

# Science education: from Plato to genomics

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## *Elementary knowledge*

For those who happen to visit Athens in the future, I warmly recommend paying a visit to the remnants of Plato's Academy, although they are not that easy to find. From the ancient agora you can walk to the *Kerameikos* area, the famous potter's quarter, North West from the city centre, which has been excavated. Here, a road leading up to the academy passed the northern wall of the ancient city. The academy was actually a park, an olive grove, with temples, monuments and sport facilities. One of these monuments was a statue of the hero Academus, from which the Park derived its name. It was here that Plato decided to become a teacher of gymnastics of the mind for young athletes from wealthy families visiting the sport facilities and spending their leisure time there. The teaching Plato offered basically consisted of logic and mathematics (Jaeger 1959, Chermis 1980, Fowler 1990).

The academy is still a park nowadays, hidden in an unimpressive suburb, where remnants of ancient buildings have been laid bare. On a warm day, a visitor can repose there for a while in order to reflect on what went on at this ancient educational site, this archetype of academic learning, twenty five centuries ago, and what this park must have looked like in Plato's time.

What did Plato teach? The answer to this question can be extracted from his writings. Plato's basic teaching consisted in acquainting his students with the elements, - **στοιχεία** in Greek -, the elements of scientific thought. The term "elements" could have a variety of meanings in ancient Greek. It could refer to material elements, the elementary particles that made up the four elements, but it could also refer to letters of the alphabet or to elementary knowledge. Thus, **στοιχεία** was the title of the famous handbook of Greek mathematics compiled by Euclides. A proper translation of **στοιχεία** would be something like basic units or elementary building blocks.

In Pompeii a mosaic has been recovered (now at the Museum of Naples) on which Plato can be seen amidst his colleagues or pupils. They are studying the characteristics of a sphere, or globe, one of the most elementary geometrical structures, conveying a three-dimensional ideal of purity and wholeness. The sphere or globe acted as a kind of model for academic thought experiments. The universe at large was regarded as a perfect sphere, the form that might encompassing everything. Studying the properties of a sphere was a way of discerning the basic structure of the universe. For Plato, the universe displayed a perfect geometrical structure: it consisted of a series of perfect concentric spheres, with Plato's garden at the centre. Therefore, geometry was the basic science that opened up the basic framework of nature to human thought. Geometry provided the elements from which the universe had been built.

It has been said that, above the entrance to Plato's educational garden, a slogan was written: *Let no one untrained in geometry enter here*, the philosophical version of the inscription that was so often placed above the doors of sacred places in ancient Greece: *Let no unjust person enter here*.

Interestingly, this same phrase, *Let no one untrained in geometry enter here*, made its reappearance two millennia later, namely on the opening page of a famous book, a science classic, written by Nicholas Copernicus and published in Latin in 1543, entitled *De revolutionibus orbium caelestium* ("On the revolutions of the heavenly spheres"). Moreover, in the opening lines of *Chapter 1*, the following is stated: "First of all, we

must note that the universe is spherical. The reason is either that, of all forms, the sphere is the most perfect, needing no joint and being a complete whole; or that it is the most capacious of figures, best suited to enclose and retain all things ... Hence no one will question the attribution of this form to the divine bodies (1543/1992, p. 8).

This sentence is, first of all, a beautiful exemplification of the Platonic type of logic, the academic style of thinking, for Copernicus was basically still an academic thinker. The universe is essentially perfect, therefore, it must be a sphere. This specimen of ancient logic demonstrates why geometry was regarded as elementary knowledge. By studying geometry, we acquire the basic tools and insights necessary for understanding and exploring the basic structures of nature as such. For Plato, scientific research was not at all an empirical endeavour. Rather it was a matter of speculation and deduction. With the help of geometrical building blocks, such as spheres of various sizes, the universe could be reconstructed.

Both in the garden and in the book, the phrase *Let no one untrained in geometry enter here* served a specific function. As a gesture of separation, it introduced a demarcation between the educated and the non-educated. Whereas his teacher Socrates loved to dwell in crowded places in the city centre, in order to enjoy his famous deliberations with people of all walks of life, Plato insisted on retreating behind the walls of his garden, where esoteric discussions took place amidst a selected company of academic peers, - all of them thoroughly trained in Greek mathematics. A similar gesture of exclusion or demarcation was placed at the entrance of Copernicus' book, in accordance with the famous adagium *Mathemata mathematicis scribuntur*, when writing about mathematical subjects, write for mathematicians. This is also the reason why Copernicus' book never caused a "Copernican revolution", at least not among the public at large. His book was only accessible for specialists, only readable for those who were initiated in the elements of science. Thus, according to the Platonic view, education was crucial.

*Plato's Republic: the archetype of science education*

The Platonic or “academic” view on knowledge, and on the relationship between the untutored masses and the educated few, also entailed an outspoken view on education. The community gathering in the garden, was the prototype of the community of philosophical guardians that, to Plato’s mind, were to govern the ideal state. His view is articulated by Plato in his famous simile of the cave, that deserves to be cited here in full, because it constitutes the archetype as it were of science education:

*Picture men dwelling in a sort of subterranean cavern with a long entrance open to the light on its entire width. Conceive them as having their legs and necks fettered from childhood, so that they remain in the same spot, able to look forward only, and prevented by the fetters from turning their heads. Picture further the light from a fire burning higher up and at a distance behind them, and between the fire and the prisoners and above them a road along which a low wall has been built, as the exhibitors of puppet-shows have partitions before the men themselves, above which they show their puppets. See also, then, men carrying past the wall implements of all kinds that rise above the wall, and human images and shapes of animals as well, wrought in stone and wood and every material, some of these bearers presumably speaking and others silent. Do you think that these men would have seen anything of themselves or of one another except the shadows cast from the fire? (1935/2000, 514A-515B).*

The inhabitants are not very eager to be released from their chains. Those who manage to escape, however, will come to see things as they truly are.

This story, like all Platonic stories attributed to Socrates, is a strange one indeed, as his interlocutor already observed. The reader is confronted with a bizarre scene, an uncanny classroom setting, with pupils tightly strapped to their benches. Instead of looking at a blackboard, however, they are depicted as being immersed in viewing a kind of projection, produced with the help of rather primitive and childish contrivances. They seem to dwell in a Flintstone-like, prehistoric cinema.

From a political perspective, we may see the inhabitants of the cave as a troupe of slaves, and education is presented as a kind of liberation. From a psychoanalytic perspective, the inhabitants seem to be finding themselves *in utero*, unable and unwilling to release themselves from their umbilical cords, and education is presented as the experience of being born, - as the trauma of birth. From a media studies perspective, the scene strikes us as surprisingly modern: the inhabitants constitute a kind of public, dominated by mass media, no longer able to think for themselves.

In this primal scene, the term education is to be taken literally, retaining its original Latin meaning: *educere*. Those who are liberated from their chains are “led outside”. They leave the *camera obscura* of an uneducated, dream-like existence in order to enter and climb upwards towards the light of reason. We do not do this on our own initiative. Rather, we like to stay in the dark. We have to be forced to move in the other direction.

This narrative can also be seen as summarizing the intellectual history of mankind, as a story about anthropogenesis, the coming into being of human beings, and of rational thinking. As Carl Gustav Jung has indicated in a famous passage on two styles of thinking (1911/1912/2001), mankind originally tended to think in images, connected with one another through networks of associations. Gradually, in the course of history, imaginary thinking came to be replaced by a new and artificial style of thinking, namely formal, discursive thinking or “thinking in words”, connected with one another through elementary logical operations. Human thinking became disciplined as it were, and Plato’s academy constituted an important milestone in this collective educational journey which is still unfinished, as the human mind is, to a certain extent at least, still captured by images. The human mind uses both imaginary and discursive forms of thinking, and education basically strives to reinforce the discursive dimension of human thought. Education as a reformation of thought, making the human mind more autonomous. It is directed towards empowerment. Through education, individuals become less dependent on “images” (as was the case in Plato’s cave). They become able to use logical reasoning consistently, both in order to think rationally themselves, but also in order to critically

assess the arguments of others. Eventually, the objective of a scientific education is to replace images by the basic units of scientific thinking: concepts, numbers, symbols and so on.

### *Elementary genomics*

Similar to the inscription on the wall of Plato's garden, the term "elements" – **στοιχεία** – likewise displays the tendency to resurge at critical moments in science history. I began this paper at the beginning, with the first revolution in science, namely the emergence of ancient Greek (Euclidian) mathematics. I will now take a leap to the other end of history, to one of the most recent revolutions in the history of scientific research, namely the emergence of genetics (1900) and genomics (2000).

In 1843, after years of hardship and poverty, Johann Mendel, the son of a poor farmer, was admitted as a novice to the Augustinian monastery at Brünn (now Brno), at the age of twenty-one. Four years later Johann, who had changed his name into Gregor, became a priest (Orel 1996). His priesthood soon ended in a debacle, however. Caring for the ill and dying was not his type of job, and as Mendel was a delicate and sensitive person, the failure resulted in a severe psychic and physical crisis. When many weeks later young Gregor finally felt secure enough again to leave his bedroom, his considerate abbot decided that, in view of his interest in the natural sciences, he should become a science teacher instead. On two occasions, namely in 1850 and in 1856, he travelled all the way to the University of Vienna for an oral examination that was supposed to bring him his teaching certificate as well as a permanent appointment. Yet, on both occasions he failed, and on both occasions he fell seriously ill. After the first failure, the considerate abbot made it possible for him to become a student at the University of Vienna (1851-1853), where he received a thorough training in physics (with Doppler), mathematics (with Ettinghausen) and botany (with Unger) and acquainted himself with the elementary logic of experimental research. After his second failure, the abbot permitted him to begin his experiments with peas in the garden of the monastery.

What did Mendel do? After removing the stamen from the plant, a kind of botanical castration, he began to systematically and painstakingly fertilize a large number of pea plants with a small brush. This allowed him to assume control over the reproduction process of his plants. Thus, the garden pea became the model organism of his famous experiments. Mendel was interested in the manner in which hereditary qualities are passed over from one generation to the next. In his famous paper he explains that qualities of pea plants, such as the colour of the flowers (red or white), or the colour of the peas the plant produced (yellow or green), are determined by what he refers to as “elements”. Mendel (1866/1913) did not use the term “gene” yet, and also the term “genetics” still had to be invented, but apparently he was thinking of basic building blocks or causal units that expressed themselves in the characteristics of the plant. In order to refer to them, Mendel used letters from the alphabet, - **στοιχεία** once again -, a capital letter if the element was considered “dominant” (for example: A) and a small letter if the element was recessive (for example: a). Suppose the causal unit connected with red flowers is dominant and the causal unit connected with white flowers is recessive. In that case, the transfer of “elements” from one generation to the next complies with the following equation, coined by Mendel:

$$(A + a) (A + a) = A + 2Aa + a$$

We may see this equation as the first important equation of contemporary biology, comparable in importance to the primal equation of Euclidian geometry, the famous theorem of Pythagoras,  $a^2 + b^2 = c^2$ . Mendel’s publication, and the rediscovery of it in the Spring of 1900, constitute the first two highlights in the history and prehistory of genomics.

A third highlight was the discovery of the structure of DNA, the stuff that genes are made of, by James Watson and Francis Crick in 1953. Once again, what they discovered were elements that come in pairs: the four nucleic acid bases A (Adenine), C (Cytosine), G (Guanine) and T (Thymine) that make up Deoxyribonucleic acid (DNA). Once again, these elements are referred to by letters from the alphabet, **στοιχεία**. Or rather we should

say that these four letters, signifying the four elements or building blocks of heredity, constitute an alphabet of their own, an alphabet in their own right.

On the basis of these four **στοιχεία**, from which genes are made, a peculiar type of book is written. These books are called genomes. The human genome has been regarded as our blueprint, a metaphor that is borrowed from the printing process and explicitly refers to characters, **στοιχεία**. The idea initially was that these **στοιχεία** that make up our DNA determine what we are. By learning to read (and perhaps even write) the language of A, C, G and T, we may come to understand the logic of life. These ideas flourished around 1990, when the Human Genome Project was officially launched. Yet, after the sequencing of the human genome was completed, things turned out to be less straightforward (Zwart 2007). The human genome is said to contain no more than 23,000 genes, which is something of a disappointment when compared to the number of genes contained by the genomes of the fruit fly (*Drosophila melanogaster*, ~14.000 genes), a nematode worm (*Caenorhabditis elegans*, ~19.000 genes) and a simple plant (*Arabidopsis thaliana*, ~25.000 genes). It is difficult to see how the complexities of human existence can be determined by our genes. Moreover, genomics researchers came to understand that the question whether and in what manner genes are allowed to express themselves is co-determined by a number of factors, by a variety of causal networks. The idea of a simple causal flow from gene to trait gave way to the logic of multi-factorial complexity. And epigenomics is the research field that studies how genetic factors are modified in the course of a lifetime. In other words, the causal flow is a dialogue. The language of DNA is a fairly complex one and the meaning of letters and words to a significant extent depend on context and environment. Rather than to a straightforward grammar, where meaning can be derived from the absence or presence of a single character, genomics should rather be compared to a nuanced and intricate philology. In short, there is more between our genome and our life than was initially expected.



*The στοιχεια of genomics education*

What does this imply for our view on education? This is also a fairly complex issue. Nonetheless, it is an issue worthwhile to explore.

Let me begin my noting that Plato's simile of the cave allows us to discern that, at a certain point in science history, something rather remarkable must have happened. A kind of dramatic reversal or revolution must have occurred. For if someone (a philosopher for instance) nowadays would try to describe (by way of assignment) the relationship between science and the outside world with the help of the image of a cave, he or she would most certainly be inclined to place the scientists *inside* the cave, rather than at the outside, in a sunlit garden, as Plato did. A research laboratory is a cave-like *camera obscura* where individuals find themselves strapped to their chairs, tied up with their research setting, looking at a computer screen, or any other type of screen, where a kind of projection is produced by intricate equipment. Only those that are properly educated, sufficiently familiarised with the elements of science, the elements of genetics for example, are allowed to enter the cave. Rather than at nature as it presents itself to us of its own accord, scientists analyze a highly artificial representation of nature. Usually, they will study a set of data listed on a computer screen. Thus, education no longer serves to escape from the cave. Rather, the reward for being educated is the dubious honour of becoming locked up or locked in.

And after spending years of research seated before this screen, as a modern version of the Platonic cave, the research will come to the conclusion that the pathway that leads from the *στοιχεια* of genetics to the complexities of human life is not a linear but rather a highly complex one. Thus, we might conclude by saying that genomics distances itself from the Platonic idea that the world can be understood on the basis of its building blocks and the elementary logical operations or causal relations that connected them. Although the elements (in the sense of elementary, handbook knowledge) of genetics is still a precondition no doubt to become involved in this type of research, - *Let no one untrained in the basic principles of genetics enter here* -, this type of education (basic genetics) is

far from sufficient to become an adequate genomics expert. Although knowledge of the basic grammar of a particular language, such as ancient Greek, is a precondition for becoming a philologist, the field of philosophy requires a series of additional skills, notably a profound knowledge of the history of the culture in which this language was written and spoken. Once we have entered the cave of contemporary genomics research, we will have to learn to think in terms of “systems” rather than “elements”. In contrast to a classical geneticist, a genomics expert should be a kind of philologist. As meaning is the outcome of an intricate interaction between grammar and cultural environment, so the complexities of human life must be seen as the emergent outcome of a complex interaction between genome, social environment and life style. Besides “hard skills”, such as a basic familiarity with the biochemistry of adenine, cytosine, guanine and thymine, this involves a series of “softer” skills as well. The distinction between hard and soft skills is similar to the one Pascal has made between *esprit de géométrie* and *esprit de finesse*. While the former is usually associated with the natural sciences, the latter is usually associated with the humanities. Besides knowledge of grammar, philology for instance calls for *esprit de finesse*, a kind of sensitivity to detail, an intellectual virtue beautifully captured by the German term *Einführung*. Like a philologist, contemporary genomics experts have to have a gift for language. They must be able to speak and understand a plethora of scientific languages as genomics is a converging, trans-disciplinary field. Besides being able to deliberate in an esoteric manner with the educated few, they also have to be able to communicate with broader audiences consisting of citizens, policy experts and professionals. Moreover, the technologies and dialects of genomics research are evolving at a tremendous pace. Thus, the language and grammar of genomics is in flux, and genomics experts have to be able and willing to re-educate themselves almost permanently. A plethora of scientific and academic debates is evolving simultaneously, and genomics experts must be able to follow and contribute to these various debates, they must develop a certain competency for simultaneous chess, playing a simul with a broad variety of partners and opponents. Genomics expert should not look at the world from inside their private case, as monads, but should rather be able and willing to migrate to newly emerging fields, as nomads.

This poses a challenge to (researchers in) science education in general, and to researchers in the didactics of biology in particular. How to educate the genomics experts of the future, as biological philologists, combining elementary knowledge concerning molecular biology with softer skills and *esprit de finesse*?

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