We begin by quoting an observation about Galilei, who many consider the first person who illustrated, with words and facts, what we today refer to as the *scientific method.*

> Galilei identified the invention of alphabetic writing as representative of a situation in which curiosity and the propensity to learn more meet a medium that allows us to satisfy them beyond any measure ..., which allows us to violate the barriers of space and time between men, to keep a huge mass of information but also to recombine it in ever new ways ...
>
> And here Galilei speaks as a man of that "Republic of Letters" [that some Italian and European humanists imagined since the fifteenth century] because he knows that this is the culture broth of modern science, if by the word "science" we mean not a set of techniques, but rather research that is exposed in every moment to the judgment of others [1].

Ignorance and curiosity

Why ?

What do Ulysses, Socrates, Christopher Columbus , Galileo have in common? What do the philosopher, the navigator, the scientist, and even a baby have in common? *Curiosity*.

One of the main drivers of scientific investigation is curiosity. Both the scientist and baby have in common the desire to discover and learn about the world, the desire to learn more.

Both "curious" and "curiosity" are believed to derive from the Latin word "cura", in the sense of concern or interest; but it is a curious coincidence that they look like the Latin "cur?", which means "why?" .

One does not always ask oneself, or did one ask oneself in the past, the why of things; we cite from [2]:

> If you read a mathematical text [...] from Pharaonic Egypt, you will find nothing in it that looks like a demonstration. You will find problems, an explanation of the solution method, and, in the end, a phrase like "if you do so, you will do well, otherwise it will be done wrong ". There is no need to explain why this should be done. Learners simply need to know what to do, they don't have to know why they have to do it. The method of transmission of knowledge was completely authoritarian, as was the political system and the transmission of technological and religious knowledge.

Ignoramus

One more quote [3]:

> Our ancestors have spent a lot of time trying to discover the rules that govern the natural world. But modern science differs from all previous traditions of knowledge in three fundamental ways:
>
> a. *The willingness to admit the ignorance.* Modern science is based on the Latin expression *ignoramus*, "we do not know". It assumes that we do not know everything. Even more critically, it accepts that the things we think we know can be proved false by learning other things that we do not yet know [...]
> b. *The centrality of observation and mathematics*. Having admitted ignorance, modern science aims to gain new knowledge. It does this by collecting observations and then using mathematical tools to link these observations into general theories [...]
> c. *The acquisition of new powers.* But this is another story we will take up later.

The scientific or experimental method

With Galileo Galilei the experimental scientific method was first introduced: synthesizing to the maximum, we can say that it is based on a first observation, followed by an experiment, developed in a controlled manner, so that we can reproduce the phenomenon we want to study. The experiment aims to validate or disprove the hypothesis that the scientist has formulated, a hypothesis that aims to explain the mechanisms underlying that particular phenomenon.

An experiment

In 1881, the French chemist Louis Pasteur performed a spectacular experiment, in front of an enthusiastic crowd, to demonstrate the effectiveness of vaccination of sheep and other animals in the prevention of *carbuncle*. It was only the final phase of an inductive process: the verification of a hypothesis which had arrived through observation and some preliminary experiments.

The hypothesis that *carbuncle* was a bacterial disease was opposed to the one that until then was more widespread and quoted, according to which animals became ill due to the exhalations of a generically unhealthy environment. [4]

The observations from which Pasteur started:

- the sheep became ill if they came into contact with the material deriving from sick animals or after spending time on the fields infected by sick animals.
- in the blood of sick animals, *bacilli* (single-celled organisms in the shape of a stick) could be observed with a microscope.

The hypotheses made by Pasteur were as follows:

- *carbuncle* was due to the action of *anthrax* bacilli
- vaccination would have increased the immune defenses and prevented infection; it consisted of inoculating the anthrax bacillus, attenuated with chemical reagent in culture at over 40°C.

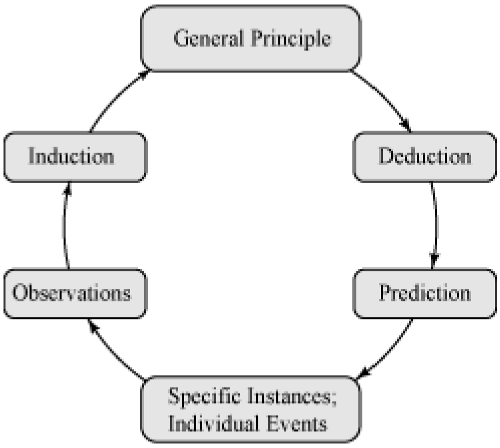
For the two-stage experiment, Pasteur used about 60 animals , especially sheep, but also goats and cows, divided into two groups :

- to a first group of about 30 animals, the attenuated bacillus was inoculated twice, at a distance of some days
- a second group, *of control*, of similar composition to the first, was not vaccinated
- both groups, after a reasonable number of days, were injected with a culture rich in virulent bacilli, not attenuated: in the first group all the animals survived except one; in the control group all the animals died in a short time, except for a couple that however became seriously ill.

Cognitive cycles

There is no shared agreement on whether there is a correct, or scientific, method to reach or consolidate knowledge on a given topic, and what the method may consist of. It is quite clear, however, that scientific research must somehow combine both inductive and deductive processes; within each process, different types of activities can be repeated cyclically.

A typical combination scheme may be the following



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The inductive cognitive cycle

In many research domains, if we place the emphasis on the experimental-inductive attitude, we can identify a cognitive cycle, divided into the following sub-phases, which can be repeated with some variants: [5]

- *Observation:* this is the stimulus for the search for the laws that govern the phenomenon in question and also allows the verification that these are actually always respected; the aim is to identify the characteristics of the phenomenon, mostly performing measurements, by the use of appropriate tools
- *Processing of measurement data;* raw data is usually made up of measures organized in tables; these can be processed in various ways, correlating different types of data, applying mathematical transformations, extracting significant values by means of statistical methods, displaying them by means of graphs
- *Model making*; one or more "physical" models can be constructed, consisting of elements whose functioning is known, and which are supposed to represent the overall behaviour of the phenomenon under study, for example one in which a gas is equated to a set of balls; or more abstract models, described only by geometric figures and/or mathematical formulas
- *Formalization of the theory*; consists in hypothesizing an organic set of laws able to explain the observed phenomenon
- *Experimentation*; where possible, the experiments are programmed by the observer who disturbs the system and measures the responses to disturbance, trying to prevent it from altering the system under observation by modifying its nature.

The deductive cognitive cycle

One of the major critics of the inductive method was the Austrian Karl Raimund Popper, according to whom

> Observation is never neutral but is always loaded with theory, the one that it wants to test. According to Popper, the theory always precedes the observation: [...] the human mind unconsciously tends to superimpose its beliefs on the observed reality. [8]

Then Popper proposes, instead of an observation cycle, the formulation of a theory and verification of the theory, one aimed at the *falsification* of theories, which puts the emphasis on the speculative-deductive attitude.

> Empirical experiments can never, for Popper, "verify" a theory, they can instead deny it. The fact that a prediction formulated by a hypothesis has actually occurred

does not mean that it will always occur. In other words, for the induction to be valid, it would require infinite empirical cases that confirm it; since this is objectively impossible, every scientific theory can only remain in the status of *conjecture*. [5]

The cycle, if we still want to consider it, identified by Popper is much shorter, composed of the following phases: [8]

- *Formulation of a theory*; according to Popper, very often a theory is already in the researcher's head even before he tries to formulate it explicitly; in any case, its formulation should already provide some deductions or facts, obtainable from the initial hypotheses, making it possible to falsify it!
- *Experimentation*; this is guided by the deductive method: the observation [...] must take place at a later time than that of the formulation of a theory, and serves not to confirm but to demolish it
- *Falsification of the theory*; by experimentation we try to falsify the theory, that is to say to demonstrate that it is false; if we fail, we cannot say that the theory has been verified; if a thesis resists attempts to refute it by deductive means through experiments, we can only consider it (provisionally) more valid than the others.

Although Popper is considered one of the greatest philosophers of science, not everyone accepts his ideas uncritically; for example, some have noted that the very notion of falsification contains in itself a contradiction: if it is true that every theory can be accepted only provisionally, up to its denial, this should be true also for the falsification of a theory, which cannot never be considered final.

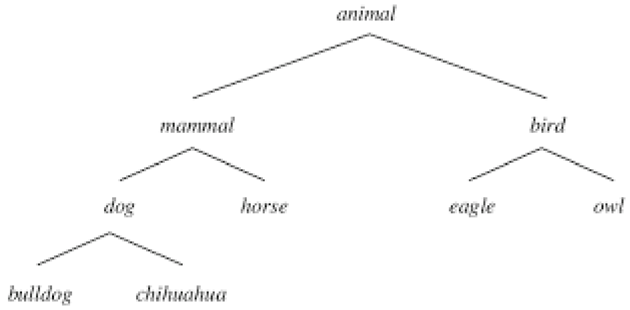
The formulation of theories

The importance of observation in the knowledge of the world can never be emphasized enough. But, as we have seen, seeking explanations of what is observed is equally important. Induction is based on the observation of events that are repeated, in a more or less similar way, a type of reasoning that generalizes experience.

Generalization and abstraction

Induction is a form of reasoning that generalizes experience in order to abstract from it general knowledge, to be used even in cases where you cannot - or do not want - to observed reality directly. But the term *generalize* is also used in the sense of bringing together in a "category" a variety of "similar" objects or events, based on properties or attributes that are recognized as common to them, neglecting differences that are considered detailed; in this sense, to generalize is to *categorize*, as we have seen when speaking of *categorical logic*.

The following image exemplifies a hierarchy of generalization (from bottom to top) or *specialization* (from top to bottom), which does not directly concern objects but entire categories of them. Until proven otherwise, or unless stated exceptions, all we can say about the horse as a category applies to each horse, but also everything we can say about an animal as a category applies to each horse.



Categorizing and generalizing are mental processes that generate simplified descriptions of reality, useful for some purpose; these processes are part of a more “general” (here we go!) process of abstraction, that is, of moving away from reality, with a more or less arbitrary extraction of a part of it, a process whose result is therefore the creation of simplified *model* of reality itself.

> Science does not simply consist in statements about nature, but in the development of theories [...] which allow one to talk about natural phenomena using two different levels of speech [...] When you talk about a segment, a triangle, an angle, you are not talking about natural objects (do not stumble over angles in the street), but of theoretical concepts that are used to describe, to offer a model of objects or natural facts or technological facts. The same thing happens in physical theories. [2]

The demonstrative method

We have seen that in research, in science, there are two planes: the plane of the concrete world and that of theory. The scientific theories concern theoretical entities (such as segments, triangles, waves and particles) not to be confused with the concrete objects of everyday life (such as houses, horses and watermelons). There are, however, relations of correspondence: a triangle corresponds to triangular objects, but a triangular object is not a triangle; this correspondence is intuited by a creative mind in the formulation of a theory and then exploited in imagining the applications of the theory itself, that is, in passing from science to technology. [2]

Another characteristic of the theories is that they constitute complex buildings, in which from the foundations, that is, from a small number of basic assumptions, tens or hundreds of theorems are deduced. The theories extend with the *demonstrative method*, which allows us to deduce necessary consequences from the premises. The oldest and best-known example of the use of this method is provided by the Euclidean geometry, which consists of theorems. The statements considered true are either the foundations of the theory (also called postulates, axioms, or principles) or those deduced logically from them. [2]

Verifiability as a unifying criterion

In any case , in order to define science and the research that takes place within it, it is necessary to adhere to some rules. The first rule is to allow colleagues to replicate the experiment, if one can speak of an experiment, or in any case to retrace an experience.

The second rule is to make public, that is to *publish*, what is done and accept the comparison with others, for example the *peer review* of scientific publications.

Transparency and openness to criticism that is required of scientific research is in part what we have tried to apply even in one of the most interesting initiatives based on the web: Wikipedia. In this case, the daring bet was made to invite not only "experts" but even "the whole world" [9] to collaborate in the compilation of *entries*. This collaboration is subjected to methodological rules of almost obsessive cross-checking, which constitute the value and limit of Wikipedia.

> The main feature for including information in Wikipedia is its verifiability. "Verifiable" means that anyone can check what s/he reads or check if what the text says has already been actually published by a reliable source. Verifiability does not mean truth or correctness: verifiable information can also be false, unverifiable information can also be true. However, in general, verifiability is a good verisimilitude criterion. [10]

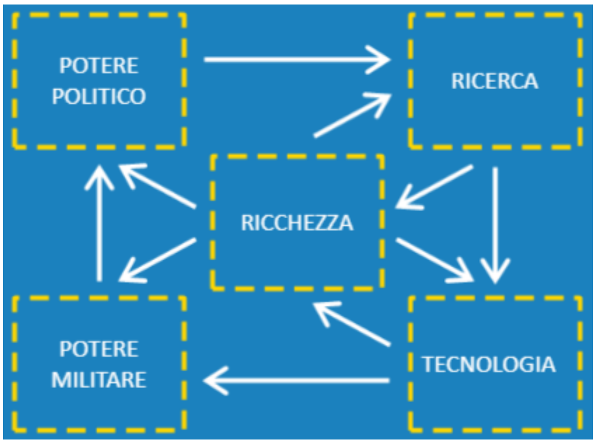
Science and society

A premise: if we try to analyze the current debate on the evolution of science, it is difficult to identify a clear boundary between science and technology and above all it is difficult to separate this debate from that on ICT (information technology and communications) and in particular on the Internet and its many applications.

Science and power - the power of science

Modern science is not content with creating theories. It uses these theories to acquire new skills, and in particular to develop new technologies. In the modern age, in correspondence with the scientific revolution initiated by the great geographic discoveries of the ' 4- ' 500 and with the birth of the modern empires, and more recently in correspondence with the later stages of the industrial revolution, and with forms of colonialism and imperialism that have come down to us, they have created virtuous (or vicious?) circles in which science, technology, power and wealth will enhance each other; for example: [3]

- the political power funds research
- research generates technology
- technology empowers the military
- military power strengthens political power
- technology generates wealth
- wealth gives additional power
- wealth allows investments in research and technology



In the modern age the relationship between science and politics has often been conflictual and harsh; in the past, the rulers feared innovation because it undermined their power; today, the contrast appears mainly to inverted roles: politics does not decide because it would be conditioned by the excessive power of *technoscience*. [12]

Science and democracy

Generally, a positive correlation was found between democracy and the development of the scientific method; it is not considered a coincidence that the first germs of it appeared in classical Greece:

> What is the link between schools of rhetoric in ancient Greece and democracy?
>
> [...[In the Greek democracies [...] assemblies are formed that take decisions by majority; then it becomes important to know how to argue in a way that can convince others of one's thesis [...] Reading Aristotle's Rhetoric, the link between the art of rhetorical argumentation, that is the art of discourse, and the logic appears very clear. [2].

However, according to some, in the modern world there is an irreconcilable conflict between science and democracy, as the former is not a pure knowledge at the disposal of humanity, but it is an indomitable web of economic interests whose promoters - the scientists - do not accept any form of external control [10] or, conversely, they are not aware of the strong conditioning that they undergo from the powers that represent those interests.

Science , information and dissemination

History shows that it is dangerous to conduct crusades against the scientific theories outside the *mainstream*, i.e. the theories dominant in the various scientific circles. However, it seems healthy to keep guard over the spread of pseudo-scientific theories and/or alarmist statements that sometimes risk producing a significant negative impact, especially in the health field.

Beyond the recurrent media campaigns, sometimes manipulated, like the one for and against vaccination, we remember the difficulty of bringing within a proper comparison, based on data and verifiable arguments, issues such as genetically modified organisms (GMOs) or the increasing use of food supplements.

In 1989, Piero Angela and a group of scientists, intellectuals and lovers founded CICAP (Italian Committee for the Investigation of Claims on pseudoscience), on the basis of the subscription of the following statement:

> Newspapers, magazines, radio and television stations devote considerable space to alleged paranormal phenomena, healers, astrologers, treating everything uncritically, without any control policy [...] For this reason we carry out a work of information and education with respect to these issues, to encourage the spread of an open and critical culture and mentality, and of the scientific method based on evidence in the analysis and solution of problems.

In Italy, quoting Piero Angela means talking about scientific disclosure [?], activities that many consider neglected, especially compared to the Anglo-Saxon countries. But if we look at the quality of disclosure, there are some fairly problematic aspects; between these

- who should make scientific disclosure? qualified scientists-researchers or professional popularizers or journalists?
- to what extent is it permissible to simplify, to use an analogy, to use images for effect?

The science always takes risks, which do not escape the best communicators, even great scientists who sought to popularize their findings (like Stephen Hawking), or to present the main points of complex theories such as the relativity and or space-time (like Carlo Rovelli), or to make understandable difficult concepts such as *entropy* [15].

Among the main risks we believe there are those of using analogies or metaphors a little too casually: for example, in the case of the alleged "duality" or "dual nature" of the electron, which sometimes behaves as a wave and sometimes as a particle, it is customary to attribute to a physical object, as its intrinsic nature, two different theories of the same phenomenon, which instead reflect the difficulties encountered by scientists in constructing a unifying theory or in disseminating it. [2]

How science evolves

Luciano Gallino speaks of "immense ignorance" about our attempts to grasp the consequences of scientific and technological development, which will be the unpredictable and unintended result of the choices we are now making. We would witness a rapid and unpredictable evolution of knowledge and technology, not guided by a clear design and not assessable as a completely positive and rational progress. The history of science and technology shows that a large proportion of innovations and discoveries has emerged in forms that are independent of the projects, expectations or forecasts of innovators, discoverers and political actors. [12]

Science or sciences?

"Hard" and "soft" sciences

If you deal with history, you can't experiment based on a theory. Biology is partly analogous to history; if you want to understand how a cell is made or how the human brain works, you should reconstruct an evolution that has many similarities with historical evolution, and that is the result of many facts and many almost random turning points.

This is a very different case from the theories that could describe the operation of a computer or the television; these are complex systems, but they have been designed on the basis of a few well-understood principles; moreover, in the latter case, it is often technology that stimulates the development of certain specialist branches of science, rather than the reverse. [2]

Many considerations on the scientific method made so far, while well suited to some so-called "hard" sciences, such as physics, do not reflect the nature of "soft" sciences: there are wide disciplinary differences that make the discourse quite more complex .

There are natural events or processes, such as meteorological phenomena or the evolution of living species, that cannot be reproduced in the laboratory. In these cases it is possible to construct models inspired by application domains with analogies; but the results obtained by "experimenting" with them , i.e. by performing *simulations*, certainly do not have the same probative force as those conducted directly on the original domain.

The discourse becomes even more articulated in the case of the social sciences or human sciences, such as juridical disciplines, historical-philosophical disciplines, sociology, psychology, pedagogy. Some of them, like experimental psychology, can use statistical-quantitative methods. Others, like archeology and paleontology, can use data obtained with advanced technologies but do not lend themselves to the construction of falsifiable theories. Psychoanalysis, according to Popper and other scholars, does not use a scientific method, at least in the usual sense of this term.

As for the economy ...

> While individual economists can claim that theirs is the best model, orthodoxy changes with every crisis or every burst of financial bubble, and it is generally accepted that the last word on the economy has not yet been pronounced. [3]

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