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Aristotle (384-322 BC): the beginnings of Embryology

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ABSTRACT Aristotle made important contributions to many fields-biology, physics, metaphysics, logic, ethics, rhetoric, psychology, aesthetics, poetry- that are now cultivated by specialized experts, but he never lost sight of the aim of unifying knowledge, of understanding the world as an organized whole. Aristotle was the first to combine wet, field biology with daring cosmological thinking. He is the father of natural history and the first embryologist known to history. Aristotle's classic treatises *History of Animals*/*Περί ζῴων ἱστορίαι*, and *On the Generation of Animals*/ *Περί ζῴων γενέσεως* "enjoyed for more than fifteen hundred years an authority altogether without parallel". Over the last four decades, the introduction of molecular techniques has gradually overturned the entire structure of the biological sciences. Biology, initially a science of inventory and classification in the hands of the 19th-century comparative naturalists, has become a science of codes and regulatory circuits. Aristotle was the first to codify laws of pure logic, and so he founded what is today known as '*proof theory*' in mathematics. Aristotle was an inveterate collector and a classifier, the master scientist of his time. His main concern was to classify "the ultimate furniture of the world", under basic headings and categories, a powerful human strategy to organize knowledge for comprehension and action. This was part of Aristotle's attempt to create a theory of reality, one strongly opposed to Plato's otherworldly doctrine of the ideal '*forms*'. To many generations of thinkers in the great era of Scholastic philosophy, Aristotle was known simply as "The Philosopher".

KEYWORDS: Aristotle, father of natural history, first embryologist known to history, founder of the science of taxonomy, first to codify laws of pure logic-founder of proof theory, teleology-intelligent design-purpose

Διὰ γὰρ τὸ θαυμάζειν οἱ ἄνθρωποι καὶ νῦν καὶ τὸ πρῶτον ἤρξαντο φιλοσοφεῖν,...
ὥστ' εἴπερ διὰ τὸ φεύγειν τὴν ἄγνοιαν ἐφιλοσόφησαν, φανερὸν ὅτι διὰ τὸ εἰδέναι
τὸ ἐπίστασθαι ἐδίωκον καὶ οὐ χρήσεώς τινος ἕνεκεν.
It is owing to wonder that people and now and from times past began to philosophize, …
and if it was to escape ignorance that people began to philosophize, it is evident that
they pursued science for the sake of knowledge and not for any practical utility.
(Aristotle *Metaphysics*, book 1, section 982 b 12-28 ff / Αριστοτέλης *Μετά τα Φυσικά*, A2, 982b, 12-28)

The importance of Aristotle in the intellectual history of Europe is too well known to require explanation or defense. The scope of his achievements places Aristotle without question on the shortest of the short lists of the giants of Western thought. To many generations of thinkers in the great era of Scholastic philosophy, Aristotle was known simply as "The Philosopher". Dante honored him with the proud title of "master of those who know". Darwin's praise testified to Aristotle's huge achievement as a biologist: "Linnaeus and Cuvier have been my two gods, though in very different ways, but they were mere schoolboys to old Aristotle," (Darwin's famous letter to William Ogle 22/2/1882, from *Life and Letters*, Francis Darwin ed., 1887, vol. 3, p. 252).

In Aristotle, we find a meeting of the two main philosophical motives, a desire to understand the world and a desire to understand man and his place in the world. What is the nature of knowledge, and what are its ultimate grounds? What are the ultimate categories of thought and the basic constituents of the universe? What is the relation between language, thought, and their objects? How is the mind related to the body? What is the place of the individual in human society? To what end or ends is human life to be directed? All these questions, and many others, are still alive, and Aristotle's answers to many of his own questions remain of primary interest and importance. Although Aristotle made important contributions to many fields - biology, physics, metaphysics, logic, ethics, rhetoric, psychology, aesthetics, poetry - that are now cultivated by specialized experts, he never lost sight of the aim of unifying knowledge, of understanding the world as an organized whole.

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Aristotle was a pupil of Plato's, whose academy he joined at the age of seventeen, remaining there for twenty years until his mentor's death. Both Plato (427-347 BC) and Aristotle were concerned with the nature of knowledge itself – the relationship between the wide external world 'out there' and our internal perceptions and experience thereof. Plato, influenced by Pythagoras (c. 580-c. 500 BC) that mathematics/the existence of mathematical constants was the one true source of knowledge, developed a distinctive theory of knowledge based on the notion of the existence of a reality of *'forms'* or *'ideas'* that is eternal and immutable. In fact, the world of *"forms"* is a reality that we can never perceive for what it is, we can only ever perceive the shadows; the route to this higher state is reason, accessible to human perception through the deductive logic implicit in mathematics. In an attempt to explain what he meant, Plato developed the famous cave allegory that he included in the *Republic/Πολιτεία*. What we take to be the physical world around us is merely a world of appearances, or of experience, and the appearances of things are mere imitations or shadows of the world of *"forms"*. What Plato is really saying is that we can never hope to understand the true nature of reality because we are locked in the prison of our mortal senses, we are prisoners in a cave.

Aristotle could not see how the notion of a Platonic ideal of *"forms"* could help us to understand the dynamic nature of the world around us, and his reality was one of perception and experience. Aristotle argued that we first perceive the objects in the natural world, and then form abstractions and ideas about them in our conscious minds. Our thoughts in relation to the forms of the things we perceive are then shaped by our ability to classify and catalogue our experiences. Today, we can broadly see Platonic tendencies in the thinking-reality that exists independently of our minds and our measurements. The latter underpins mathematics and physics, while Aristotle's emphasis on the primacy of observational and empirical methodologies motivates the biological sciences.

The history of the progress of biology dates back to the earliest ages of humanity. It was a vital necessity for early humans to have an intimate acquaintance with the landscape - with plants and animal behavior. Survival concerns led to hunting-fishing-fruit gathering, and eventually to crop growing-stock raising, and to using animal and vegetable substances for therapeutic ends or as poisons. All these activities provided biological knowledge based on observation and experimental tests. Our distant ancestors left traces of all these preoccupations in the form of cave paintings, rock engravings, statuettes and carvings in bone and ivory. The cave paintings at different sites across the world (e.g., Lascaux, Chauvet, Altamira) are not crude outlines, but evidence of extraordinary observation and figurative skill; one stands in awe of the color and movement in the silent procession of bison, bulls, rhino, ibex, wild horses, deer, hunt scenes across cave roofs and walls, all drawn with the simplicity and vivacity of illustrations for a children's fairy tale.

Today's amazingly complex structure of modern biology began many centuries ago, and through numerous vicissitudes weaves a wonderful story of adventure and endeavor. It is a tale of the contributions made by precise observation, and of philosophical speculation and intuition. The direct origins of modern biology must be sought in ancient Greece. Waddington (1962) indicates that "the astonishing Greeks, who seem to have opened and poked their head out of almost every window of the mansion provided for man's habitation on earth, cast their eye over this landscape also". Greek philosophers established a framework of theories and principles out of the mass of practical knowledge handed down by their ancestors; this framework constitutes a real science of considerable proportions (Caullery, 1966).

Aristotle was the first biologist, examining plants and animals to discover their nature, step by step, then going on to classify them according to their basic functions. This almost inexhaustible profusion of living shapes, which had not attracted the attention of the earlier Greek philosophers in Ionia and Magna Graecia, but had for centuries inspired vase-painters and other craftsmen, was now for the first time the subject of exhaustive study. Aristotle posits "And that would be a strange absurdity, if we study mere likenesses of these things and take pleasure in so doing, because then we are contemplating the painter's or the carver's art which fashioned them, and yet fail to delight much more in studying the works of nature themselves, though we have the ability to discern the actual causes/*Καὶ γὰρ ἂν εἴη παράλογον καὶ ἄτοπον, εἰ τὰς μὲν εἰκόνας αὐτῶν θεωροῦντες χαίρομεν ὅτι τὴν δημιουργήσασαν τέχνην συνθεωροῦμεν, οἷον τὴν γραφικὴν ἢ τὴν πλαστικήν, αὐτῶν δὲ τῶν φύσει συνεστώτων μὴ μᾶλλον ἀγαπῷμεν τὴν θεωρίαν, δυνάμενοί γε τὰς αἰτίας καθορᾶν*" (Aristotle's *On the Parts of Animals/ Περί ζῴων μορίων*, book I, chapter 5). Aristotle recognized that to develop an adequate "feel" for nature meant probing deeply into minute empirical details, relying on experience or observation alone. A true understanding of the natural history of animals involved the knowledge of their internal structure, and he himself had dissected and examined many kinds of animal embryos, mammalian and cold-blooded.

Aristotle was an inveterate collector and classifier, the master scientist of his time whose influence on biology is felt even today. Haeckel (1903) wrote that Aristotle is the mighty naturalist of old, whom a grateful aftertime honors as the Father of Natural History, and that "Aristotle's classic *History of Animals*, in addition to the minor writing on special details, his comparative anatomical work on animal parts, and his ontogenetic work on their reproduction and development, gives us a conception of the animal world so universal, so large, that it is not difficult to conceive why his work has for more than fifteen hundred years enjoyed, as a textbook of zoology, an authority altogether without parallel".

Embryology proper really began with Aristotle, who 'discovered' in the chick embryo the ideal object for embryological studies (Hamburger and Hamilton, 1951; Gilbert, 2010). Aristotle opened fowl's eggs and examined the developing chick within. In his treatise *History of Animals/ Περί ζῴων ἱστορίαι*, Aristotle found and described the "primordial heart/ *καὶ ὅσον στιγμὴ αἱματίνη ἐν τῷ λευκῷ ἡ καρδία"* that "leaps and moves/ *πηδᾷ καὶ κινεῖται*" at the end of the "the third day/ *τριῶν ἡμερῶν καὶ νυκτῶν παρελθουσῶν*" of chick incubation; Aristotle continues his description saying that "two twined veins containing blood/ *δύο πόροι φλεβικοὶ ἔναιμοι ἑλισσόμενοι* bring blood to each of the two chambers… - *Ταῖς μὲν οὖν ἀλεκτορίσι τριῶν ἡμερῶν καὶ νυκτῶν παρελθουσῶν … καὶ ὅσον στιγμὴ αἱματίνη ἐν τῷ λευκῷ ἡ καρδία. Τοῦτο δὲ τὸ σημεῖον πηδᾷ καὶ κινεῖται ὥσπερ ἔμψυχον, καὶ ἀπ' αὐτοῦ δύο πόροι φλεβικοὶ ἔναιμοι ἑλισσόμενοι φέρουσιν αὐξανομένου εἰς ἑκάτερον τῶν χιτώνων τῶν περιεχόντων….* (Aristotle's *History of Animals/ Περί ζῴων ἱστορίαι,* book 6, part 3). Aristotle considered the starting point of life, the embryonic heart.

Aristotle's treatise *On the Generation of Animals/ Περί ζῴων γενέσεως* is the first great compendium of embryology ever written

(Needham, 1959). The treatise is divided into five books and contains extensive embryological material, and a huge amount of comparative anatomy/general biology analysis of animal parts. It is of considerable interest in relation to the variety, structure, behavior, classification of animals, and marks the landmark/origin/starting point of the science of taxonomy. The treatise deals with the development of the embryo and foetal nutrition, the nature of maleness and femaleness, the forms of penis, testes and uterus, and the way in which different animals copulate. It speaks of viviparity and oviparity, mentions viviparous fishes (the selachians), and the relationship between the urinary and the genital systems. The text addresses the nature and origin of semen, refuting the widely held views that semen originates from all the parts of the body, and that it is an unnatural element - a growth, a mere nutriment or a waste product. Aristotle argues that semen is a true secretion and why fertilization by the male is necessary, and puts forward the theory that semen supplies the "form" to the embryo, and whatever the female produces supplies the matter fit for shaping.

Needham (1959) recognizes that book II of the treatise *On the Generation of Animals/ Περί ζῴων γενέσεως* is by far "the most important in the history of embryology". The book opens with "a magnificent chapter" on the embryological classification of animals in a hierarchy from lowest to highest, showing Aristotle, the systematist/taxonomist, at his best. As Waddington (1962) points out, referring to Aristotle's classificatory system, "many problems of the natural philosophy of evolution had been formulated ages before Darwin wrote"; evidently, Aristotle classified living organisms into a hierarchical system in terms of degrees of perfection and not in terms of historical succession.

Aristotle was an inveterate collector and classifier. One of the reasons why Aristotle is known as 'the philosopher of common sense', 'the worldly philosopher', is that his main concern was to classify the types of things in the material world/"the ultimate furniture of the world", under basic headings and categories, a powerful human strategy to organize knowledge for comprehension and action. This was part of Aristotle's attempt to create a theory of reality, one strongly opposed to Plato's otherworldly doctrine of ideal '*forms*'. Aristotle was the first to codify laws of pure logic, and so he founded what is today known as '*proof theory*' in mathematics. In the great era of Scholastic philosophy, which lasted for three centuries, up to the Renaissance, Aristotle was referred to simply as "the Philosopher".

Book II of the treatise *On the Generation of Animals* also includes "a brilliant discussion" of *epigenesis* or *preformation*, an antithesis which Aristotle was the first to perceive, and the subsequent history of which is almost synonymous with the history of embryology (Needham, 1959). Aristotle asked whether all the structures of the embryo form in succession, or are preformed and appear via simple unfolding of pre-existent structures. Aristotle favored the successive formation of new structures and forms during development, and coined the term '*ἐπιγένεσις/ epigenesis*'; he rejected *preformation* on philosophical and experimental grounds, thus defining the *epigenesist/preformation* controversy. This question was to dominate the field and was not settled until the nineteenth century. Chapter 3 discusses the degree of aliveness, the series of forms adopted by the embryo throughout its developmental stages. Needham (1959) observes that this chapter returns to a high level of speculation and thought and that "Aristotle does not here anticipate the form of the *recapitulation theory*, but he certainly suggests the essence of it in perfectly clear terms". This chapter is also of interest in terms of the history of *theological embryology*, since its description of the entry of the various souls into the embryo subsequently became the basis for the legal rulings concerning abortion.

Aristotle was the first to combine wet, field biology with bold cosmological thinking. He spoke of the '*ψυχή/ psyche*', or life force, an immaterial principle that animates matter, and nature as ordained by a supreme intelligence with a purpose in mind. Whence the doctrine of '*teleology*', his conception of a *final cause*- a design towards which events in this world are tending- the view that existing things come into being in relation to a formulated *design*, but the design is placed, as it were, after rather than before. The entire Aristotelian universe was subordinated to the same principles, including the idea of purpose

It was Aristotle who was the first curator of the animal world, and this comparative outlook colors his embryology. The depth of Aristotle's insight into the generation of animals has not been surpassed by any subsequent embryologist, and considering the breadth of his other interests, cannot have been equaled (Needham, 1959). According to Needham, what is most extraordinary is that building on nothing but the scraps of speculation offered by Ionian philosophers, and the exiguous data of the Hippocratic school, Aristotle produced a text-book of embryology similar in essence to Graham Kerr's *Textbook of Embryology with the Exception of Mammals* (1919) or Balfour's *The Elements of Embryology* (1874, with Michael Foster).

Aristotle is believed to have written some 170 works, but fewer than fifty have survived. His various treatises address many branches of biology. Aristotle's main book on embryology was "*On the Generation of Animals/ Περί ζῴων γενέσεως*". Data on embryology also appear in the treatises: "*The History of Animals/ Περί ζῴων ἱστορίαι*", "*On the Parts of Animals/ Περί ζῴων μορίων*", "*On the Progression of Animals/ Περὶ ζῴων πορείας*", "*On the Motion of Animals/ Περὶ ζῴων κινήσεως*", "*On Respiration/ Περί ἀναπνοῆς*".

Aristotle was born in 384 BC in Macedonia, the northern province of Greece. At the age of seventeen, he left his provincial birthplace, Stagira, for Athens, the cultural capital of Greece, and remained there for twenty years as a pupil of Plato. After Plato's death (347 BC), he left Athens to take up residence at Assos in Ionia, and later at Mytilene on the island of Lesbos. In 342 BC, Aristotle returned to Macedonia to begin tutoring King Philip II's son, Alexander the Great, and remained there until Alexander acceded to the throne of Macedonia (336 BC) - the future master of the known world at the feet of the "master of those who know". Aristotle returned to Athens, where he set up his own school, the Lyceum, alongside the Platonic Academy, which was in the hands of Platonists. Aristotle retired to Chalcis on the island of Euboea, where he died in 322 BC.

Ancient science, particularly biology, did not come to a standstill with Aristotle's death. In Athens, there were philosophers who succeeded him, but their preoccupations were different, apart from Theophrastus (370-263 BC), who continued Aristotle's work on the science of botany. However, after Alexander the Great during the Hellenistic times, the center of Greek intellectual life was Alexandria, where a famous library was established, containing the treasure of acquired wisdom. Progress was to continue along a truly scientific path for some generations in the domain of medicine. Alexandrian doctors (e.g. Herophilus, Erasistratus) dissected the human body and considerable progress was made in anatomy, especially that of the nervous and circulatory systems. In the Ionian Greek city of Pergamum, a city rivaling Alexandria, Galen (130-200 AD) dissected numerous mammals (e.g. elephants, monkeys), and came to be known as the creator of experimental physiology. His works formed a vast medical encyclopedia that remained the basic medical reference work until the Renaissance. Galen's work represents the apogee of ancient biology.

The gradual decay of the Greco-Roman world soon dry up the spring of progress, and ancient science collapsed when the Empire experienced tumultuous events and fell to barbarian hordes. Much of the learning accumulated during the height of the Greek and Roman civilizations was lost as Europe stumbled into the Middle Ages. Haeckel (1903) recognizes that "until the sixteenth century, no inquirer emerged who would undertake to continue the vast work that Aristotle had begun, or even to develop in detail any special parts of the plan of knowledge that he had sketched; men were rather content with transcribing, translating, and annotating the works of Aristotle".

The forward march of progress was not to be resumed until the sixteenth century, when the Renaissance resurrected the thinking of classical antiquity. Natural History begun to awaken from its slumber with the work of the great comparative naturalists-Linnaeus, Adamson, Buffon,Cuvier, Geoffroy Saint-Hilaire and so many others during the 17th century and the Age of Enlightenment. Carl Linnaeus' epoch-making work, the binary nomenclature of animals and plants based on the distinction between the species and the genus, was brought on the scene in 1735. 'Natural Philosophy' gave way to 'science' in 1833, when the term began to be used in its modern sense.

The Renaissance, the Age of Enlightenment and the Industrial Revolution sidestepped Greece that was under Ottoman occupation. The country was liberated from the Ottomans in 1821. In subsequent decades, Greece suffered many vicissitudes, rocked by regional wars, economic and social upheaval, two World Wars, and a brutal civil war (1946-1949) that devastated the country.

A new era in biological sciences began in the late 1970s. With the advent of molecular biology, the introduction of molecular techniques now being applied to the classical problems of embryonic development transformed classical embryology; a combination of genetics, classical embryology, and molecular biology has provided tools for identifying key developmental programs.

Embryology sprouted again in 1970s Greece. Returning Greek academics, assumed posts in Universities-Research Institutes and revived previously dormant research efforts in the country. Among these academics was Fotis Kafatos (1940-2017, http://www.nasonline.org/publications/biographical-memoirs/memoir-pdfs/kafatos-fotis.pdf), an outstanding developmental biologist. It was in 1972, while continuing his research and teaching at Harvard University, that Kafatos was invited to assume the position of Professor of Biology at the University of Athens. Fotis remained in Athens for about 10 years, and can be credited as the scientist who introduced modern molecular biology to Greece. Developmental biology began to flourish in the 1980s and is now a vibrant interdisciplinary field in our Universities-Research Institutes.

Over the last four decades, molecular biology has gradually overturned the entire structure of the biological sciences. Biology, initially a science of inventory and classification in the hands of the 19th-century comparative naturalists, has become a science of codes and regulatory circuits. With the new techniques of altering the genetic constitution of organisms - ethical issues aside - understanding how genes control development can provide us with a better understanding of the living world and of what we call 'human nature', bringing metaphysical speculations back into play. Aristotle believed that it is wonder/innate curiosity that motivates science; *not rewards in money and honor/ 'καὶ οὐ χρήσεώς τινος ἕνεκεν'*, but the excitement of knowledge, the discovery of new truths.

Aristotle was a this-worldly philosopher whose logic increased knowledge of the natural universe, of things as they really exist, virtually from scratch. If some of Aristotle's scientific conclusions are quite incorrect, far removed/ distant from the present day views, it is important to realize that each discovery is better assessed when viewed in its contemporary setting; a mistake more forgivable in Aristotle's day, in an era without microscopes, without telescopes, without a fundamental grasp of scientific concepts. Aristotle did not hesitate to use hypotheses and speculation in support of logic and basic principles, with no earlier work to quote and dependent on tentative research. He informed his readers know that if they had an inkling of how difficult the task had been, they would refrain from grumbling and complaining about the results, and that:

"If, therefore, on consideration, it appears to you that, in view of such original conditions, our system is adequate when compared with the other methods which have been built up in the course of tradition, then the only thing which would remain for all of you, or those who follow our instruction, is that you should pardon the lack of completeness of our system and be heartily grateful for our discoveries"

Εἰ δὲ φαίνεται θεασαμένοις ὑμῖν, ὡς ἐκ τοιούτων ἐξ ἀρχῆς ὑπαρχόντων, ἔχειν ἡ μέθοδος ἱκανῶς παρὰ τὰς ἄλλας πραγματείας τὰς ἐκ παραδόσεως ηὐξημένας, λοιπὸν ἂν εἴη πάντων ὑμῶν [ἢ] τῶν ἠκροαμένων ἔργον τοῖς μὲν παραλελειμμένοις τῆς μεθόδου συγγνώμην τοῖς δ᾽ εὑρημένοις πολλὴν ἔχειν χάριν (Αριστοτέλης, Σοφιστικοὶ Ἔλεγχοι/ Aristotle, *On Sophistical Refutation,* 184b Forster 1955)

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