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Some notes on the pedagogical value of historical pathological science examples from Chemistry and Physics and related sciences

Sérgio Paulo Jorge Rodrigues

Resumo

Os dados biográficos sobre cientistas, e em particular de químicos e físicos, podem ser usados como elemento motivador dos estudantes e público assim como um instrumento humanizador da ciência e demonstrativo da forma como esta funciona na prática. A dimensão humana da ciência emerge naturalmente da análise de apontamentos biográficos que enfatizem os dilemas e os sucessos e fracassos dos cientistas. Os episódios históricos e as atitudes e acções dos cientistas mostram como funciona a ciência e dão aos estudantes e público a possibilidade de reflectirem sobre a ciência e a sua humanidade, assim como de desenvolverem a capacidade de desconfiar do anacronismo, da pseudo-ciência, da ciência patológica e da fraude científica, para melhor apreciarem e entenderem o desenvolvimento da ciência. Começando com uma breve revisão dos sintomas e critérios propostos na literatura para distinguir desvios anormais, neste trabalho são analisados alguns casos de produção de ciência patológica nos campos da química e da física, procurando, a partir destes, evidenciar caminhos pedagógicos que fomentem o espírito crítico dos estudantes e do público.

***Palavras-chave**: Biografias de cientistas, estratégias pedagógicas, humanidade da ciência, pseudo-ciência, ciência patológica.*

Abstract

Biographical data about scientists, and in particular about chemists and physicists, can be used for engaging students and the public, humanizing the science image, and for demonstrating how it works in the practice. The human dimension of science emerges naturally from the analysis of biographical aspects that emphasize the dilemmas and the successes and failures of scientists. The historical episodes and the attitudes and actions of scientists show how science works and offer students and public the opportunity to reflect about science and its humanity, as well as to develop the capacity to distrust anachronism, pseudo-science, pathological science, and scientific fraud in order to better appreciate and understand the action and development of science. Starting with a brief review of the symptoms and criteria proposed in the literature to distinguish deviations from normal science, this work analyzes some cases of production of pathological science, focusing on chemistry and physics, seeking pedagogical paths that foster the critical spirit of students and the public.

***Keywords**: Biographies of scientists, pedagogical strategies, the humanity of science, pseudo-science, pathological science.*

INTRODUCTION

The advantages of using history of science in science teaching are well established.[1],[2] In particular, the use of bibliographic information in general contexts, including teaching, with the explicit

[1] Matthews, Michael R., *Science Teaching: The Role of History and Philosophy of Science*. New York: Routledge, 1994.

[2] Prestes, Maria Elice de Brzezinski, Silva, Cibelle Celestino (eds.), *Teaching Science with Contex: Historical, Philosophical, and Sociological Approaches*. Springer, 2018.

inclusion of human anecdotal and borderline aspects of science can be valuable.[3] The present work will focus on the use of pathological aspects of science activity, centered on scientists practice and biographic aspects, for teaching and popularization purposes.

Of course, science teaching should be centered in the normal aspects of science, but there are situations when the pathological aspects can be useful, namely for a deeper understanding of the nature of science (NOS) and for exercising the critical thinking of the students.[4]

The difficulties of the present endeavor start with the definition of "pathological science"[5] that is connected to the "demarcation problem", *i.e.*, the formal distinction of science from non-science, which is a difficult subject involved in much discussion.[6] Thus, the initial part of this work will be devoted to a brief review of terminology and discussion of its scope. A pragmatic view will be attempted based on examples, instead of a more formal treatment.

The first set of relevant concepts are "science" versus "pseudo-science", and "non-science". Within the concept of "science" one can also consider "normal science" versus "fringe science" or "revolution science", and "good science" versus "bad science",[7] "flawed science," and "pathological science." One can also discuss whether "bad science," "flawed science," or "pathological science" are still "science" in contrast with "pseudo-science" or "non-science" that by semantic criteria are not science. Let's accept that "science" is (i) research work that is produced by scientists, i.e, persons trained as scientists and recognized as scientists by their peers, and (ii) is presented as science, following the rules accepted by the scientific discipline and community, in particular, theories having a generalized empirical verifiable scope and internal logic, and is reviewed or, can be analyzed using scientific tools, by peers. Let us also consider that such definition excludes pseudo-science and non-science works, which is, of course, tautological, as it depends on the definition of what is "pseudo-science" and "non-science."

Non-science is easy to distinguish from science and can include, but are not limited to, works of art, literary and religious texts, poetry, and speculation, that may be characterized by the accepted view of the authors, and of the generality of the scientific community, that are non-scientific works in the above

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3 Rodrigues, Sérgio P. J., "What can Chemists and the Public Learn from Biographies of Chemists?" in *Perspectives on Chemical Biography in the 21st Century,* Isabel Malaquias, Peter J. T. Morris (eds.). Cambridge Scholars Publishing, 172-179.

4 Allchin, Douglas, "Teaching the Nature of Science through Scientific Errors." *Sci. Ed.* 96 (2012): 904–926.

5 Langmuir, Irving, "Pathological Science", Report no. 68-C-035, April, General Electric R&D Center; transcribed by Robert N. Hall, 1968. Available http://galileo.phys.virginia.edu/~rjh2j/misc/Langmuir.pdf (accessed June 23, 2019); Langmuir, Irving, Hall, Robert N., "Pathological Science", *Physics Today* 42 (1989): 36-48.

6 A revision and recent proposal can be found in Fasce, Angelo, "What do we mean when we speak of pseudoscience? The development of a demarcation criterion based on the analysis of twenty–one previous attempts", *Disputatio. Philosophical Research Bulletin* 6 (2017): 459–488.

7 Goldacre, Ben, *Bad Science.* London: Fourth Estate, 2008.

sense. In addition, pseudo-science contemplates works those works that are presented as science but are not accepted by the scientific community as scientific knowledge. Fasce,[8] based on the review of previous works published on this subject, collected 21 criteria that split into 70 claims, from which he obtained the following criteria for defining "pseudo-science" here restated as questions: It is presented as science? The entities studied are scientific subjects? The methodology is adequate? It is supported by evidence? Clearly, these criteria are also tautological, as they depend on the definition of the concepts what they want to define.

One can refer to the more formal Popper's falsifiability criteria,[9] Kuhn's paradigms and puzzle-solving,[10] and Lakatos' idea[11] of scientific progress through progressive and productive programmes, but all have same kind of difficulties as a general tool.

Less formal approaches are available. In a popular internet site, Compound of Interest,[12] the separating of "science" from "pseudo-science" is based on a set of twelve symptoms: (1) Sensationalized headlines, (2) misinterpreted results, (3) conflicts of interest, (4) correlation & causation, (5) unsupported conclusions, (6) problems with sample size, (7) unrepresentative sample used, (8) no control group used, (9) no blind testing use, (10) selective reporting the data, (11) unreplicable results, (12) non-peer reviewed material. It is obvious that most of this criteria are somehow failed by one or another scientific discovery now firmly accepted, but it is fallacious to think that they are not valid as symptoms or as alert flags of bad science, or, conversely, that a scientific claim that does not infirm of any of this is correct. But this does not mean that they are non-useful, as the larger the number and the more evident are the criteria failed, the more "bad science" it could be. This claim is reminiscent of the idea of probabilism, referred by Lakatos: Instead of a sharp distinction between science and pseudoscience, one can have a continuous scale from poor theories with low probability to good theories with high probability.[13] Some of these criteria are not failures of the scientific methodology, but failures of the integrity or abnormal development of the scientific process. Moreover, lack of peer-review, conflicts of interest, and call the media before publishing can also be considered a criterion for being outside science.

In summary, there are various approaches for defining what is "pseudo-science" and "bad science", some including the latter in the former or vice-versa, but it is very difficult to establish universal criteria.

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8 Fasce, What do we mean when we speak of pseudoscience? 476.

9 Popper, Karl, *Conjectures and Refutations*. New York: Basic Books, 1963.

10 Kuhn, Thomas S., *The structure of scientific revolutions*. The University of Chicago, 1970.

11 Lakatos, Imre, *Philosophical papers. Vol I: The methodology of scientific research programmes*. New York: Cambridge University Press, 1978.

12 Brunning, Andy, "A Rough Guide to Spotting Bad Science", 2015. https://www.compoundchem.com/-2014/04/02/a-rough-guide-to-spotting-bad-science/ (accessed July 6, 2019).

13 See Lakatos, *Philosophical papers*, 1978, 3, 11, and references therein.

It is also evident that a human factor is always involved in science activities, even in "normal science", something that is not always taken into account. Lakatos points out that:

> *No single experiment can convince scientists that their point of view is wrong, even in science considered "normal": Scientists have thick skins. They do not abandon a theory merely because facts contradict it. They normally either invent some rescue hypothesis to explain what they then call a mere anomaly or, if they cannot explain the anomaly, they ignore it, and direct their attention to other problems.*[14]

This conducts us to the idea of "pathological science"[15],[16] that is "science" resulting from "normal science", "fringe science", or "revolution science" that, due cognitive failure, delusion, or stubbornness, evolves to "foolish". Some authors[17] discuss that eventually "foolish" can evolve to misconduct, and fraud, but there is no need to include this two classes of "bad science" in the concept of "pathological science." Conversely, Bauer[18],[19] claims that "pathological science" do not implies misconduct and is not pathological at all, as we will see in the next section. In any case, real fraud is a distinct aspect of "bad science" due to its intentional mark. The Schön scandal is one of the best known recent cases of fraud in science, but there are many others.[20] It can be a matter of reflection that some of Schön's claims were confirmed or attained by others using nor-fraudulent methods, even if the self-correcting aspect of science took much time.[21] Differently, from non-fraudulent wishful thinking or non-intentional error, that can be considered as "pathological science", fraud and forgery, are considered unacceptable and forgers are expelled from the scientific institutions and community and consigned to oblivion and disdain.

From a psychological point of view, Mitchell[22] describes the pathology in science as a two-level failure of the normal scientific critical inquiry process: *first, a hypothesis is accepted without serious attempts being made to test it; and, second, this first-level failure is ignored.* As the error and its correction are normal in science, the pathology is related to a persistent failure of the cognition that creates an

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14 Lakatos, *ibid.,* 3-4.

15 Langmuir, Pathological Science.

16 Rousseau, Denis L., "Case Studies in Pathological Science." *American Scientist* 80 (1992): 54-63.

17 Park, Robert L., *Voodoo Science: The Road from Foolishness to Fraud*. New York: Oxford University Press, 2000.

18 Bauer, Henry H., "Pathological Science is not Scientific Misconduct (nor is it pathological)." *Int. J. Phil. Chem. (HYLE)* 8 (2002): 5-20.

19 Bauer, Henry H., *Science Is Not What You Think: How It Has Changed, Why We Can't Trust It, How It Can Be Fixed.* Jefferson (NC): McFarland, 2017.

20 Odling-Smee, Lucy *et al.* "Where are they now?" *Nature* 445 (2007): 244-245.

21 Reich, Eugenie Samuel, *Plastic Fantastic: How the Biggest Fraud in Physics Shook the Scientific World.* New York: Palgrave MacMillan, 2009.

22 Michell, Joel, "Normal Science, Pathological Science, and Psychometrics". *Theory & Psychology* 10 (2000): 639–667.

incapacity to see the error or ignores the possibility of error. This is in fact, what is considered being "foolish," and it is a very human characteristic. Moreover, in an interesting work that proposes the use of astrology to discuss the problem of demarcation,[23] it was concluded that the *methods and behavior of disciplinary practitioners should also be examined,* in contrast to a discussion solely based of ontological demarcation principles.

Previous works,[24,25] although not explicitly pointing to the human aspects of science, provide useful sets of situations to analyze. Allchin's proposal, directed for teaching the nature of science based on errors and their corrections,[26] most of them of normal nature, provide interesting examples, with a very useful bibliography. Conversely, Epstein[27] proposes the use of "bad science" to teach good chemistry, with a myriad of different claims, including a useful bibliography and suggestions of exploration: poly-water, cold fusion, n-rays, bio-transmutation, Landolt violation of the conservation of mass, Allison magneto-optical methods for chemical analysis, standard reference materials syndrome, Brown's gas, red mercury. Minor frauds or delusions, as the *water [quality] tester* based on the electrolysis of salts in tap water, laundry disks (or balls), "miracle" battery additives, and, a much more problematic, and large scale delusion that is homeopathy. Epstein also refers to popular pseudoscience subjects as [modern] alchemy, pyramid power, UFOs and cattle mutilation, and psychokinesis. The supposedly material demonstrations of miracles (opposed to Faith that is non-science) as the ones involved in Saint Januarius' blood and the Shroud of Turin, and search for the mass of the soul are also proposed. Most of these subjects involve significant human, sociological, and philosophical aspects.

In the next sections, the concept of "Pathological Science" and the symptoms proposed for identifying it are analyzed and discussed at the light of the works and lives of Dorothy Wrinch, Irvin Langmuir, Fred Hoyle, Linus Pauling, Jacques Benveniste, and Martin Fleischmann (see Table 1).

LANGMUIR'S PATHOLOGICAL SCIENCE SYMPTOMS

Irvin Langmuir (1881-1957) was a chemist, Nobel Prize in 1932, that worked in university and industry – with 138 personal patents - that have contributions on theory of gases, chemical bond, reactions on surfaces, and is known also for the improvement of the tungsten lamp.[28] His well-known talk on

23 Turgut, Halil, "The Context of Demarcation in Nature of Science Teaching: The Case of Astrology", *Sci. Educ.* 20 (2011): 491–515.

24 Allchin, Douglas, "Error Types", *Perspectives on Science* 9 (2001):38-59.

25 Epstein, Michael S., "Using Bad Science To Teach Good Chemistry", *J Chem Ed* 75 (1998): 1399-1404.

26 Allchin, Teaching the Nature of Science.

27 Epstein, Using Bad Science To Teach Good Chemistry.

28 Suits, C. Guy, Martin, Miles J., *Biographical Memoir of Irving Langmuir (1881—1957)*. Washington (DC): National Academy of Sciences, 1974.

"pathological science" was delivered in 1953[29] and was transcribed by Hall in 1968 with questions and answers, and published in an abridged version in 1989. In this, Langmuir analyzed a set of works, namely Davis-Barnes Effect, Blondlot's N-rays, mitogenetic rays, Allison effect, Rhine's extrasensory Perception, and flying saucers, and propose a set of six symptoms to identify Pathological Science:

> *L1. The maximum effect that is observed is produced by a causative agent of barely detectable intensity, and the magnitude of the effect is substantially independent of the intensity of the cause.*
>
> *L2. The effect is of a magnitude that remains close to the limit of detectability; or, many measurements are necessary because of the very low statistical significance of the results.*
>
> *L3. Claims of great accuracy.*
>
> *L4. Fantastic theories contrary to experience.*
>
> *L5. Criticisms are met by ad hoc excuses thought up on the spur of the moment.*
>
> *L6. The ratio of supporters to critics rises to somewhere near 50% and then falls gradually to oblivion.*

Denis Rousseau[30] analyzed three more examples, polywater, the memory of water, and cold fusion, and restated Langmuir's symptoms in the following form:

> *R.1 Effects are often in the limit of detectability and have very low statistical significance.*
>
> *R.2 Readiness to disregard prevailing ideas and theories.*
>
> R.3 blindness to critical testing experiments and critics.

The use of the word *symptoms* points better to *pathology* in science and is more adequate than the word *criteria* that points to demarcation, but, in practice, most of the authors mix the use of both terms.

Bauer[31] claims that Langmuir's text is *not a technical philosophical treatise,* which is a fallacy. Bauer also presents examples of "good science" (or supposedly so) that invalidate in a way or another Langmuir symptoms. For instance, being almost isolated defending a theory, or working alone, is invalidated by the works Einstein, Mendel or Wegener. Also, according to Bauer, Langmuir's symptoms fit in the discovery of prions by Prusiner, and in high-energy physics, that deals with phenomena with a "magnitude that remains close to the limits of detectability" and "many measurements are necessary". Bauer continues claiming that L4 describes well modern cosmology – Big Bang, black holes, string theory, 11-adimensional universes and many-world theories, and Anthropic Principles. Curiously many physicists, consider that some of these theories are speculation, thus non-science. Bauer also refers to the revival of field theories of life and the works of the plant physiologist Rupert Sheldrake, that are in the fringe of science classified by the generality of the scientific community as pseudo-science or non-science.

29 Langmir, Pathological Science.
30 Rousseau, Case Studies in Pathological Science.
31 Bauer, Pathological Science is not Scientific Misconduct.

Bauer (b. 1931) was trained as a chemist and has a solid career in Analytical Chemistry and is emeritus professor from Virginia Tech.32 In recent years Bauer becomes a defender of fringe theories, that approach "pathological science", arguing in favor of the existence of the Loch Ness Monster, and supporting non-virus HIV hypothesis. Of course, claiming, or even discuss, that Bauer attacks the idea of "pathological science" due to his fringe theories support is an unacceptable a*d hominem* fallacy, but knowing the theories that Bauer defends and his strong views on science33 provide a more accurate context.

It is notable, that during the discussion of Langmuir's talk it was remarked that those symptoms would apply very well to the theory of relativity that involves the *measurements of very small fractions of a degree of arc in the neighborhood of a bright disk of the sun.* In the answer, Langmuir preferred to remember that Laue and Bragg's theory of x-rays as electromagnetic waves first reports could have been another case of wishful thinking, but in a few years, they were able to make precise measurements. It is not the wishful thinking that is pathological but the persistence on it.

Non-pathological theories can lead to new experimental facts that can be tested. Even if they appear to suffer form symptom L4 (or R2), they do not suffer from L5 nor L6 (R3). Lakatos[34] analyzes the cascade of events, proposed theories, and experiments, that eventually lead to the confirmation of the discovery of the neutrino, originated by Chadwick's discovery of the continuous spectrum of radioactive beta-emission in 1914. It was proposed violation of the conservation of energy, conservation only in a probabilistic sense, and at the end, a new conservation principle emerged, the spin conservation. Although errors occur, and some degree of stubbornness is natural, they were corrected during the process.

The failed demonstration of the existence of tachyons (hypothetical particles that travel faster than light) in 2011 suffer from symptoms L1-L3 (R1) but the theories are firmly anchored on general relativity theory (L4 and R2 are absent). The error was promptly corrected, so L5 (R3) symptom does not manifest.

In summary, not all Langmuir's (or Rousseau's) symptoms have to be verified for suspicion of "pathological science", nor verification of some of the symptom is a guarantee of pathology. In the end, as Langmuir said in the talk "*the test of time is the thing that ultimately checks these things"* but sometimes not even the time as happens with pathological science related to homeopathy.

DOROTHY WRINCH, LANGMUIR, AND THE CYCLOL THEORY OF PROTEINS

Langmuir is the co-author with Dorothy Wrinch (1894-1976) of a series of papers, from 1937 to 1939, on the cyclol theory of proteins, in which proteins are taken as sheets of rigid hexagonal structures

32 The Wikipedia page about Henry H. Bauer and its references are comprehensive: https://en.wikipedia.org/wiki/-Henry_H._Bauer (accessed Jully, 30, 2019).

33 Bauer, *Science Is Not What You Think.*

34 Lakatos, *Philosophical papers*, 81-86.

(the cyclols) formed by amino acids held together by covalent bonds, that proved to be wrong.[35] Nothing pathological in this, except that Wrinch, having proposed the theory in 1936, continued to defend her theory after the scientific community considered it to be false, till the end of her life. Coffey[36] give a very vivid picture of the public and private scientific discussions involving Wright and Linus Pauling about the cyclol structure. According to Coffey, they were both arrogant and acerbic. Langmuir defended her and states that Pauling and its collaborators were unfair with her, and eventually suggested her for the Nobel Prize in 1939. Pauling, as a chemist, proposes that Wrinch's cyclol structure was wrong, because it does not conform with experiment, and theories that contradict experiment must be rejected. Wrinch interpreted experiments differently, and, as a mathematician, believed that topology is superior to chemistry and that the beauty of the theory guarantee that it must be valid somewhere, even if some details are wrong. In fact, the theory was thermodynamically and sterically inadmissible.[37]

Coffey points out, that till the 1940s there was still room for scientific dispute about the structure of proteins, but somehow related with the violence of the discussion and the attitude of the participants, Wrinch was somehow put aside from funding. But this was somehow due to her arrogance and sense of persecution when criticized.[38]

A brief account of Dorothy Wrinch life and works was published by Maureen Julian,[39] followed by a letter[40] from Pauling proposing some clarifications on his role and his view of the discussion, and another claiming that Wrinch was not a good female model as Dorothy Hodgkin, and others.[41] A more extensive biography of Dorothy Wrinch is also available[42]. She was the first women to obtain a doctor of science degree from Oxford and was known for her ambitious attitude and forceful manner among male peers. Wrinch also published more than a dozen of philosophical works on the scientific method and can be considered a pioneer of chromosome theory and molecular biology.

Interestingly, a major contribution of Langmuir for this theory was the idea of hydrophobics interactions that proved to be the most important factor in holding together proteins, something that Bernal,

35 Patrick Coffey, *Cathedrals of Science: The Personalities and Rivalries That Made Modern Chemistry*. Oxford University Press, 2008.

36 *Ibid.*, 259-268.

37 Tanford, Charles, "How protein chemists learned about the hydrophobic factor", *Protein Science*, 6 (1997): 1358-1366, 1997.

38 *Ibid.*, 1360.

39 Julien, Maureen M., "Dorothy Wrinch and a search for the structure of proteins". *J. Chem. Educ.* 61 (1984): 890-891.

40 Pauling, Linus, "Dorothy Wrinch and a search for the structure of proteins (letter)". J. Chem. Educ. 64 (187): 286.

41 Martin, R. Bruce, "Dorothy Wrinch and a search for the structure of proteins (letter)". J. Chem. Educ. 64, 1987, 1069.

42 Senechal, Marjorie *I Died For Beauty: Dorothy Wrinch and the Cultures of Science*. Oxford University Press, 2012.

also disproving and angry with the cyclol theory was able to see, managing *to find the gem of truth within the dross*, and Pauling, concentrated in the hydrogen bond, was unable to notice.[43]

Do the Langmuir symptoms for "pathological science" apply to cyclol theory? Coffey proposes that only L6 applies, at least in the beginning of the discussion. But, as after some time it becomes evident that the theory does not conform to experimental results, and Dorothy Wrinch continued publishing articles on it and working on it, focusing on special or ambiguous cases, symptoms L4 to L6 (R2 and R3) clearly apply (of course, symptoms L1 to L3, or R3, are not applicable to this theory).

Cyclol theory provides an interesting situation for a class discussion or a historical simulation using Allchin[44] methodology. It involves human aspects of science, including the behavior of the scientists in public and in private, and the supposedly non-applicable gender aspects (Bernal and Pauling are known to be non-misogynistic), and the analysis of two different theories based on different molecular structures, as well as the consequences of the theories. It is also relevant the interdisciplinary aspect, involving biology, and the appearance of molecular biology.

LANGMUIR AND CLOUD-SEEDING

Another work of Langmuir that can be analyzed in terms of pathological symptoms is the

cloud-seeding experiments that he and collaborators have done after 1948, and that he considered "the most important paper I have ever given" and never admitted the possibility that he was wrong, until his death in 1957.[45] He claimed to have changed the weather in all United States by one of such experiments, but the meteorologists and statisticians were skeptics of this claim as they knew the bias that can appear in such experiments. It can be attributed to this claim the symptoms L1 to L4 (R1 and R2), but the experiments had been conducted very carefully based in solid science from surface chemistry extended to meteorology. Probably Langmuir had been somehow "fooled" by the perceived importance of his discovery and even today there not a consensus on the efficacy of cloud-seeding.

This case can also be brought to class. The emphasis can be the discussion of the interdisciplinary aspects involved, that could have lead to resistance from the scientists in the other fields, the "foolish" of thinking to have a definite solution, and the knowledge that the answer for the scientific problem is not yet known with certainty, many years after.

PATHOLOGICAL SCIENCE AS A CONSEQUENCE OF THE SUCCESS OF SCIENCE AND SCIENTISTS

43 Tandorf, How protein chemists learned about the hydrophobic factor, 1362-1364.

44 Allchin, Douglas, *Teaching the Nature of Science. Perspectives & Resources*. Saint Paul: SHiPS Education Press, 2013.

45 Coffey, *Cathedrals of Science,* 283-290.

Extraordinary claims need extraordinary proves, and scientists with courage and self-confidence to continue fighting for their ideas, even when almost alone. This can give high returns and posterity. Pasteur claims of the existence of microorganisms that do not appear by spontaneous generation, eventually led to sterilization, medical asepsis, pasteurization, and the understanding and the rational development of vaccines, creating new fields of research, and giving Pasteur's name immortality.

New discoveries and paradigm change need creativity and divergent thinking, self-confident scientists, sometimes fighting against all odds. The price that some pay for having this treats is being caught by delusion, wishful thinking, or foolishness, producing "pathological science" instead of "revolution science".

It is often difficult to distinguish a "replication failure" from a "non-confirmation", or simple error from intended deception. Newton, Millikan, Mendel, all appear to have discarded data that do not confirm their theories. Einstein rebuilds his demonstrations several times. Only the time can show that the theories and models are right and able to produce new knowledge and discoveries.

Moreover, when prominent scientists are tempted or feel an urge to enter in new but already established fields, they do it usually with excess confidence, if not with arrogance, extrapolating the successes obtained in their original field. Langmuir entered in meteorology, supported by his results on surface chemistry and smoke studies, willing to solve rain problems. Another paradigmatic case is the Linus Pauling claims form vitamin C in medicine, supported by his chemical and biochemical achievements, thinking that he can solve the problem of mental illness, flue, and cancer! Both were somehow caught by a kind of "foolishness" that can be discussed in the category of "pathological science".

Other cases related to human "foolish" to consider here are the memory of the water theory, of Jacques Benveniste, the cold fusion of Fleischmann and Pons, and the *panspermia* hypothesis of Fred Hoyle. Other pathological science episodes as "poly-water" and the ones pointed out by Langmuir will also not be analyzed here. Nevertheless, it must be remarked that Bauer's opposition[46] to Feynmann's thermodynamic argument against the existence of poly-water – that if this water existed an organism had found a way of using it to obtain energy – based on the stability of diamond and graphite is erroneous!

LINUS PAULING AND VITAMIN C AS A PANACEA

Linus Pauling (1901-1994) is one the most well known chemists, Nobel Prize of Chemistry, 1954, and Peace, 1962. Working in various fields, Pauling contributed to quantum chemistry, chemical bond and molecular structure, the structure of proteins and DNA, and other fields. He started in the mid-1950s developing the idea of "orthomolecular" medicine based on the idea that the right amount of some

46 Bauer, Pathological Science is not Scientific Misconduct.

necessary molecules will promote reactions equilibrium and health. His claims that taking high doses of vitamin C is advantageous for health started at the end of the 1960s, and, based on a study that was highly criticized, in 1976, he also claimed that it can cure cancer. The meta-analysis of all the clinical studies made and the accumulated evidence are inconclusive for any effect of vitamin C for cancer[47] but there are many persons, including medicine doctors that still believe in the great advantages of vitamin C.

This is a case of a well-known scientist that enters in other fields and uses his influence to promote a theory that turns out to be "pathological science" (L1-L6 and R1-R3, apply) with impact in the life of the persons. The developments of believes, delusion, and blindness to error, are in this case also very important.

FRED HOYLE AND THE PANSPERMIA THEORY OF THE ORIGIN OF LIFE

Fred Hoyle (1915-2001) can be view as a different case of possible "pathological science" because his later theories are somehow out of science, and can be classified as speculation. Hoyle is a respected cosmologist that could have received the Nobel Prize, as some of his collaborators, but preferred to give more attention to the hypothesis that life began on space, and spreads in the universe through *panspermia*, as well as, that evolution and life on Earth are influenced by viruses from space via comets.[48] And when journals start refusing to accept his papers on those theories, Hoyle abandoned the normal process of science of peer-reviewing and published popular books about those theories. Hoyle and Chandra Wickramasinghe (b. 1940) proposed that comets had a significant percentage of organic compounds, before this was confirmed, and defended that the pandemics of flu had an extraterritorial origin. Also, although being a co-author of the theories that helped to confirm the Big Bang theory, ironically, never accepted it, preferring the idea of a steady-state universe. Wickramasinghe continued his works and are still active and respected publishing his works in journals of the productive area they had been pioneers, the Astrobiology. A particular challenge of this case of supposedly pathological science, that suffers from L1-L5 (or R1-R3), but ironically not L6 (as this theory have nowadays much more followers) is to discuss if it can be classified as pathological or not.

HOMEOPATHY, JACQUES BENAVISTE, AND THE MEMORY OF WATER

47 Cabanillas, Fernando, "Vitamin C and Cancer: What can we Conclude – 1,609 Patients and 33 Years Later?" *P. R. Health Sci. J.* 29 (2010):215-217.

48 Hoyle, F., Wickramasinghe C., *Lifecloud – The Origin of Life in the Universe*. J.M. Dent and Sons, 1978.

Although the prevalence of the use of homeopathy is relatively small, between 1-3% worldwide,[49] it is well known that its use can delay the introduction of really effective methods for dangerous diseases as cancer or infections. Although the scientific demarcation problem is in this case solved for the majority of the scientific community, homeopathy dismissed as pseudoscience, the problem continues as a sociological problem beyond the rational scientific attitude expected even from scientists.[50] A survey among Swiss medical doctors[51] reveals that 23% prescribed homeopathic medicines but only 23% actually thinks that it has any effect, so, only around 5% of the doctors believe in homeopathy. These numbers show again that the human factor is of utmost relevance.

By proposing an increase of potency with dilution, homeopathy is not congruent with the accepted science and is a pseudoscience. Since more than one-century homeopathy is dismissed as impossible. In Portugal, just to refer some examples, the writer Camilo Castelo Branco (1825-1890)[52] refers to it as the method for transforming the ocean in a useful medicine with ten drops of a poison, and the famous medicine doctor Sousa Martins (1843-1897), "explained" that "a homeopathic chicken soup" can be made from the shadow of a chicken on hot water. Besides the incredible amount of studies that failed to show the effects of homeopathy or are inconclusive, and the recent approaches based in the hormesis effect, it is relevant, due to its "pathological science" signature, the 1988 article of Jacques Benveniste (1935-2004), published in Nature,[53] and dismissed as erroneous due to unintentional bias of measurements and bad control.[54] This work, that promotes the "water memory theory", has more than 950 citations, a reasonable part still using it to support homeopathy. The main "pathological" aspect is that Benveniste continued, till the end of his life, defending the water memory theory and researching on the transfer of biological activity by electromagnetic fields, and other related subjects.

MARTIN FLEISCHMANN AND THE COLD FUSION

Martin Fleischmann (1927-2012) was a respected researcher on electrochemistry, Fellow of the Royal Society, but in 1989, age of 56, with Stanley Pons (b. 1943), pressed by their university, due to a

49 Relton, Clare et al. "Prevalence of homeopathy use by the general population worldwide: a systematic review", *Homeopathy* 106 (2017): 69-78.

50 At the *Fist International of History of Science in Education*, in Vila Real, Portugal, 2019, where a preliminary version of this paper was presented, the author found, in a non-systematic way, during small talk with participants, five scholars that had used homeopathy and believe that it has some effect.

51 Stefan, Markun, et al. "Beliefs, endorsement, and application of homeopathy disclosed: a survey among ambulatory care physicians" *Swiss Med Weekly* 147 (2017): w14505.
Available https://smw.ch/article/doi/smw.2017.14505 (accessed July 30, 2019).

52 Rodrigues, Sérgio P. J., *Jardins de Cristais: Química e Literatura.* Lisboa: Gradiva, 2014, 150.

53 Davenas, *et al.*, Human basophil degranulation triggered by very dilute antiserum.

54 Maddox, John, Randi, James, Stewart, Walter W., "High-dilution experiments a delusion" *Nature* 334 (1988): 287-290.

competing group, announced to the media what was become known as "cold-fusion," before publishing the details of the experiment and the results. This appeared after some time published in a relatively obscure scientific journal of electrochemistry, but, immediately, after the announcement, all around the world, several groups tried to replicate the results, with a generalized failure. After a relatively public disapproving for "bad science", Fleischmann and Pons moved to France in 1992 and worked in a Toyota-sponsored laboratory that was closed in 1998 without conclusive results. As an additional consequence, Pons rejected American nationality. This episode and its sequels, namely the continuing of the research on "cold fusion" by Fleischmann and Pons, and several other enthusiastic researchers and groups, with scientific meetings and journals, books, fantastic theories, "bad science" technologies, fraud, and even some parts of conspiracy theory, is considered a typical example of "pathological science"[55,56] that still today, 30 years after, inquires us about the way science work.[57]

This episode, involving also L1-L6 (or R1-R3) symptoms, raises various human questions related with the pressure to obtain and present new and amazing results, delusion, "foolishness" and (possibly) incapacity to recognize errors when the publicity attains large proportions. Personal biographical reminiscences and analysis can be useful.[58,59] The limits of science and theories "to good-to-be-true" can also be discussed, in the perspective of the scientist and the public.

CONCLUSIONS

A brief review of the symptoms proposed in the literature for "pathological science" has been done and employed in the analysis of well-known cases. The emphasis is on the biographical and human aspects that foster the critical spirit of students and the public.

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Table 1: list of scientists proposed to discuss "Pathological Science" issues.

Scientist	Date of the theory	abriged	Langmuir or	Observations

55 Rousseau, Case Studies in Pathological Science.

56 Park, *Voodoo Science.*

57 Ball, Philip, "Lessons from cold fusion, 30 years on". *Nature* 569 (2019): 601.

58 Simon, Bart, "Public science: media configuration and closure in the cold fusion controversy" *Public Understand. Sci.* 10 (2001): 383–402.

59 Martin Fleischmann, "Interview: Fusion in a cold climate" *The New Scientist* 203 (2009): 28-29; see also https://www.infinite-energy.com/iemagazine/issue11/fleishmann.html, 2005 (accessed July 30, 2019).

	or work	description	Rousseau symptoms	
Dorothy Wrinch (1894-1976)	1936	cyclol theory of proteins	L4-L6, R2, R3	Personalities clash; false gender problem; role of wrong theories
Irvin Langmuir (1881-1957)	1948	cloud-seeding	L1-L4, R1, R2	Excess confidence; entering in other fields; inconclusive results even today
Linus Pauling (1901-1994)	1960s	vitamin C as a panacea	L1-L6, R1-R3	Excess confidence; entering in other fields; consequences and impact on peoples live
Fred Hoyle (1915-2001)	1970s	panspermia and viruses from space	L1-L5, R1-R3	Divergent personalities; abandon the normal scientific process; evolution to a respected area of research
Fred Hoyle (1915-2001)	1970s	panspermia and viruses from space	L1-L5, R1-R3	Divergent personalities; abandon the normal scientific process; evolution to a respected area of research
Martin Fleischmann (1927-2012)	1989	cold fusion	L1-L6, R1-R3	Abandon the normal scientific process; To-good to be true theories; public exposition in the media

SOBRE O AUTOR:

Sérgio Paulo Jorge Rodrigues
CQC, Chemistry Department, University of Coimbra,

Rua Larga Coimbra, Portugal

spjrodrigues@ci.uc.pt