

THE DISCOVERY OF DNA AS A CONTRIBUTION TO UNDERSTAND THE ARISTOTELIAN THEORY OF GENERATION

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My contribution to this conference is quite unusual, because, unlike almost all the other members of the illustrious Academy gathered here, I'm not a scientist, but a philosopher, or rather a historian of philosophy. Consequently, the work I have done in over fifty years of research has not contributed at all to the development of twentieth century science, while the opposite is true, i.e. the scientific progress of the twentieth century has helped me solve some problems of a philosophical nature that I had come across in the course of my historical research. The main object of my research is the thought of Aristotle, which I have studied in its historical context and philosophical value. I have also pieced together its fate over the centuries and tried to highlight its present-day importance. At first I concentrated on the metaphysics of Aristotle, which I believed to be the most valuable aspect of his thought, because of its historically proven ability to provide a solid philosophical basis for a religious – not only Christian – conception of reality. Then, in the wake of the revival of practical philosophy that occurred in the second half of the twentieth century by philosophers such as Gadamer and Ritter in Europe, MacIntyre and Nussbaum in the U.S., and many others, I discovered the value of Aristotle's ethics and politics, which still seem feasible today, even independently of a religious vision of reality. More recently, that is in the last ten years, I have turned my attention to the study of Aristotle's biology, particularly his theory of the generation of animals, and this is where I have encountered some major problems.

As it is well known, in the *De generatione animalium*, the treaty expressly devoted to the breeding of animals, Aristotle explains this phenomenon by means of his theory of the four types of cause: material, formal, efficient and final. He asserts that, in animals that reproduce by mating, the female provides the matter, while the male provides the 'principle of movement and generation', i.e. the moving or efficient cause, which, as we shall see, is also form. Indeed, for Aristotle, generating means giving form to matter. More precisely, the 'principle of generation', provided by the male, according to Aristotle is the 'semen', while the matter, provided by the female, is the menses. Obviously Aristotle did not have a microscope, which would have allowed him to see

the eggs, but simply noted that menstruation ceases in the pregnant female, deducing that menstrual blood was used to form the 'first mixture of male and female', which he calls 'the fruit of conception'. The male seed does not become part of the fruit of conception, that is, it does not in any way constitute its matter, which is provided entirely by the female, but it transmits impulses or movements to it, which give it form.

At this point we must remember that, for Aristotle, the form of the living beings is the soul. Indeed, for Aristotle, the soul is no longer a demon, as it was in the Orphic-Pythagorean tradition, i.e. an intermediate being between man and god, which pre-exists the body, embodies in the latter at birth, and exits it at the time of his death, to transmigrate into another body. Nor is it a substance similar to ideas, temporarily united to a body and destined to survive it, as it was for Plato. According to the famous definition of *De anima*, the soul for Aristotle is 'the form of a natural body that has life in potency', namely the form not of an artificial body but, precisely, of a natural one, which, thanks to it, is capable of living. It is therefore the principle of life, the very capability to live.

However, given that by life we mean many things, first of all self-nutrition and growth, which are proper to plants, then movement and feeling, which are proper to animals, and finally thought and will, which are peculiar to human beings, there will be three kinds of souls: the vegetative soul, the ability to absorb nutrient and grow, which belongs to plants, the sensitive soul, the ability to move and feel, which belongs to animals, and the intellective soul, the ability to think and want, proper to human beings. All living beings, therefore, have souls: plants, animals and humans. But note the following: each genus of living beings has only one kind of soul, plants only the vegetative soul, animals only the sensitive soul and humans only the intellective soul. Indeed, as Aristotle explains, the types of soul are like geometrical figures, where the following contains in potency the previous one, for example the quadrangle contains in potency the triangle. Thus the sensitive soul contains in potency the vegetative soul and the intellective soul contains in potency both the vegetative and the sensitive soul. This means that the ability to perform superior activities, such as thinking and wanting, contains in itself the ability to perform lesser activities, such as eating, growing, moving and perceiving. The human soul, therefore, is the effective presence of all these capabilities in a single body, i.e. the ability to live in the fullest sense. The soul is generally the formal cause, that is, the cause of being, i.e. of living, because, for living things, being is living, and it is also the final cause, that is, the goal, because, according to Aristotle, the goal of living things is experiencing life in all its dimensions, namely carrying out all the functions of

which living things are capable, from the lowest, such as absorbing nutrients, to the highest, such as thinking.

A first problem of this theory arises when Aristotle observes that the various parts of the new body, i.e. heart, lung, liver, eye, do not form together at the same time, but are formed consecutively, 'in the same way as the knitting of a net'. It is well known that Aristotle observed the gradual formation of a chick by examining the development of the embryo contained in the hen's egg. So he can say that, through observation, at a given moment some parts of the embryo are already there and others not yet, and not because they remain hidden because of their smallness: indeed, the lung, which is larger than the heart, appears later. Thus the parts of the embryo are formed one after the other, not because one generates the other, but because the essential form of each part is contained in potency in the part that exists already in agency. According to Aristotle, the body part that is formed first is the heart, because it is the cause of nourishment and thus of the growth of all the other parts. After the heart comes the brain, then the internal organs and finally the external ones. The generation of the different parts is described as a series of consecutive actions, which automatically follow one another according to a sort of programme that is contained in the semen, or in the fruit of conception.

The form is called also *logos*, i.e. the ratio between the various components of each tissue or of each organ, and which causes a tissue or an organ to be what it is. But *logos* also means 'notion' or 'discourse', that is, 'formula'; therefore form is a notion, or a speech, or a formula: today we would call it an 'information'. While the matter of the tissues and organs that are formed in generation comes from heat and cold, that is, from the properties of matter from which they derive, provided by the female, their form derives from the form contained in actuality in the male parent and transmitted through the motion produced by the sperm. How is such a process possible? This was the first problem that Aristotle's theory of generation posed to me.

Another problem that arises further is what kind of soul is transmitted in the generation of animals. Indeed from certain passages of *De generatione animalium* it seems that the vegetative soul is present first of all in the animal embryo, by which it lives the life of a plant, because the first tasks that the embryo carries out consist essentially in its growth, which is consequent to nourishment; then the formation of the sensitive soul in it, through which the embryo lives the life of an animal; and finally, in the case of a human embryo, it seems that the intellectualive soul is formed in it, after the entry of the intellect in it, which apparently comes 'from outside'. This interpretation was enormously successful both in late antiquity, and in the Middle Ages, that is,

in ages dominated by a creationist vision, whereby the human soul did not come from the parents, but appeared to be created directly by God. This however seems incompatible with the doctrine contained in *De anima*, according to which the animal only has one soul, the sensitive soul, and consequently it must be assumed that man too possesses a single soul, the intellective one. The late ancient and medieval interpreters therefore had to assume that real substantive changes were produced in the development of the embryo, i.e. that the embryo was initially a plant, equipped with the vegetative soul only, and then turned into an animal, equipped with the sensitive soul only, and finally became a man, equipped with the intellective soul only. But there is no trace of these substantial mutations in the Aristotelian doctrine of generation, rather generation appears as an ongoing process, driven by a single form, which remains the same.

The solution of both problems came to me after reading of an article by a biologist about the discovery of DNA. As you know, DNA was discovered during the 1950s by James Watson and Francis Crick who, also on the basis of the research carried out by other scientists, were able to describe the structure of deoxyribonucleic acid, i.e. of one of the two acids which form the nucleus of cells. Watson and Crick found that DNA molecules consist of two chains of nucleotides in the shape of helixes intertwined with each other. At the time of cell division the two helixes separate and on each of them another is built, in order to reconstitute the original structure. Thus, DNA can reproduce without changing its structure, except for occasional errors or mutations. For this discovery, Watson and Crick obtained the 1962 Nobel Prize for Medicine.

The philosophical significance of this discovery for the interpretation of Aristotle was brought to light some years later by the physicist and biologist Max Delbrück (1906-1981), who in turn won the Nobel Prize for Medicine in 1969 for his research on bacteriophage viruses, in an article dedicated to Aristotle with the ironic title, *Aristotle-totle-totle*.¹ In it Delbrück argued that, if it were possible to give a Nobel Prize in memory of someone, it should be given to Aristotle for the discovery of the principle implied in DNA. He then quoted the passages from the biological works, where Aristotle argues that the male parent contributes to generation by providing the principle of motion through his semen, giving rise to form, and the female parent provides matter, with her menses, translating phrases like ‘principle of motion’ with

¹ M. Delbrück, *Aristotle-totle-totle*, in J. Monod and E. Borek, *Of Microbes and Life*, New York 1971, pp. 50-55.

‘plan of the development’, and ‘form and essence’ with ‘program of development’. He wrote:

Put into modern language, what all of these quotations say is this: The form principle is the information which is stored in the semen. After fertilization it is read out in a preprogrammed way; the readout alters the matter upon which it acts, but it does not alter the stored information, which is not, properly speaking, part of the finished product. In other words, if that committee in Stockholm, which has the unenviable task each year of pointing out the most creative scientists, had the liberty of giving awards posthumously, I think they should consider Aristotle for the discovery of the principle implied in DNA.

Meanwhile, a similar conclusion had been reached by Marjorie Grene, a scholar of Aristotle and biology expert, who argued that the Aristotelian notion of ‘form’ operates in many ways like the concept of organization (or information) in modern biology, which is an example of the DNA sequence.² But Delbrück’s thesis was authoritatively confirmed by the great biologist and historian of biology, Ernst Mayr, who wrote:

Some of today’s authors have had the courage to use modern terms in exposing Aristotelian thought: the words that Aristotle would probably have used had he lived today. I refer to the use of the term ‘genetic program’ by Delbrück to clarify the intentions with which Aristotle used *eidōs* in the description of the development of the individual’. And ‘it has been said, not without justification, that the Aristotelian separation of a formative principle (*eidōs*) from the matter on which it acts, does not deviate much from the modern concept according to which the genetic program controls the modelling of the phenotype (Delbrück, 1971)’.³

More recently, as a partial criticism of Delbrück and Mayr, it has been stated that, according to modern genetics, the function of DNA is limited by the environment of the cell with which it interacts, so that rather than a ‘genetic program’ guiding development, we should speak of an ‘epigenetic program’; however, it was recognized at the same time that this corresponds in a way to what Aristotle said in his concept of ‘potential form’, which interacts with matter, therefore the Aristotelian theory must be interpreted

² M. Grene, *Aristotle and Modern Biology*, Journal of the History of Ideas, 33, 1972, pp. 395–424.

³ E. Mayr, *The Growth of Biological Thought*, Cambridge Mass. 1982 (It. transl. *Storia del pensiero biologico*, Torino 1990, p. 13).

not as a 'genetic vitality' based only on the notion of 'entelechy', but implies a mechanism, as shown by Aristotle's example of the automated puppets.⁴

If we now return to the problem of human development, we must recognize that, according to today's genetics, what distinguishes the human genome from that of other living species, although in a minimal (but important) percentage, is the 'sequence' of the various components that make up genes, i.e. the DNA segments of which the chromosomes contained in the cell nucleus are made. Well, the components of DNA, which are equivalent to what Aristotle called 'matter', are the same for all living beings, while the 'sequence', i.e. the order in which they are arranged, is different. However this order is equivalent to what Aristotle called 'form' and all the characteristics that develop in the living being depend on this order, just as for Aristotle all the characteristics of plants and animals depend on their form, that is, on their 'soul'.

In conclusion, the discovery of DNA permits to understand the Aristotelian theory of generation in a new way, following which it emerges that, unlike the traditional interpretation, in *De generatione animalium* just as in *De Anima* Aristotle admits one soul, which in the case of animals is the sensitive soul, containing in potency the vegetative one, in the sense that it implements first of all the functions proper to plants and then those proper to animals, and in the case of human beings it is the intellective soul, which implements first the functions of plants, then those of animals and finally those that are proper to human beings. The sentence according to which the intellect comes 'from outside' does not express Aristotle's thought, but expresses what, according to Aristotle, should have been the opinion of the Platonists, that is, of the supporters of the soul pre-existing the body, had they been able to take into account the way in which generation actually takes place. The only part of the soul that, from the point of view of pre-existence, could pre-exist the body, appears to be the intellect, thanks to the immateriality of its functions. But for Aristotle the intellective soul, thus including the intellect, does not pre-exist the body, but is generated in the embryo through the motive action exerted by the father through the sperm, an action which transmits to the embryo the faculties proper to the form possessed by the father, which is a distinctly human form. Therefore the soul generated in the embryo, if it is generated by human sperm, already contains in potency even the intellect, because it is a specifically human soul.

⁴ T. Vinci and J.S. Robert, *Aristotle and Modern Genetics*, *Journal of the History of Ideas*, 66, 2005, pp. 201-221.