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TRILHA PRINCIPAL

Scientific Methodology through the looking glass

Gilson Luiz Volpato[a,b]

[a] Retired from the Department of Physiology at the Institute of Bioscience, São Paulo State University, UNESP, Botucatu, SP, Brazil.
[b] Currently at IGVEC – www.igvec.com – Botucatu, SP, Brazil
Contato: admin@igvec.com

***Abstract*— Scientific methodology is undoubtedly a necessary discipline because it deals with how a scientist reasons. This reasoning is certainly useful also for fields outside of science. Despite the credibility of science in producing knowledge on what the world is and how it works, some misunderstandings are still at the heart of scientific methodology. These are mistakes of tradition that still persist. Here I choose some of them and present logical ways for improvements. The following topics are challenged: method or methods; one or more sciences; research, or science; (re)classification of the rational knowledge; the three logical types of scientific studies; the three criteria for concluding about "cause and effect" relationships; and warning about the need to establish elementary science education focused mainly on scientific mentality rather than on scientific research.**

***Keywords:* science, research, logic, human knowledge, cause-and-effect, scientific mindset.**

1 INTRODUCTION

SCIENTIFIC methodology is an exciting and necessary field for scientists. It is guided by deep logical and creative thinking. However, some traditions have been incorporated in this scenario, thus resulting in logical mistakes with serious consequences to science. Despite the enormous number of such traditions, here I focus on a very limited number of them, but basal in importance.

My reasoning starts with the challenging aim of defining science and proceeds with the crazy aim of defending just one scientific method and one science. Of course, this resulted in the need of (naively, but honestly) reclassify the human rational thinking. In the following, I deal with methodological and reasoning gaps of tradition in science, exploring some usual practices that must be rethought.

Most of the concepts presented here evolved during my activities on teaching scientific writing and scientific methodology, in the last 35 years; so, they have appeared in my books on these subjects throughout these years (Volpato, 2017; Volpato; 2019) and here they appear in their most updated version.

To do so, this paper is organized as follows. Section II discusses the definition of science and its importance. Section III defines what researchers are, while Section IV discusses the concepts of scientific methodology. Section V discusses the design of scientific experiments, Section VI discusses some concepts on scientific education and, finally, Section VII concludes with some final remarks.

2 WHAT THEN IS THIS ENIGMATIC THING CALLED SCIENCE?

I intend to explain in simple words what science is. I will not be reviving radical discussions of scientific concepts that have permeated the modern science, *e.g.*, positivism, induction, deduction, truth, radical empiricism etc. I conceive that concepts about science evolved a lot during the last 300 years. This, however, does not imply that all the earlier concepts must be rejected and neither that all the recent concepts must be accepted. For a broad and more comprehensive approach, I was obligated to contrast a few philosophical disciplines about science (Philosophy of Science, Epistemology, Logic and Ethics) with current scientific practices in an international scenario where prominent scientists debate and share published scientific knowledge, which have been used by Technology and Education. Thus, I have defended that this mixed attempt linking theories and practices gives a more appropriate view to accommodate the concept of science. This aim is developed here in 5 steps, as follows.

2.1 The importance of evidence for the scientist's discourse

Looking at the practice of science, the presence, highlighted or not, of "results", whether qualitative or quantitative, is noteworthy in all original research (in item 2.2, I discuss theoretical researches). Scientific review articles use results or result-based conclusions of published papers as a base for their conclusions. When a "scientific paper" has no "results" at all, scientists usually assume it is a philosophical argumentation or merely an opinionated text. Thus, "results" are undoubtedly imperative on the practice of scientific research.

In 1959, Bertrand Russell[1] was asked about what he would like to say to humanity if he knew that people would discover this message many centuries later (similar to what occurred to

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[1] Extracted from the last question of an interview to BBC, Face to Face, London, asked by the journalist John Freeman.

the Dead Sea Scrolls). On the intellectual realm, he said "*When you are studying any matter, or considering any philosophy, ask yourself only what are the facts. And what is the truth to the facts? Bear out never let yourself be diverted either by what you wish to believe or by what you think could have been efficient social effects if it we're believed. But look only and surely at what are the facts."* In other words, do not allow your wishes about the world to prevail over the facts. Scientists should prevent preconceived ideas from telling us about the world, mainly when ignoring evidence on the contrary. According to Lawler (1971), "*Theory without data is fantasy, but data without theory is chaos.*" Although both authors mentioned above express a radical emphasis, science is somewhere between these extremes.

An instructive example of how scientists value evidences can be depicted from the discovery of the Higgs' boson. See this report: "*A problem for many years has been that no experiment has observed the Higgs boson to confirm the theory. On 4 July 2012, the ATLAS and CMS experiments at CERN's Large Hadron Collider announced they had each observed a new particle in the mass region around 125 GeV. This particle is consistent with the Higgs boson but it will take further work to determine whether or not it is the Higgs boson predicted by the Standard Model…"*[2]. In 2013, François Englert and Peter Higgs were awarded jointly with the Nobel Prize. Note that Higgs did the theoretical prediction, which he had already published in the 1960's (theoretical science, discussed in item 2.2). But the Nobel Prize was awarded only after the predicted evidence was detected, thus awarding both, the one who predicted the boson (Higgs) and the one who detected evidence of this structure (Englert).

These examples, and many others, reinforce how scientists do value factual evidence (both qualitative and quantitative). Once they get evidence, they incorporate them into their discourse, by testing hypotheses and/or inducting general explanations, in both cases reaching conclusions about "what the world is" and "how does it work".

Currently, scientists recognize that unambiguous objectivity is impossible, but also that scientific facts are our best judges for regulating explanations about the world. That is, evidences temper the scientific discourse, assuming evidence, creativity and logic as tools to build scientific knowledge. This does not imply that facts determine conclusions, as previously argued in the early modern science. In this way, scientific conclusions are not definitive ideas, but explanatory speeches about the world; speeches that do not contradict facts and also do not rely only on them, thus staying between the two extremes of Lawler's phrase above quoted.

The importance of evidence for scientific reasoning is unquestionable. However, the way evidence is used may vary among studies. Historically, evidence as described above is greatly connected to sensory and physical evidences, like accepted by empiricism, thus resulting in the empirical science. At the beginning of the modern science, empiricism was heavily, almost dogmatically, used to build science. This approach represented a soundly "no" to speculative speeches that could easily be influenced by conscious or unconscious desires. However, this thought focused mainly on inductive ways to build knowledge, overvaluing the role of evidence on conclusions.

As science moves away from philosophy, it concentrates power on evidence (firstly by strengthening induction). Deductivism was also incorporated into the scientific discourse as deductive hypotheses take shape and the evidence is used to confirm them. In the 20th century, Karl Popper's falsificationism emphasizes evidences to falsify theories. In any case, deduction is used through a *Modus Tollens* system[3] with evidences helping pass judgement on theories or hypotheses. However, inductivism defends that evidence also enables scientists to inductively emerge conclusions. Our practices show that as an empirical research is carrying out, an unexpected fact may arise that can change the scientist's perception about an explanation or conclusion. Despite that, in the scientific scenario the verb "to confirm" is still used, mainly because most researchers are not deeply immersed in philosophical themes about science.

Later, Thomas Kuhn highlights the role of paradigms (general assumptions, broader than theories) affecting scientist's decision on theories (I could include this concept even for specific hypotheses). This idea was greatly popularized in the 1960's and still reveals a real reaction of scientists: some paradigms operate to maintain confirmatory theories. For example, consider that the notion of sustainability is a paradigm in modern times. Every theory that contradicts this notion will be more easily discharged, while those reinforcing the concept of sustainability are more expected to resist. The same occurred about the concept of molecular and nanomolecular approaches on the world. Imre Lakatos added to this scenario an attempt to link Popper's and Kuhn's approaches to decision about theories in science. He included the concept of research programs, what could help some theories be not easily rejected even in the face of contrarian evidence, because other theories in the program needed the contradicted theory, at least until a better theory could replace the rejected one.

The very brief explanation above indicates the role of evidence for the scientists' world, although there is no clear agreement about induction or deduction (even confirming or neglecting hypotheses). Currently, some area's traditions accept as science only studies using hypotheses (*e.g.*, too many in the field of ecology), while others accept the induction from physical evidences to produce knowledge (*e.g.*, mostly in qualitative studies, but also in some quantitative ones). In this paper, I emphasize that the mandatory point in science is the evidence, while scientists can use deduction or induction just as methodological tools for the scientific reasoning. To better control the scientist's passion by his/her hypothesis, I have strongly suggested that scientists should not be compromised with either confirmation or denial of the hypothesis, but to try a reliable and logically deduced test, and be happy with any result, irrespective of what you were previously assuming.

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[2] Extracted on dec 1st, 2020, from https://home.cern/science/physics/higgs-boson.

[3] Necessary predictions deduced from a hypothesis are confronted with empirical evidence; when the hypothesis is corroborated, it still remains provisory; when it is denied, the hypothesis is falsified.

2.2 What about the theoretical scientific disciplines?

Theoretical disciplines do not require evidence. This is the case of the classical “formal sciences”, such as Mathematics and Logic, or even “theoretical sciences”, such as theoretical biology and theoretical physics.

These disciplines may use scientific empirical evidence (see item 2.3 below) in their discourses, but this is not a distinctive trait and knowledge is mostly, or exclusively, built from pure reason. Usually, this approach starts from an accepted (necessary to be accepted) statement and deduces gradually to more specific statements. How is this possible?

Formal disciplines are languages through which people “see” or “express themselves about” the natural world, usually strongly regulated by mathematical and logical predefined rules. These are very restricted languages that imply very little influence of personal wishes on the conclusions. Sometimes, they might use empirical evidence, but usually as a very small part of a much higher and more complex theoretical construction, thus being a very different argumentation than that on the science as defended in item 2.1.

Let´s contrast this approach with philosophy’s way of constructing knowledge. Philosophy usually uses words (non-mathematical) guided by rigid logic for argumentation. They develop strong arguments and conclusions, surely. However, philosophy lacks a unique and universal referential, and thus different views about the world emerge. That is, empirical evidence is not a necessary condition in philosophical discourses. Philosophy also uses analogy of imaginary fictitious scenarios to support conclusions, rather than only for didactical communication. Classical examples are dilemmas from which impossible situations are used to provoke discourses to support some conclusions. For instance, the Plato’s cave or the imaginary creation of a time machine to transport someone backward or forward in time. Science do not use this analogical argumentation, but only logic and evidence.

The main difference between the mathematics-based language and the traditional philosophy built by reasoning and natural words is undoubtedly the assumption of the strength mathematics adds to a discourse. However, both use only languages (mathematics or just words) and rational reasoning to understand the world. This makes philosophy and theoretical sciences more similar among themselves than with science. Science needs such a rational discourse, but contrasting with physical evidence is undoubtedly necessary (remember the Higgs’ boson). Logic, however, is a basic requirement for all of them, what includes all in the category of rational knowledge. Note that the reported Higgs’ theory was published in a theoretical physics field of science decades before detection of a physical evidence of the boson. Accordingly, in item 2.5 I rearrange positions of these approaches and deal with the situation in which evidence is included in the theoretical sciences.

2.3 Characterizing the scientific method

Now I present a general view of the necessary characteristics of the scientific method. Firstly, this method needs physical evidence in the discourse and whenever there is conflict between discourse and evidence, the discourse must be changed. In this line of reasoning, scientists are free to use deductive or inductive logic. Analogy is accepted only for didactic explanations and suggestions of some possibilities, but never to decide about conclusions.

Now, let us better understand what scientific evidences really are. They include not only physical evidences, but also all the theoretical assumptions based on evidences. This is easily understood when considering the variables scientists study.

Variables are *operational* when they can be registered directly (irrespective if scientists do need devices to register, or not) and *theoretical* when scientists cannot register the variables directly and need to infer them from the operational ones. For instance, a scientist can study grades on tests to infer learning; the hormone cortisol level to infer stress; specific answers in a questionnaire to infer depression, happiness, and other feelings; body weight to show growth; size to express dilatation; rules, laws, and some words to infer political tendency; and so on. Thus, the theoretical variables here considered have the same, or very similar, meaning as for the term “category” in the qualitative research. They are accepted as scientific evidence because they are based, either directly or not, on physical facts. Below I present the two main characteristics a scientific evidence must have.

a. *Scientific evidence must be durable*, that is, the evidence must last for a very long time. In fact, this is like what occurs in criminal law about proof. If the proof (evidence) disappears, the lawyer’s discourse can be rejected, or start being discredited. In science, if an important evidence disappears, or is rejected, the discourse is every time somewhat discredited. To solve this problem, the scientific evidence must be fixed and there are two ways scientists can make an evidence unchanged. Scientists can physically fasten evidence by printing words, getting pictures, video- or audio-recording, or even chemically fixating (e.g., biological materials) or keeping the material (e.g., fossils and specimens; documents) in museums and libraries. However, the other most disseminated way to make an evidence durable (physically fixed or not) is by describing in details the procedures to obtain very similar evidences. If another scientist follows these procedures, similar evidences should be obtained.

b. *Scientific evidence must be interpersonal.* At least other scientists from the same specialized field of study must be able to detect the same evidences. Otherwise, the study is not accredited. Thus, by making the evidences durable, this fundamental need is achieved; that is, the study is reproducible.

Furthermore, making science requires a theoretical conclusion, which consists of affirmative statements, even if provisory ones, that answer at least one question by using the above requirements. Some other requisites for a valid scientific study are logical reasoning and control of variables whenever it is possible (controlling directly or by data analyses). Strategies to reduce conscient or inconscient personal wishes while obtaining the results (*e.g.*, double blind strategies) are imperative always whenever the scenario indicates and their use is possible.

In an epistemological sense, however, science is an interconnected mesh of scientific accepted (or still under debate) knowledge linked to build a conceptual network provided by application of the scientific method (described in item 2.3). This network is changed and expected to be improved every time a new scientific work is published, although in practices this network is very slowly changed and only very few changes occur gradually or abruptly. That is, not all published scientific papers enter this interconnected mesh.

2.4 Science as a provisory body of changing knowledge

The classical knowledge classification has been mostly guided by traditions and so it can be reorganized according to the way science has evolved. Usually, philosophy has been kept apart from science and the scientific knowledge has been differentiated between *Natural Sciences* (Physical and Life Sciences), *Social Sciences* (including Human Science areas), *Formal Sciences*, and some include even *Applied Sciences*. More recently, qualitative, and quantitative studies have been treated as different sciences.

Such classifications, however, have been mostly maintained by traditions that need to be rethought. Here I suggest a classification based on requisites for knowledge acceptance: basically, direct, or indirect physical evidence for science and natural or mathematical language discourses for philosophy. This assumption restructures the traditional separation between science, social sciences, and formal sciences. The false and prejudiced separation among soft and hard sciences also disappears due to these methodological reasons. Finally, a new consideration about knowledge classification is proposed, so that theories and other theoretical propositions can be moved from one type of knowledge to another one, if empirical evidences are available or not.

A discourse interacting with physical evidences (or evidences turned physical) and based on logic argumentation, not disrupting evidences in favor of the discourse, has brought an incommensurable gain to our comprehension about the world (from subatomic particles to human social relationships, reaching the universe as a whole). Such need to contrast ideas with scientific evidences is of the utmost importance and explains that when the scientific method is applicable, the knowledge is stronger and usually able to reach and help much more people, either at the current moment or years, decades or centuries later. However, this does not imply that science deals only with physical things of the world, because scientists conclude about physical-fact-based theoretical variables, such as “ideology”, “beliefs”, “happiness”, “frustration”, “velocity”, "gravity", “stress”, “plasticity”, “love”, “competition”, “learning”, “memory” etc., whenever these variables can be represented by operational evidence accepted as material facts that are durable and interpersonal.

Philosophy is not necessarily much impressed by the support of physical evidences to the discourse, mainly because rationalism is part of philosophy. Notice that the above mentioned Bertrand Russell’s discourse emphasizes “facts”, but this does not mean he is talking specifically about physical facts. To avoid misunderstanding, here I focused “scientific evidence” on physical facts, but with the understanding that a speech can be a physical fact when it is transcribed on writings, and audio or video recordings (see item 2.3). While studying theoretical variables, science requires linking these variables to physical facts. However, such evidences are not requisites in philosophy and logical sciences.

Mathematical reasoning works predominantly with proof on different ways but working with the truth of statements in all possible cases, or theorems and axioms that follow clear inference rules, and knowledge built by exhaustive deductive reasoning. Conjectures (or hypotheses) can be used, even if they are unproven propositions believed as truth. Anyway, philosophy and mathematics use languages with different emphases and logic tempers both to build acceptable knowledge. Natural language underlies the discourse in philosophy; in formal sciences, specific mathematical symbols are usually required together with logical deductive reasoning. Both natural language and the language of Mathematics are languages used by human beings. Thus, mathematics (meaning formal science) and philosophy accept producing rational knowledge by logically arguing purely by means of language(s), with no need of physical evidence. This imposes a clear-cut difference between science and those areas. Scientists deposit a distinctive value to empirical facts while building knowledge. This makes philosophy and mathematics more similar among themselves (to build knowledge) than with science.

The above considerations imply that philosophy and science are two main areas of rational thinking. In terms of the way to construct knowledge, *philosophy* is thus composed of two fields: a) *Qualitative Philosophical Approach* (the traditional philosophy using natural language, but sometimes also supported by mathematics) and what I named as *Logical-Mathematical Approach*, grouping formal sciences and other theoretical areas.

Every scientific discipline constructs theoretical explanation, but necessarily dialoguing with physical evidence (not just arguments, rhetoric). This does not make science more truthful, but science better explains the world in physical terms, in expressed theories and other abstractions; but surely science’s method is not involved with metaphysics.

Now, let us consider reclassification into science, arguing that some non-logic traditions still need to be removed. For instance, the traditional separation of natural sciences and human sciences makes no sense. Firstly, there is no significant differences between the scientific methodology among these areas, at least in the very raw consideration about the use of physical evidence as depicted above (item 2.3). Moreover, by separating humanities, which investigates fundamentally human beings, tradition has raised erroneous connotation that humans are not part of nature. If we understand basic biology, which deals with live organisms from their origins to how they are and functions at molecular, physiological, ecological, psychological, and evolutionary terms, the exclusion of humans from the nature takes us back to more than one century ago. This anthropocentric division brings as a consequence that all things humans do are named artificial. How should we name a dam built by humans in a natural river flow? Is it natural? And how could we refer to dams built by castors: are they natural or artificial? Referential exclusively based on human vs non-human organisms is surely biased. Even though science has shown every day the extreme interdependence among study areas and parts of the world, this separatist approach claims for disconnecting humans from nature.

Ptolemy's geocentric theory had already abused this view, as also historical gods have usually been represented in human bodies. This approach is also linked with considerations of animals *versus* humans, as if humans were not animals. What should we be, then? Gods, plants?

Therefore, I insist that science is science anywhere, irrespective of being developed into the traditional exact, biological, social sciences (human sciences) or any other science one can suppose. These areas share the same basic methodology whenever they deal with physical traits of their subject/object of study, irrespective of being detected by quantitative and/or qualitative properties.

There is also no sense referring to as "hard" and "soft" science. This is an obviously prejudiced definition. The fact that the exact area deals with very precise numbers does not allow "their science" to be considered harder or stronger. If they come to study, for instance, phylogeny in biology or social sciences in humanities, they can be faced with some events or phenomena on which they cannot use their sophisticated apparatuses, and thus they have to deal with even more subjective qualitative evidences. Notice that inside a specific subject of study we have to use the "hardest" available technique and logical reasoning to produce high level knowledge in this subject. Scientific reasoning does not allow us to judge necessary evidences in one area in terms of technical characteristics of another area. For instance, whenever quality traits are necessary evidence for a study, they must be obtained by the highest-level technique available, but not by technical paradigms of other areas. Thus, qualities or quantities are determined by what variables scientists are interested to study; these traits imply what to register and they define much of the way they will be analyzed. That is, study each thing with the best possible technique; it does not imply that studying by questionaries can be considered weaker than study by a high-level quantitative technique that is not fitted to interview people. Thus, "hard" and "soft" sciences are just prejudiced concepts. Science requires the strongest procedures available at a specific context. Thus, if in a qualitative study a double-blind study is necessary and possible, it just must be used.

According to the above considerations, I propose that rational knowledge be arranged as in figure 1:

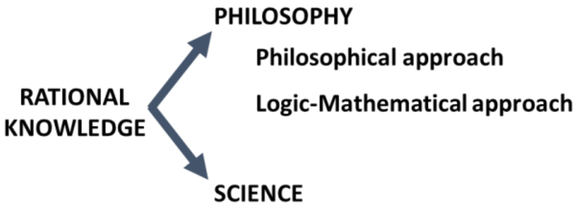

Figure 1. (Re)classification of rational knowledge. The logic-mathematical approach includes classical formal sciences and theoretical sciences of several areas. Science requires an evidence-integrated discourse and excludes other divisions.

Another aspect for reconsideration is that the above classification should include that theoretical knowledge might be classified in the logic-mathematical approach at a moment and then, when solid evidence is obtained, it can be displaced to Science. Let us look at the Higgs' boson case again. While his theory was far disconnected of accepted empirical support, he was not awarded the Nobel Prize. As soon as the boson was detected, this picture changed dramatically, although his theory's basic argumentation had been published almost 50 years ago. Before detection of the boson, his theory was strictly in the scope of theoretical physics; the boson "materialization" changed this scenario. The same may occur with other knowledge points. This means that some knowledge points can be displaced from one denomination to another according to discovery of necessary evidence. In the meantime, knowledge stays in the area where it is accepted. If some knowledge is displaced outside science, it might remain in another sphere of knowledge; forcing it to be maintained in philosophy or in science will just displace it to pseudo-philosophy or to pseudoscience. The "fixist" thinking of knowledge in one permanent field must be rethought.

The view of science I defend is not the same as admitting that physical evidence determines conclusions. It is very different from that. I advocate that practice of the scientific discourse must include both abstractions and evidence (an evidence-integrated discourse) for a logical acceptance in science; otherwise, the discourse is considered "just an opinion" or a "philosophical argument". What is true in science will depend on which part of the scientific published material some influent (unfortunately) scientists will accept. This is the same in all, or almost all, areas of the human knowledge. The advantage of science, if any, is that the debate can be permeated by physical interpersonal, durable evidence, thus helping, in some cases, avoid the prevailing of authority.

3 RESEARCHERS AND SCIENTISTS

Although these terms have been used almost interchangeably, practice of science is in urgent need of specific denomination. Is using the scientific method to discover whether an industry is polluting a river the same as discovering the pattern of industries that pollute rivers? When answering whether high-tech class improves learning of my 2nd grade university students, although useful, am I doing the same as discovering whether this class type improves learning in students everywhere? My answer is no.

Differentiation of research from science, and thus researcher from scientist, is a necessary goal, rather than an academic useless concept. Several mistakes arise from lack of a clear-cut conception about science, technology, pragmatism, immediatism, the arms of science to impact on the society, among others. Here I will use the necessary information to differentiate these two concepts and to understand their role from a scientific career to the whole society.

All researchers and scientists do scientific research. Research is any activity developed to find elements that allow us to answer one or more questions. A scientific research necessarily uses current accepted scientific procedures. It is not worth trying to define the scientific method in terms of being systematic, rational, analytic, precise, observational, hypothesis tester, rigid, experimental, started by observation, systematic and many other similar incongruences, because these aspects, alone or grouped, do not characterize the method. They are general aspects also used in several other human activities. In the above-described discussion (item 2.3) I showed the necessary procedures for a scientific study, thus defending only one scientific method. While there are other strategies and tactics in the scientific methodology, those described here are enough for now, without excluding any necessary control of undesirable variables, design creation, data analysis techniques, communication strategies and so on. All effort is done to reduce at maximum logical mistakes to explain the world from very little evidence. The unique corpus of the scientific method is strong and offers to the rational reasoning a wonderful way to produce knowledge wherever its criteria are applicable.

The important thing here is to differentiate "doing research" from "doing science". This is not meant to be a prejudiced decision, but an understanding to better take advantage of science. The scientific method is a validated way to answer several questions about the world. Thus, it can be used in science and in several other activities wherever applicable. Scientific research can be carried out in industries, companies, rural or urban areas etc., not necessarily to do science, but to solve local problems. Following this conception, society takes advantage of one of the best contributions of human reasoning.

In studies carried out exclusively under laboratory conditions, the strong control of variables usually allows scientists to elaborate valid conclusions to a wider scenario (the wide empirical universe). In field studies, however, the situation is usually not so universal. It requires of scientists epistemological challenges to elaborate more general conclusions from localized researches. This is not the same as just generalizing from local conclusions to a wider scenario. It requires a more general conception about the theoretical area where the local research can be inserted. Scientists should extract from a local research principles or patterns that can be linked to a theoretical network (defined at the end of topic 2.3), thus improving this network. That is, adding new scientific knowledge. For instance, new characterization, novel association among variables, new mechanisms and new variables still not considered, or finally enlarging or challenging generalizations already accepted.

What happens when the person makes science from the research? A research with the scientific method carefully developed will bring local solutions, which reaches a small, but necessary, part of the society. This is obviously a valuable contribution. When the scientist makes the same, he also offers this valuable contribution, but if he/she improves the scientific theoretical network, he/she reaches a very expressive larger part of the society. Note, for instance, how many products and instructions, in education, technology and other activities, our society has taken advantages and for which the necessary research was developed abroad. I am used to say that every field research is developed in a localized area. The difference is what science we can do from this localized experience. By studying the logistic of a specific industry in his/her town, a scientist can unravel a genuine dynamic of that organization and thus collaborates with recommendations for improving the logistic. This improvement might be generalized in some extent as theoretical constructions for science in the logistic subject, a knowledge that can be adapted all over the world to industries with similar profiles. It depends, of course, on having found genuine improvements in the industry under study.

4 THE LOGIC OF SCIENTIFIC THINKING

Scientific studies are based on just three logical reasonings, from which science understands the world, from the structure of the smallest particles to the most general patterns and processes of human society and the organization of earth and the entire universe. Thus, these reasonings organize any scientific research and the resulting scientific knowledge. This implies that the scientific methodology must consider such reasonings in several stages of making science and teaching. However, this has not been common practice.

4.1 What does a scientist investigate about variables?

Scientists study variables[4] and do only two things: they characterize them and test hypotheses. Hypotheses proposes associations among variables. In fact, a hypothesis relates two or more variables, one to another. It is a provisory, affirmative statement to a question, but still not adequately tested. Thus, despite a conclusion being also a provisory, affirmative statement to a question, differently from hypothesis, a conclusion was already tested satisfactorily. These two simple procedures, characterization, and testing of hypotheses, enable scientists to understand the entire world.

For instance, scientists can characterize the mean height of a population. They select a representative sample (people) and measure the height of each individual, calculating the mean value and deviations around it. Following this same focus, scientists can know what a population thinks about any subject; what things are made of; what is the profile of something; what is the growth pattern of newborn children in a national population, or blood constituent patterns, and so on. Despite the usual variations in the described traits of the subject being characterized, scientists find general patterns or the mean "normal" range representing the focused variable. They can also get a representative sample (people) of a population to characterize what their opinion about globalization, or another subject. Then, scientists ask this question to each individual of the population. Thus, from the answers of the sampled individuals, they try to detect what should be characteristic of that population and end up showing this general pattern and also discrepant results. It does not matter if they are dealing with quantitative or qualitative variables; they do the same!

When dealing with association among variables, scientists necessarily test hypotheses. The first inquiry at this aim is to know whether a relationship between the investigated variables is reasonable. In an interesting study (Oliveira et al., 2010) published in the British Medical Journal, the authors asked to 11.869 Scottish people their frequency of toothbrushing to contrast with estimates of risk of cardiovascular disease. They found these variables are associated to each other (e.g., those

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[4] Note the way I conceive variables. It is similar to concept used for categories in qualitative studies and a variable can be a physical fact or a extremely theoretical construction somehow related to distant physical variable. See topic 2.3 for more details about variables.

who reported less frequent toothbrushing had about 70% higher risk of cardiovascular disease). The next question (they still addressed) was to decide whether this association occurred because oral health affects risk of cardiovascular diseases or whether this is just a non-causal relationship, maybe related to a third subjacent variable. This theoretical question is the most exciting and intriguing to a scientist. They cannot answer these questions only based on mathematical or statistician reasoning (see topic 4.4); this needs logical and epistemological considerations.

4.2 Scientists describe variables to characterize them

Scientists can tell us what a variable is, that is, they can *characterize* variables. This is undoubtedly an important aim in science. Exciting examples are the characterization of the DNA molecule (Watson & Crick, 1953), classification of living organisms (from virus to humans) and immaterial objects for diverse purposes (ex., classification of species for phylogenetic interpretation, characterization of the dark hole for better answer questions about how it works, the earth shape (not flat, of course) to understand the universe, cultural profiles, geographical regions, climate changes to then better understand anthropogenic participation, and many others.

My proposal to replace the mostly used "descriptive studies" with "characterization studies" relies on didactical and logical purposes, both requiring changes in the methodological reasoning.

The didactical reason is that although scientists can describe variables for characterization purposes, they also can describe variables to inspect associations between them (in this case, to test hypotheses). Reasoning in these two types of investigation relies on different logical backgrounds and implies different types of research. Therefore, researchers often misinterpret that they are characterizing variables when, in fact, they are testing hypotheses. Even though the term "description" can easily be also used in the sense of "characterizing" something, this practice reinforces confusion of both types of attempts we described, because a scientist might need to describe variables to test hypotheses. For instance, they need to describe male and female vocabularies used in social media to test whether language is related to declared gender (male and female - e.g., fig. 3 in Shwartz *et al.*, 2013). The logical reasoning is very different when description is achieved to characterize one variable or to test effect of one variable to another (see, for example, reasoning to conclude about interference among variables – topics 4.3 and 4.4 below). Furthermore, in descriptive studies the separation between results and conclusions is usually not so obvious as in the case when you describe variables focusing on characterization of a variable. Results are the description aspects of the variable, from which a subset might be used to characterize the studied variable(s).

One situation where these assumptions can occur in Anthropology is easily understood if the scientist describes religious rituals in one indigenous tribe. He/she can define operational variables that will be described to result in reasonable traits that characterize that religious practice. However, the scientist can also study more than one tribe to test hypotheses about cultural elements or regional traits that can be used either to explain profiles (association hypotheses) of religious tribe rituals or to investigate which traits might have modulated such ritual profiles (interference relationships). The same reasoning is valid for studies in social sciences, education, industries, worker's class problems, economic systems, ethnic studies and so forth, until subatomic investigations. These logical reasonings are the only ones a scientist can study in the world. That is, this is a concept of science methodology.

4.3 Scientists can test hypotheses about relations among variables

Whenever a scientist has a hypothesis, the procedure is to test it, a process which is made by trying to find if the predictions resulted from the hypothesis occurred as expected. For such a goal, they must compare (a procedural consequence) levels of the supposed causal variable with the behavior of the supposedly affected variable. This is achieved by either testing quantitative correlations or by testing changes by comparing magnitudes or qualitative changes among treatments (conditions). For instance, a significant linear correlation r = 0.99 indicates a numeral correlation between two variables, an important evidence for acceptance of association and an important corollary for accepting cause-and-effect relationship (see detailed discussion in topic 4.4 below). In qualitative research, the reasoning is not different, but, of course, using qualitative evidence. You may detect correspondence between presence (+) or absence (-) of inspections in airport customs and a variation in level of attempts to smartphone smuggling, basically contrasting presence and absence of high intensities of both activities at the same times. You may also study qualitative changes in meaningful levels of expressed words, drawing traits, photos traits, color visual intensities etc. All these techniques can be used to test whether change in one variable has any correspondence with changes in the other one. This simple reasoning is the first logical step to decide about a cause-and-effect action. Of course, more detailed interference might require further tests considering multifactorial variables in the system, but this is almost a multiplication of the same basic reasoning.

That is, variables might be associated to each other either because one variable is affecting the other or even not assuming any effect among them. When the scientist assumes interference between variables, emerges the concept of independent (causal or just interferent factors[5]) or dependent variables (affected by a causal or interferent variable). This occurs even when a circular relationship exists. For instance, changing "consumer behavior" affects "goods price"; but changing "goods price" also affects "consumer behavior". In circular relationships, scientists deal with two hypotheses, in different directions. Thus, the consumer behavior is a causal factor (independent

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[5] The distinction between "causal" and "interference" is just a way to mitigate preconceptions about the term "cause and effect" currently widespread in scientific studies. Such preconceptions were born in older scenarios of science (for instance, against positivism ideology in older versions), but they are not justified in recent scientific discourses (even considering that most scientists today are still alienated from this problem).

variable) in the first hypothesis, and an effect (dependent variable) in the second one. That is, the concept of independent or dependent variable is a relative one that depends on the context a variable is considered and appears only when any interference can be accepted.

When supposing associations with no interference relationships among variables, some explanations might be thought to better conclude this is a real, not spurious, association. For instance, scientists can study the relationship among an increased number of churches and the number of serial killers, in some cities. They can find a straight association, that is, the higher the number of churches, the higher the number of serial killers. This, of course, does not imply that churches are increasing the number of serial killers, or vice-versa. When associations like this occur, scientists intuitively are not going to assume promptly an interference relationship. Following the Occam's razor (parsimony law)[6], they will interpret this relationship as a consequence of a third variable that might affect the other ones. For instance, increasing the city population could cause concomitant increase in both, number of churches and number of serial killers, thus resulting in the detected association. Because these two variables are governed by a same third variable, both express associated behavior between themselves.

Consider now that usually, but not always, lack of association implies absence of interference among variables. Why "not always"? Imagine a multivariate situation, where a set of several variables affect a dependent variable. Some or all these independent variables can be necessary, but not sufficient to the effect. That is, they need to be joined with the other interferent variables because they alone cannot cause the effect. In such a multivariate interaction, the effect is produced because of a combination of different effects. However, this does not occur when you inspect only one causal variable. This means that this interferent variable is necessary in the set, but it is not sufficient to create the effect on its own. For instance, a "soft" virus is necessary to induce flu symptoms, but if the organism is resistant to that virus, no symptoms will appear; the person must be not resistant to express the symptoms. This implies that the virus presence might be not associated with the flu symptoms in some circumstances. In population analyses, the association is not reached unless the number of non-resistant people is expressive in the sample. In this case, whenever you test association of only one variable (virus presence), it is possible the association with the flu symptoms does not appear. That is, some effects (interference or only associative) might emerge only when some combination of variables is found, and association does not appear when a causal variable is not combined with other necessary variables. For instance, increased food intake is causally related with increased body weight, but this also needs participation of necessary vitamins and enzymes to allow the ingested food to be converted into appropriate substrates for growth. Presence of undesired growth-suppressing variables (e.g., stress variables) also can result in absence of association between increased food intake and increased growth.

4.4 What criteria do scientists use to conclude about interference (cause and effect) among variables?

Note that from the three criteria shown below, only one is determined by rigid methodological ways. However, this determinist criterium is rarely usable in several areas of science, although conclusive discourses about cause and effect are widespread in all scientific areas. An important, but small, group of areas (*e.g.*, the health area) is the most restrictive about the two first criteria shown below, but the rationality of different areas still could conceive these three criteria valid in science. This applies even into the health sciences. This is assumed considering that available methodology in one area cannot be imposed for scientific studies where such applications are impossible and causal and effect relationships really occurs. This contrast is most visible between controlled experiments (in labs or field) and studies based on observations of spontaneous responses where interventions are ethically or methodologically impossible. These are not limitations of studies, but specific traits that cannot be abolished and thus should be accepted. Considering my reasoning about the three criteria I have depicted from studying different scientific areas, this dilemma should be easily unraveled even wherever traditions still prevail.

Criterium 1 – Does it make sense?

Although many scientists say that Statistic prove cause and effect among variables, it is based mostly on beliefs, not scientific reasoning. Statistic can detect association among variables, what is also obtained by non-numerical tests for qualitative variables. In figure 2, I present two graphics to discuss this criterium.

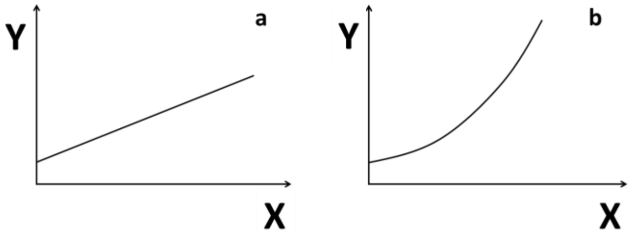

Figure 2. Significant correlations obtained for two different pairs of variables each case (a and b). See explanations in the text.

From figure 2a, a significant correlation ($p = 0.008$) occurred between axis **X** (number of pairs of reproductive storks in the respective region) and axis **Y** (number of stork chicks). We then infer that the higher the number of reproductive pairs of storks, the higher the number of stork births. This makes sense, of course. I am sure nobody doubts that this correlation represents a cause-and-effect phenomenon. Exactly why does it make sense? Because it is widely known that reproductive pairs of storks produce stork chicks. The more the storks are mating, the more chicks appear. However, consider now that the real graph obtained in the study (Matthews, 2000) had the **Y** axis as

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[6] It stablishes that one should use a more complex explanation only after the simplest ones have been neglected.

number of human baby birth rates. Ok, you are excused from now considering that this is not a causal relationship… storks do not deliver babies!

Although Matthews' study was carried out to demonstrate the difference between association and cause-and-effect relationships, here I use it to discuss a next step in this scenario: the criterium to accept cause-and-effect relationship from observation of just correlations (or associations), irrespective of methodological procedures (or designs). In this sense, notice that the conclusion on graph of figure 2a was not based on statistics, but rather on the meanings of the associated variables. This is, of course, one criterium scientists use to indicate causal effect when they obtain association among variables in which such a relationship is expected. This imposes a non-statistical consideration, but still accepted.

For instance, in graph 1b the axis **X** is number of physiotherapy sessions and axis **Y** is muscle function recovery (fictitiously regressed here). Do you accept this populational fictitious study, with samples of different people for each number of sessions, as resulted from an effect of physiotherapy on muscle recovery? How do you argue about your decision? Have you used methodological restrictions, logical content support or tradition reason?

In fact, when there is no logical causal effect between variables, scientists accept only associations. When they have a valid reason to assume interference between variables, they really attribute causal effects to the relationship. In Matthews' paper, the author got samples from regions of different sizes, so that both variables are expected to change greatly and at the same direction over regions. These effects on both variables imposes correlation between presence of storks and baby birth rates. Thus, you might be happy not to have to accept that storks deliver babies, despite p value of 0.008.

Criterium 2 – Could you better explain the effect?

Whenever you find an association that could imply interference among variables, it is helpful to detect, or suggest, a mechanism that could explain the cause-and-effect relationship. If you find such a mechanism, the conclusion about the interference between the variables is reinforced.

A mechanism is a sequence of causal relationships among variables. For instance, **X** → w → z → **Y**. This means that **X** affects **Y** and the mechanism is by the effects of **X** on w, of w on z and of z on **Y**. This means that the solution depends on other accepted cause-and-effect relationships among the variables composing the supposed mechanism. This can dive to infinite regression arguments. However, scientists accept this way cautiously by requiring that the steps of the mechanism be already widely accepted in scientific literature or that original physical evidence be included in the current study. In both cases, the logical problem persists. Although this criterium should logically validate criterium 1, as a known mechanism reinforces obviousness of criterium 1, both still continue to have to accept a non-statistical modulation of the scientific reasoning.

Criterium 3 – Have you controlled for the necessary scenario?

The third criterium is easily comprehensible, but it is a solution to very specific cases and has been mistakenly imposed as a necessary one. According to this methodological assumption, scientists must impose an obligatory change (by experimental intervention) on the supposed causal variable and register the response. I include in this method scientists should make a *random change* in the independent variable and register the dependent variable. Thus, if you detect a valid association between them in this random change, you are logically correct to accept a cause-and-effect relationship.

Despite that, the bad news is that such a solution is almost impossible to be used in most field studies required in almost all areas of science. There is a lot of cause-and-effect relationships we can imagine in field conditions. Therefore, imposition of this present criterium to areas where it is obviously impossible to be used is a fantastic way of ranking science power based on biased criteria. In some areas of study, scientists are forced by reviewers and editors to apologize in the form of "study limitations" when they infer cause and effect contrary to area traditions. Scientists should know in their hearts that the possible best knowledge should be achieved in each paper, but not definitive responses through unambiguous procedures (they also might be ambiguous in future).

Can you imagine how to test the hypothesis that the number of trees in a natural biome affects bird populations? Or that the altitude at which a species lives affects reproducibility? How can we know what a global warming can do to several organisms, considering that such warmth might increase gradually in long-time scale, changing continuously other associated variables of the environment? These problems are similar to those human sciences are faced when planning to answer several scientific questions. In this way, scientists use a reasonability criterium for inferences about causal relationships, not provoking inertia in decision making. They use the three criteria described here to infer processes of cause-and-effect.

5 THE STRENGTH OF THE STUDY DESIGN

Everyone accepts the importance of the study design for acceptance of a scientific study. But this should mean a complete design and not just a part of it. Such complete design involves information about what the main variables are, including the independent and dependent ones when dealing with interference relationships. Moreover, study design must include the differentiation of the variables and the spatial and/or temporal conditions they are distributed in the study. Moreover, it should involve sampling decisions and subject/object necessary traits.

All these information reside on the intellectual plan of a well-reasoned research and must be included on the design. Unfortunately, the study design has been resumed to very few conditions that do not allow readers to understand the theoretical architecture of the study and to better comprehend methods, results, and discussion in order to judge conclusions.

In many scientific areas such as the health sciences, it is imperative that conclusions about causal effects rely on some study designs. They almost always do not accept field observational studies to conclude about such causal effects.

They move these studies to a lower level of explanation and comprehensibility.

This imposing solution violates precepts that the history of more than 300 years of science has allowed us to use today. For example, this violates the notion that scientific truth is relative, that it must be accepted until proven otherwise, or that it is the best possible explanation at the present moment. The search for immutable truths, which logically is outside the scope of science, can lead scientists to impose what might be assumed as "gold criteria", proof, strong demonstration etc., all of which admit this truth in an environment clearly governed by uncertainty. See what happened to scientific truths, even the methodological ones, published about 5, 10, 30, 50 and 100 years ago?

One such imposition is by mandating longitudinal studies to accept interference relationship among variables, and disposing cross-sectional studies for association inferences, with no validity for causal conclusions. Sometimes, such correlational studies are used as "suggestive" of causal effects, what is reported in the respective papers as "study limitation". These thoughts drag almost, if not all, qualitative research into the hole of the "soft" science (see item 2.5), reinforcing degrees of truths clearly pre-conceived.

This situation is worst when we detect unquestionable high-level scientific journals dealing with the traditional "types of study" in an attempt to indicate the relative "strength" of the study. See bellow some examples from abstracts in a high-ranked medical journal. Some journals still include such designs in the title of the publication!

DESIGN: Retrospective cohort study; Prospective cohort study; Multicenter cohort study; Longitudinal study with up to 32 years of follow-up; Qualitative interview study; Cohort study; National population-based survey; among others.

These few examples connect to study traits that are supposed in the area as elements for decisions about quality (strength) of the conclusions. This stated in the Design represents two main faults: one that this is not a design and, except for traditional concepts, do not say much about that study; and the other is that the medical area overestimates the strength of such strategies as indicative of truth or validation of the study. Validation of a study just starts with a complete design study, properly details of procedures to run on the chosen design, appropriate techniques for data analyses and valid logical methods to elaborate conclusions in a high theoretical level.

The refereed area, and some others, deems that studies based on cohort, meta-analyses, prospective and meta- or multicenter arrangements are at a higher level of validity. On the contrary, studies using qualitative, retrospective, or cross-sectional studies are low rated to refer to some relations a scientist can study. However, which area has no study limitation? Where limitations exist, they must be faced by the authors in the sense that conclusions must be always valid for their data. Moreover, every scientist knows that each conclusion is accepted at least at the level of the respective methodology, but it might reach higher theoretical levels. In such literature, it is not difficult to detect papers declaring as limitations the fact that the sample did not represent the population, which should be a reason to not accept the paper.

6 EDUCATION FOR A SCIENTIFIC MINDSET

Due to the strength of science, teaching of the scientific mindset has gradually become more common in elementary schools. However, these classes have mainly focused on either teaching scientific knowledge by explaining the world or teaching elements of scientific research. Although this is interesting, priority in the first steps of education should be on basic elements of the scientific reasoning. These are elements necessary for adequate human values and reasoning. I name this broader universe as the scientific mindset. Despite specific rules of experimentation and other scientific studies are included, the first steps should focus on the most known logical elements (deduction, induction, analogy) and creativity, but prevailing broader concepts of scientific thinking. Unfortunately, such broader concepts are usually never properly included in the school contents. The main focus has usually been on research itself. They are concepts brought from science's basic principles useful and necessary for any human being.

The study on the theoretical bases of science indicates essential elements for scientific reasoning, far beyond the simple creation and elaboration of a scientific research by means of themes choice, elaboration of objectives including or not hypotheses, creation of designs and emerging conclusions from the results. The scientific mentality involves logical and creative elements underlying this specific elaboration of the research, as well as enthusiasm for situations that enhance the scientific formation. Let us look at some of these precepts: mastery of deductive, inductive and analogous reasoning; perception of patterns within variability; high commitment to intellectual honesty; truth concepts; strength to face intellectual obstacles; passion for novelty and challenges; mental restlessness; taste for uncertainty; communication ability; among others. More importantly, a deeper commitment with human values (the endpoint of scientific activities). These concepts are dictated by scientific methodology and philosophical bases of modern science (in the terms shown in this paper), but they require specific teaching because they breast bases of authoritarianism, prejudices, dishonesty and illusory naïve social arrangements.

When substrates such as those listed above are incorporated into educational programs to be treated from kindergarten to elementary school, we will in fact be developing scientific mindset, much more than just training the most technical part of being a scientist. Such a mentality is a necessary substrate for scientific thinking that will be practiced via research, as well as for the integral development of a necessary human being. Therefore, such a scientific mindset is also of undoubted importance for the humankind, irrespective of the career each one will follow.

7 FINAL REMARKS

For all the reasons presented in this brief text, I emphasize the need for caution when referring to scientific methodology. It cannot be considered a multifaceted construction to accommodate traditions of different areas.

It is worth thinking about a unique scientific method, so that each area can learn with others, and do not justify traditions from differences in data traits or scenarios. Every scientist study variables, both operational and theoretical, trying to say what they are and how they are associated to each other, thus understanding the world. Such reasoning requires a deep learning processes, starting in the beginning of formal school and focusing on logical and communication skills necessary for a scientific reasoning in the future.

REFERENCES

Matthews R. Storks deliver babies (p = 0.008). *Teaching Statistics* 22(2): 36-8, 2000.

Oliveira C, Watt R, Hamer M. Toothbrushing, inflammation, and risk of cardiovascular disease: results from Scottish Health Survey. *British Medical Journal*, 2010;340:c2451, doi:10.1136/bmj.c2451.

Shwartz H. A. et al. Personality, gender, and age in the language of social media: the open-vocabulary approach. *Plos One* 8(9): e73791, 2013.

Volpato, G.; “Método Lógico para Redação Científica”, 2nd Ed., Ed. Best Writing, Brazil, 2017

Volpato, G. “Ciência – da Filosofia à Publicação”, 7th Ed, Ed. Best Writings, Brazil, 2019