Essay

The method in science: origin and divergences according to Ruy Pérez Tamayo

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Abstract

Scientists have the challenge of studying different phenomena, this leads them to raise a diversity of questions that are answered using different research methods that also vary depending on the degree of development of each particular area of knowledge. Despite this diversity in science, there is the connotation that there is only one scientific method: the hypothetico-deductive method. This article takes up the work by Ruy Pérez Tamayo: does the scientific method exist? to go through the historical development of various methods and concepts relevant to science with the aim of allowing the reader to have a vision that is holistic but focused on the various methods and tools to do science.

Keywords: hypothetico-deductive method, inductivist method, philosophy of science.

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The way in which humanity has approached the knowledge of objects and phenomena has changed steadily throughout history. The ancient Greeks conceived of science as total knowledge; however, they focused on natural and physical phenomena, and it would not be until centuries later, with the contributions of Auguste Comte who would point out the need for a science of society.

The diversity of existing phenomena (natural and social) has generated a variety of methods to do science (Sousa, 2016) and not only a method to do science (Hill, 1985; Hodson, 1996; Ariza *et al*., 2020). These may include: open discussion (Teixeira *et al*., 2015), modeling, analogy, pattern recognition, induction, computer simulation (Wivagg and Allchin, 2002), cohort studies, case control studies, cross-sectional studies and other observational studies such as case series (Feinstein and Horwitz, 1982) or case studies (Yin, 2017) as well as other tools other than experimentation and that require the development of creative thinking.

To this, we must add more contemporary discussions on the role of gender in the way of doing and disseminating science (Bernabé, 2019), as well as new ways of doing science: multidisciplinary, transdisciplinary, interdisciplinary, as well as cross-border collaboration of various areas of knowledge and at different levels (Aguilera and Pino, 2019; Errecaborde *et al*., 2019).

The fact that not all scientific hypotheses can be tested through experimentation, such as historical studies that involve phenomena that are not observable and cannot be replicated in a laboratory (Cleland, 2001), has generated a debate about whether they are science. This has generated that, in areas such as agronomy, a study where there is no experimentation can be rejected as it is not considered scientific (Maat, 2011).

Within this context, this paper aims to present various historical contributions related to scientific work. Referring to the scientific method seems trivial; however, some teachers and researchers do not know either the origin of the experimental method or the diversity of existing methods to do science, which generates a gap in the understanding of why and how scientific work is carried out (Ioannidou and Erduran, 2021).

To give an approach to the history of the evolution of the scientific method, the work by Pérez-Tamayo (1998), does the scientific method exist? is taken up as the main reference, a work in which several philosophical and scientific thought schools are addressed. The work has a historical and philosophical approach that fits within the area of philosophy of science (Cassini, 2013), in this essay, the historical component is not addressed, as it is intended to show the reader a synthesis of the elements related to scientific work and thus allow the reader to have a more focused vision of the method or methods in science throughout history.

The ancients

The historical evolution of scientific thought finds the Greek culture in its beginnings, which developed from before the seventh century BC, until the year 323 BC. Although there are several thinkers for this period, Plato and Aristotle are considered the fathers of Western philosophy (Burgos-Lázaro *et al*., 2020).

For the first, the soul was immortal and lived in the world of ideas, so it already knows all possible ideas in such a way that experiences serve to remember the ideas it already knew. In this sense, by acquiring knowledge, what we do is increase the understanding of the ideas that we are already have, so the intellect was the best way to approach knowledge (Pérez-Tamayo, 1998).

Aristotle was a disciple of Plato, although he differed from his teacher in considering that it was impossible to know all universal truths and all ideas, and that knowledge was the product of learning from the experiences acquired through one's senses and own experiences (Pérez-Tamayo, 1998).

For him, science is the knowledge of the universal, which is demonstrable and valid for everyone, and logic and observation are the instruments that all sciences must use (De Hoyos-Benítez, 2020). According to Pérez-Tamayo (1998), Aristotle presented four ideas about the scientific method: 1) theory of the syllogism; 2) theory of definitions; 3) the inductive-deductive method; and 4) theory of causality.

The third contribution is still valid and is frequently used in the contemporary scientific world. Induction refers to reaching generalizations from individuals, divided into induction by simple enumeration and intuitive induction. For the first type, one of the most common examples is: crow one is black, crow two is black, crow three is black. All crows are black.

While the second requires direct appreciation, of what is essential in a sensory data set, where the observer with extensive experience is able to perceive the essence of objects or phenomena. Once generalizations are reached by induction, they are used as premises for the explanation of initial observations, this logical process is called deduction. That is, when the reverse mental operation of induction is carried out and one goes from the general to the particular. At this stage, passive observation was central to reaching conclusions (Dzurec and Dzurec, 1992).

One of the limitations of the Aristotelian method is that it is based on the use of language for induction and deduction, so theories become linguistic structures; that is, statements, which have logic in their base, generating technical problems related to the use of the language among scientists. As there is no regulatory or normative force that allows confirming a logical deduction, the latter is at the discretion of the scientist, who can make mistakes or create irrational conjectures (Griesemer, 1985).

The scientific revolution

One of the first contributions was that by Vesalius (1514-1564), which consisted in giving nature the supreme authority over truth, leaving behind the Galenic tradition of giving supreme authority to texts, daring to dissect human bodies and criticize pre-existing teachings.

This attitude of criticizing dogmas opens the door to a characteristic of scientists: to question the existing. Another of the main actors of this period is Galilei (1564-1642), who used experiments to explore specific ideas, tested mathematical theoretical conclusions and explored phenomena in the area of astronomy and physics to increase the amount of data he could include in his theoretical calculations. Becoming the first great scientist (Pérez-Tamayo, 1998).

Harvey’s (1578-1657) contribution to the scientific method was his success in using experiments to explore nature in the area of biology. For him, as well as for Galileo, his contributions point to the importance of mathematical analysis of natural phenomena and the use of experiments in the study of reality. In his book *De motu cordis*, Harvey (1578-1657) adheres to the same protocol: he begins by carefully describing his observations, then examines whether they coincide with what is reported by other authors and finally interprets the meaning of the observed facts, trying not to go beyond the facts themselves (Pérez-Tamayo, 1998).

Newton (1642-1727) insisted that the generalizations of the ‘natural philosopher’ -as he called the scientist (De Hoyos-Benítez, 2020)- should be based on the meticulous examination of reality, leaving dogmas even further behind. He took up Aristotle’s thinking of the inductive-deductive method and referred to it as the ‘method of analysis and synthesis’.

For him, the analysis of reality should be based on making experiments and observations and deriving from these, general conclusions by induction and if no exception occurs in the phenomena, the conclusion could be accepted as general, but if any exception occurred, then it should be enunciated including the known exceptions. While the synthesis would consist of assuming the causes discovered and established as principles and through them explaining the phenomena that come from them (deduction) (Pérez-Tamayo, 1998).

The first to use a microscope Hooke (1635-1702), who is known for and making contributions to the knowledge about cell structure, for the history of the scientific method, his greatest contribution came from his study of earthquakes, asking: where they have occurred and where not, to thereby apply the rule of ‘rejections and exclusions’. It consisted of formulating four hypotheses, demonstrating that three of them were not satisfactory and he proposed a method to test the fourth, which he never tested (Pérez-Tamayo, 1998).

The last scientist to be covered in this section is Leibniz (1646-1716), who regains importance since, in his conception of phenomena, he includes God as the creator who knows everything and is perfect. While mortals, perhaps one can never get to know everything and therefore it is required to make observations and hypotheses. The role of God in science appears, at that moment, as a factor that explains the inexplicable for Leibniz and becomes important, as will be seen, for philosophical thinking about the scientific method (Pérez-Tamayo, 1998).

The first philosophers of science

Until the sixteenth century, science and philosophy were the same thing. The man of science who philosophized and the philosophers who, although they retain some of scientist, were characterized by thinking. Among them is Bacon (1561-1626), who was a critic of Aristotle’s philosophy. He proposed a new method, which provides a procedure for making gradual and progressive inductions and a method of exclusion. So, first a ‘series of natural and experimental stories’ had to be collected and until there was extensive empirical information, not to move on to the next step, which would be to eliminate some possibilities.

He also proposed that the legitimate questions for the study of phenomena were: what? how? and why? His opinion that the best science is the one that is carried out by groups of researchers; that is, the one that is institutionalized, in contrast to the one that remains private and is the result of individualized work (Pérez-Tamayo, 1998).

It is for the above, that, in the vision of Voit (2019), both this thinker: Sir Francis Bacon and the one that will be presented below are considered as the founders of the scientific method, because they insisted on careful, systematic and high-quality observations, rather than on the metaphysical speculations that were fashionable among the thinkers of those times. Thus, the empirical will be considered from then on as ‘scientific’ (Villalobos-Antúnez *et al*., 2020).

For Descartes (1596-1650), he conceived of science as a pyramid whose top was occupied by more general principles or laws of reality and that, through deduction, one reaches real nature. So, knowledge can be achieved *a priori* or in the absence of reality. Proposing the principle of: *cogito ergo sum* (I think, therefore I am), to this he added the idea that God, the Perfect Being, exists and is the one who puts ideas in the mind, making us thinking beings, this is known as Cartesian thinking (Pérez-Tamayo, 1998).

Another philosopher of that time is Locke (1632-1704), considered the founder of empiricism, a method or procedure that is based on experience and on observation of facts, opposed to proposals such as that of Descartes or Plato, stating that there are no general intuitive or *a priori* principles. So, in this experience, on which knowledge is founded . He was the first to clearly ask the question of how an object is constituted in consciousness (Inverso, 2019).

Berkeley (1685-1753) considered that the only thing that has real existence is the world of sensations, while external reality not only cannot be perceived, but even does not exist. In his vision, the things that fill this world exist because they are perceived by God and his power is so great that, through him, we also perceive them.

With this, he provides God with the power to be able to perceive the world in an orderly and rational manner. This causes the phenomena to be deduced, but not demonstrated, because the deductions depend on the rules that are taken to explain the nature of things and whose operation can obviously not be known because the external reality cannot really be perceived (Pérez-Tamayo, 1998).

For Hume (1711-1776), the absence of ideas or concepts *a priori*, on the other hand, divides them into two classes: impressions, those that derive from the senses and ideas, conjured by the mind. In such a way that the elements that contribute to a complex idea come, ultimately, from sensory impressions or ostensive definitions. Demonstrating that pure empiricism is not enough for the development of science (Pérez-Tamayo, 1998).

The scientist Kant (1724-1804) proposes that, although none of knowledge transcends experience, a part of it is *a priori* and is not inferred inductively from experience. For him, things in themselves are unknowable and what one does have access to is phenomena. Kant proposed his doctrine of the schemes that are required to achieve pure understanding. This left out God and the soul, the first as a regulating principle and the second because it was not possible to prove its existence (Pérez-Tamayo, 1998).

These ideas that seem like only philosophical debates have had a great impact on the way we do science today. Since, if we take a Cartesian position, knowledge is there to be thought and discovered, whereas the empiricist would say, that reality not only does not exist, but cannot be perceived. Then, the senses are needed to create it and coupled with this, it is necessary to delimit the circumstances in which it is addressed and have certain ideas *a priori* to approach it, but never touch it. And when something could not be explained, it was always possible to put God into the equation.

The empiricists

The two most important trends in the philosophy of science of the nineteenth century were empiricism and positivism. The first is a philosophical trend that emphasizes experience and evidence to acquire knowledge, above sensory perception, seeking to find a unitary structure as the foundation of all scientific activity.

One of its main exponents is: Herschel (1792-1871), whose contribution was to establish that, for each new scientific fact, for each hypothesis confirmed by experimental data, for each theory that successfully predicts reality, there are two different aspects: the discovery and its verification. In his view, laws could also be formulated by generating hypotheses and testing them, rather than by rigorous induction. This is one of the first steps towards a science based on hypotheses (Pérez-Tamayo, 1998).

Studies such as those by Stuart-Mill (1806-1873), he established that the objective of all sciences, natural and social, is the discovery of general laws that can be used for explanation and prediction and that the observers can isolate themselves from experiments, in such a way that objective and dispassionate descriptions can be obtained (Dzurec and Dzurec, 1992).

With this, the deduction is removed from the scientific process, since in reality he considers that this process, of going from the particular to the general, is nothing more than a summary of many individual observations. Therefore, induction becomes the fundamental principle of the uniformity of nature, establishing that what happened once will happen again when the circumstances are sufficiently similar (Pérez-Tamayo, 1998).

The positivists

Positivism is a philosophical trend that establishes that the only authentic knowledge is that derived from observable facts and the laws of nature, excluding concepts such as the soul, value, God, the atom or gravitational force, among others. For these thinkers, science is the true source of ethics, politics, and even religion. Finally, in their view, reasoning is not an operation attributable to God, since it requires a discourse, temporality, and selection of premises (Arana, 2014).

Among its representatives is Comte (1788-1857), who is the first to demonstrate the need and ownership of a science of society and the first to give a category to the science previously possessed by philosophy. For this thinker, the methods to approach knowledge are: 1) observation, where the task of the scientist is to establish definitive laws that describe the invariable relationships of the facts, from their verification by means of observation; 2) experimentation, which is only possible when the natural course of a phenomenon can be altered in a definitive and controlled manner and if it cannot be done, it can only be overcome by observation, and 3) comparison or analogy, this is the best method for areas such as biology or sociology (Pérez-Tamayo, 1998).

Authors such as Mach (1838-1916), he argued that all laws and principles of science should be based exclusively on experience, which, for him, means a set of sensations. In his view, Cartesian concepts *a priori* do not exist, Kantian imperatives are fictitious entities, the only thing that must be believed is what can be experienced through the senses.

The three different forms of reasoning, or 'inference', were studied by Peirce (1839-1914), commonly used in science: deduction, induction (ampliative or synthetic) and hypotheses (explanatory, inference, retroduction or presumption as he called them) (Hoover and Wible, 2020).

His scientific method was based on three successive steps: abduction or retroduction of a hypothesis, deduction of its consequences and tests performed. In this view, hypotheses should be tested experimentally, and it should be done with the greatest economy, not only of ideas but also of work, time, and material resources, with special emphasis on the practical consequences of the whole process. In case two hypotheses were equally predictive in practice, both should be considered equally true (Pérez-Tamayo, 1998).

In the view of Poincaré (1854-1912), the scientific method is based on the existence of a general order in the universe that is independent of man and their knowledge. The goal of scientists is to discover and understand everything they can of the postulated universal order, accepting that the certainty of its universality is unachievable, the progress of science is nothing more than the progressive extension of the limits of the knowledge of the universal order (Pérez-Tamayo, 1998).

One of the weaknesses of positivists is that, in their view, science grows by incorporating new knowledge into a previous one. However, when it is recognized that certain knowledge seen as true is false, the new knowledge also loses validity (Griesemer, 1985).

Logical positivism

One of the most important philosophers of the last century Wittgenstein (1889-1951), whose contribution to the scientific method lies in establishing that observation is an active process, nuanced by theoretical experiences, cultural assumptions, language attributes and other factors, both social and individual, so that observation is a conceptual process that influences or determines perception (Pérez-Tamayo, 1998).

Carnap (1891-1970), a member of the group of philosophers and scientists known as the Vienna Circle (1907-1931), established that the principle of verifiability of a proposition is given by the conditions of its verification and that such a proposition is only true when it is verifiable in principle (Pérez-Tamayo, 1998).

Reichenbach (1891-1953) incorporates the theme of probability into science. In his view, the very essence of knowledge is its uncertainty, since physical predictions are never (and cannot be) accurate, since it is impossible to incorporate all relevant factors into calculations. Therefore, it is not a limitation of the intellectual capacities of scientists, but rather of the way the universe relates to our observations. For him, a proposition has meaning only if it is possible to determine a definite degree of probability for it (Pérez-Tamayo, 1998).

Falsificationism

One of the most influential philosophers of the twentieth century, Popper (1902-1997), referred to by (Sousa, 2016), distinguishes true science from pseudosciences in that the former is constituted by theories that can be proven false by testing their predictions, while the latter are not refutable.

He put at the center, not the mechanisms for generating theories, but rather the methods for testing them, suggesting that such tests should be aimed at showing the false or wrong aspects of the theories and not at verifying or confirming them (Pérez-Tamayo, 1998).

In his opinion, the formulation of a general assertion or theory derived from a limited number of observations was logically invalid (Hill, 1985), becoming conjectures or inventions created by researchers to explain some problem and which then had to be tested through confrontations with reality designed for possible refutation (Pérez-Tamayo, 1998).

For Popper, hypotheses or models as mathematical expressions must be ‘falsifiable’, that there must be one or more circumstances logically incompatible with them (Smiatek *et al*., 2021), otherwise proving them would also be debatable (Voit, 2019).

And this is the origin of the Popperian version of the hypothetico-deductive scientific method, also known as the trial-and-error method or the conjecture and refutation method (Pérez-Tamayo, 1998) or what philosophers call logical positivism (Dzurec and Dzurec, 1992).

Despite the impact that this method of raising hypotheses that can be falsified has had, many theories do not follow this method because they are phenomena that cannot be falsified, such as Darwin’s theory of evolution, which does not make them less useful to explain the world and that is a clear weakness of this method (Vigue, 1980).

Research programs

Lakatos (1922-1974), who proposes research programs (Orensanz and Denegri, 2017), argues that science resembles a dispute between three contenders, two theories and an experiment and that the interesting result is most often the confirmation of one of the theories and not its falsification. His program has three components: 1) a central core, which brings together the basic and essential assumptions of the program, that is, everything that is fundamental to its existence; 2) the central core is protected by a protective belt called a negative heuristic, a methodological principle stipulating that the components of the central core should not be abandoned despite anomalies; and 3) the outer layer of the scientific research program known as positive heuristic, represented by general directives to explain already known phenomena or to predict new phenomena (Pérez-Tamayo, 1998).

Historical relativism

According to the scheme of Kuhn (1922-1996), the cycles to which the sciences are subjected throughout history begin by a more or less prolonged stage of ‘prescience’, during which observations are collected almost randomly, without a definite plan and without reference to a general scheme, in this period there may be several competing schools of thought, but without any of them prevailing over the others.

However, little by little a theoretical system acquires general acceptance, with which the first paradigm of the discipline arises, formed by a theory and a method, which together constitute a special way of seeing the world, this period would be that of ‘normal science’. This period is characterized because the research is developed according to the dictates of the prevailing paradigm; that is, models that have proven successful within accepted theories are followed (Pérez-Tamayo, 1998: 232-240).

One of the characteristics of Kuhn (1922-1996) is that he explains the patterns of growth and change in science with sociohistorical models of scientific work, differentiating himself from the heirs of logical empiricism who analyze the structure of theories in formal terms, promoting an ahistorical and asocial analysis (Griesemer, 1985).

In addition to this, it is not easy to dare to rethink previously accepted ‘truths’ and develop radically new ideas, despite being necessary since, contrary to the traditional scientific method (the hypothetico-deductive) that requires rigorous rules to be followed, scientific advances have required critical and innovative thinking (Voit, 2019).

Epistemological anarchism

This trend of thought is represented by Feyerabend (1924-1994), who declares himself an anarchist, because in his opinion, there is nothing that can be identified as a scientific method. From this perspective, Feyerabend considers that ‘anything goes’, particularly in methodological terms, to reach knowledge, in the same way, in his vision, changes in theories and paradigms are nothing more than a change in interest and advertising (Pérez-Tamayo, 1998).

A more contemporary dimension of science

One of the great changes in science is the possibility of obtaining large amounts of data, this, contrary to the traditional method where there is a hypothesis that is tested on some altered conditions, for example: in laboratories. Under this new reality, the trend is data mining, where data is what reveals things, taking away from scientists preconceived ideas that can divert the interpretation of what is observed.

These data-driven studies have the challenge of eliminating the noise that may be in the data, so specialized software is required to ‘clean’ the data through machine learning techniques. This way of doing science has been criticized because many decisions are left to computers (Succi and Coveney, 2019).

In addition to the fact that the basic principle that is followed is that of induction, which cannot reveal general laws, regardless of the size of the databases, but the data can allow one to see patterns, trends, and principles.

Therefore, rejecting this way of doing science would be wrong, because it has contributions to knowledge, what should be done is to standardize processes and have controls that make the method followed valid and reproducible (Voit, 2019).

Finally, what is acceptable after reviewing several historical contributions on the way of doing science is that there are different methods and that they all have two aspects in common: reasoning and empirical evidence. Which is obtained in different ways according to the area of knowledge.

The reproducibility of the method, the impact and novelty of the findings and currently, the scientific publications and their requirements are more contemporary challenges for the scientists of these times (França and Monserrat, 2019).

Conclusions

The scientific method, says Ruy Pérez Tamayo, is the sum of the theoretical principles, the rules of conduct and the mental and manual operations that men of science used in the past and continue to use today to generate new scientific knowledge, and that the author classifies into four categories: 1) inductive-deductive method; 2) a priori-deductive method; 3) hypothetico-deductive method; and 4) there is no such method.

The selection of method will depend on the research question, the type of study and the maturity of each area of knowledge. Knowing this allows one to value the work of researchers who do not follow the experimental method or the hypothetico-deductive method, on the contrary, they face other possibilities enriching our vision of the world and providing us with benefits from their findings. It allows being scientists who follow their intuition and who question their observations, who explore to generate novel and relevant information and consider possible errors, who understand that perhaps their findings generate more questions than successes and that even, in some cases, those ideas are discarded, therefore, not a method is required but a series of tools and various methods.

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