for absolute values nor predicated on a perfect world beyond the senses.

40 ARISTOTLE’S SCIENTIFIC METHOD is all of a piece with his epistemology. We have to begin, he says, with the phainomena —whence comes our ‘phenomena’, but perhaps the

best translation is ‘appearances’, for he means by this not only what he sees with his own eyes, but also what other people have seen, and their opinions about it.

44 Aristotle himself doesn’t scorn popular wisdom. He often says that we should begin investigations by considering what most people think, for they are often right.

74 Many zoologists have praised Aristotle, for they have seen him as one of their own. ... Now I take it that in regard to biology Aristotle did much the same thing as Boyle, breaking through a similar tradition...

79 Aristotle thinks that the cosmos—the stars, the planets, the earth, the living things it contains, the elements themselves—obviously have a purpose; they show the hallmarks of design.

Only a child would ask ‘what are the stars for?’ But that’s not a childish question to Aristotle.

81 it suggests that in Aristotle’s time the idea of selection as a source of order was a commonplace. Certainly Epicurus, a generation younger than Aristotle, gave an even more elaborate selection-based cosmogeny.

82 The heart of Aristotle’s rejection of materialism is his conviction that the cosmos, and the creatures it contains, have order and purpose. His dismissal of Democritus’ conviction that order can simply arise spontaneously is, perhaps, understandable.

86 Aristotle was deeply impressed by the resemblance between organisms and artefacts, particularly machines. ... Yet repeatedly and decisively he denies that there is a divine craftsman who made it all.

89 It is the ‘information’ or the ‘formula’ which was transmitted to it by its parents, from which it built itself in the egg or womb, and which it will, in turn, transmit to its progeny. It is in this sense that Aristotle thinks that the nature of a thing resides primarily in its form. To speak of eidos as ‘information’ risks anachronism.

90 Aristotle’s belief that we should attend less to the matter than to the informational structure of living things makes him seem like a molecular geneticist avant la lettre.

91 But ‘cause’ isn’t quite right: ‘four questions’ or ‘four kinds of causal explanation’ capture his meaning better...

I take them in reverse order. The efficient (or moving) cause is an account of the mechanics of movement and change. It is now the domain of developmental biology and neurophysiology. The material cause is an account of the matter—the stuff—of which animals are made, and their properties. It is now the domain of modern biochemistry and physiology. The formal cause is an account of the information transmitted that any creature received from its parents, and that is responsible for the features that it shares with other members of its species—that is, the subject matter of genetics.

Four causes are research programs.

98 THE NATURAL PHILOSOPHERS of the Renaissance... For them Aristotle was primarily a naturalist who sought to give a comprehensive account of all the creatures that he knew,.

- 118 Aristotle is searching for patterns—patterns of a very subtle sort. He isn't interested merely in how parts vary, but also in how they covary.
- 123 Aristotle **distinguishes** the rules for debating opinions from the rules for constructing scientific explanations. The first he called 'dialectic', the latter 'demonstration' (the Greek is *apodeixis*).
- 127 Some people, he says, claim that scientific knowledge is impossible because any inference we make must rely on some previous inference. ... No, there isn't an infinite regress of inferences, nor is it true that everything can be demonstrated, because our arguments ultimately begin with axioms and our perception of the empirical world.
- 149 He also supposes that more complex animals tend to have more specialized parts.
 These auxiliary principles pervade his explanations of diversity. ...
 Collectively these auxiliary principles are a model of the body's economic design.
- 157 Aristotle asserts, with fairly little argument, two propositions: that all living things—plants, animals and humans—have souls; and that, when a living thing dies, its soul ceases to exist. These were probably commonplace among fourth-century Greek intellectuals.
 Aristotle's forms are present even when they are invisible. They are somehow present in an animal's seed and are responsible for the development of the embryo and the appearance and functions of the adult. So an animal's soul is its form, albeit under particular circumstances:
 The key word here is 'actuality'—*entelekheia*. It is this word, a bit of Aristotelian jargon, that is most distinctive about his theory of the soul.
 [C] Soul → form ~ information?
- 159 When combined with the claim that the soul of a living thing is 'its form in its body', it becomes clear that he means that the forms of unfertilized seed are mere potentials; and that those forms when realized in growing embryos and functioning adults are souls.
- 160 Souls, THEN, BEAR a heavy burden. They embrace no fewer than three of Aristotle's four explanatory causes - the formal, moving and final—leaving only the material cause for the stuff of which it is made.
- 163 The belief that living things transform food into uniform parts hardly seems like a stunning insight, yet it seems to have been original to him.
- 165 The structure of the metabolic network—is the nutritive soul.
- 167 'Fire is always coming into being and flowing like a river'—how very true. But no fire can rage unchecked for ever lest it consume itself. All fires must be fuelled, stoked, damped—regulated—if the tenuous flame of existence is to be maintained. That, too, is the work of the soul.
 Where is the soul located? The Aristotelian answer is 'everywhere' and 'nowhere'.
- 171 The term that Aristotle uses for the mental representation of some object is *phantasia*.
- 191 Aristotle was trying to show that the power of semen to direct development rests not on the transmission of seminal matter itself, but on something else.

What? To solve this problem Aristotle once again invokes that mysterious stuff, pneuma. It's not only an instrument of the sensitive soul, but also a component of the inheritance system. The upshot is a theory for how an animal's soul is reproduced in the embryo. The structure of the father's soul is, in effect, encoded in his semen by pneumatic action.* We must not think of pneuma as the carrier of genetic information itself: it's not Aristotelian DNA. Rather, Aristotle's units of inheritance are much more abstract; they're the movements that pneuma induces in the semen.

264 Adaptive = teleological

275 When Darwin said that his 'two gods'—Linnaeus and Cuvier—were mere schoolboys compared to Aristotle, he was insufficiently precise. He should have said that old Aristotle taught them.

ARISTOTLE'S CLASSIFICATION OF the animals is the starting point of our own.

285 Perhaps Aristotle's most important legacy is one that I have not touched on at all, but that also runs throughout the history of zoology. It is his insistence that the organic world is structured into natural classes that our classifications should not tear apart.

289 Aristotle, was structured on a conflict between creationist and naturalistic explanations for the origin of its living inhabitants. For Aristotle, there's not much to choose between them. Both fail to grasp one of the most salient features of the biological world: its regularity.

298 Aristotle understands as Darwin did and we do that:

- (i) the complex morphologies and functions shown by living things require a primal source of order or information, his 'formal natures' or simply 'forms';
- (ii) that these forms are dynamic, self-replicating systems;
- (iii) that they vary among kinds to give diversity;
- (iv) that they exert their power by modifying the flow of materials in development and physiology;
- (v) that organisms gain these materials from nutrition which is transformed internally;
- (vi) that this material is limited in quantity;
- (vii) that the manufacture of parts, production of progeny, indeed survival itself, all expend this material—that is, are costly;
- (viii) that these costs limit the forms and functions of organisms such that if they do or make one thing it is at the expense of not being able to do or make another;
- (ix) that these costs are not absolute: some organisms are more subject to them than others;
- (x) that these material constraints act in concert with functional demands to give the diversity of animals that we see in the world;
- (xi) that the parts of animals are suited to the environments in which they live, that they are, in a word, adaptations;
- (xii) that the functions of different organs depend on each other—that is, living things must be understood as integrated wholes. Much of modern evolutionary science is in this list—but evolution isn't.

Aristotle and Darwin, however, share the more unusual conviction that though the organic world is filled with design there is no designer.

Aristotle, however, generally appears to agree with Darwin: organs exist for the sake of the survival and reproduction of individual animals. This is why so much of his biology seems so familiar.

Yet there is a deep difference between Aristotle's teleology and Darwin's adaptationism, one that appears

353 Medawar was, indeed, re-enacting, for a new generation, the origin myth of modern science; the myth in which Aristotle was the giant who had to be slain so that we could pass through the straits of philosophy to reach the open sea of scientific truth. that lay beyond; the myth in which Aristotle is little more than an endlessly fecund source of empirical, theoretical and methodological error;

Aristotle's science was the principle casualty of the Scientific Revolution.

353 The triumph of the Thomist synthesis rendered Aristotle's philosophy supreme. .. The cost of philosophy was science. Following Thomas, the schoolmen of Oxford, Coimbra, Padua and Paris toyed ... the Philosopher's metaphysical machine. Their method was disputatious, their factions innumerable, their writings interminable and their conclusions stultifying. Much of it wasn't very Aristotelian at all. They reigned over Europe's universities for three centuries.

355 ARISTOTLE'S PHYSICAL SYSTEM suffered grievously at the hands of the new scientists. Even in the thirteenth century Albert Magnus drew from it the right conclusions. 'The aim of natural science', he wrote, 'is not simply to accept the statements of others, but to investigate the causes that are at work in nature.' And: 'Experiment is the only safe guide in such investigations.' ... Compare Albert's use of Aristotle to Thomas's and it is hard to resist the conclusion that the **eclipse of the former by the latter retarded the development of natural science by centuries.**

This thought gains additional force from the fact that in the sixteenth century Aristotle's biology helped to break the hold of Thomist scholasticism.

356 Yet it was neither his association with scholasticism nor his zoological errors, nor even the falsification of his physical theories, that accounts for the oblivion of Aristotle's scientific thought; ... rather, it was the belief, a foundation stone of the New Philosophy, that his explanatory system was corrupt to its core. ... Enter Francis Bacon.

359 Bacon's most serious charge was aimed at Aristotle's explanatory system. Of the four kinds of causal explanations that Aristotle insists natural science demands, Bacon ruled two—the formal and final - illegitimate. Natural philosophy should concern itself with the properties and movements of matter and them alone.

Bacon's aversion to Aristotle and Aristotelianism— he scarcely distinguishes the two— also stemmed from a particular vision of the purpose of science and its proper object of study. Its purpose, in Bacon's view, was not merely to understand the world, but to change it.

In biology, the cheerleader of mechanism was Descartes.

361 BACON AND HIS successors said that Aristotle's methods were wrong and that his explanations were too. Both charges are grave, but are they just? ... Should you read Aristotle's biology, you may, however, wonder why Bacon and Glanvill...

368 THERE IS A belief, and I think it is a very widespread one, that something is wrong with Aristotle's explanations... Moliere's Aristotelian quacks explain that opium induces

sleep because it possesses a sleep-inducing principle. Ever since, arguments of this kind have been known as *virtus dormitiva* explanations and rightly treated with scorn. ... And then there are those who have said that final or formal causes are those creative impulses and occult forces and have no place in modern science.

370 In this book I have sketched Aristotle's account of five interlocked biological processes: (i) the nutritional system; (ii) the thermoregulatory cycle; (iii) the CIOM system; (iv) embryonic development; (v) the inheritance system.

All these processes are, collectively, soul; more precisely, soul is the dynamic structure of these physical processes (or their result). Again, that Aristotelian souls run on an obsolete theory of motion, a defunct chemistry and an oft-erroneous anatomy is beside the point.

Aristotle sees that artefacts and living things are both made of more basic stuff, that they change and that these changes must be explicable in terms of physical principles. Yet, when looking at his world, he also sees that there is no artefact remotely capable of doing what creatures so effortlessly do.

Aristotle's enemies (and some of his friends) have also made formal and final causes far more mysterious than they really are. ... Long absent from science, molecular biology made form—*eidos*—respectable again. Max Delbrück, in the course of a long correspondence with Andre Lwoff, discovered the Philosopher's works. After quoting bits from *The Generation of Animals* he wrote, 'What all of these quotations say is this: **The form principle is the information** which is stored in the semen.¹

Final causes, too, have been demystified. Aristotle saw that they are needed when the phenomenon to be explained appears to have a goal.

373 Aristotle could not have conceived just how vast the science that he founded would become. ... I conclude that we can now see his intentions and accomplishments more clearly than any previous age has seen them and that, if this is so, it is because **we have caught up with him**.

375 Aristotle even said so: Failure to understand what is obvious can be caused by inexperience: those who have spent more time with the natural world are better at suggesting theories of wide explanatory scope. Those who have spent time arguing instead of studying things as they are show all too clearly that they are incapable of seeing much at all.

378 Aristotle wrote thousands of sentences, but one, the first of his *Metaphysics*, defines him: 'All men, by nature, desire to know.' Not all forms of knowledge, however, are equal—the best is the pure and disinterested search for the causes of the things. And, he has no doubt, searching for them is the best way to spend a life. It is a claim for the beauty and worth of science.

¹"I should like to utilize this opportunity to state the conjecture that this wonderful man discovered DNA. Let me explain" (in "Of Microbes and Life" J Monod and E. Borek, eds. Columbia UP 1971).