JEVONS AND THE ROLE OF ANALOGIES IN EMPIRICAL RESEARCH

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Abstract: Suppose a scientist discovers a new, unpredicted phenomenon (such as galvanism or ultraviolet radiation). How can one ascertain the causes, properties and laws of the phenomenon? How can one plan the investigation of the circumstances that affect the phenomenon, and of the effects that the new phenomenon could produce? If the phenomenon is completely unexpected and does not fit any previous theory, it is impossible to provide a theoretical prediction of its likely properties. In the empiricist tradition, therefore, the recommended method was to investigate all possibilities, because in such cases it is impossible to exclude *a priori* anything. William Stanley Jevons (1835-1882) provided a clear criticism of this method. It is impossible to investigate all possibilities, because they are boundless. Is it then impossible to plan the research of unexpected new phenomena? No. Jevons pointed out an alternative. According to Jevons, a scientist confronting a new, unexpected phenomenon, should compare it to other known phenomena to establish *analogies*. This comparison should allow the researcher to find out one or several known phenomena similar to the new one. This paper will present and discuss Jevons' proposal in the context of late 19th century methodology of science.

Keywords: scientific method; empirical research; analogy; Jevons, William Stanley

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1. INTRODUCTION

In 1874 William Stanley Jevons (1835-1882) published the first edition of his book *The principles of science – a treatise on logic and scientific method*. In that work he discussed, among many other subjects, the strategies for the empirical inquiry of new phenomena in a pre-theoretical context. Suppose a scientist discovers a new, unpredicted phenomenon (such as galvanism or ultraviolet radiation). How can one ascertain the causes, properties and laws of the phenomenon? How can one plan the investigation of the circumstances that affect the phenomenon, and of the effects that the new phenomenon could produce?

If the phenomenon is completely unexpected and does not fit any previous theory, it is impossible to provide a theoretical prediction of its likely properties. In the empiricist tradition, therefore, the recommended method was to investigate all possibilities, because in such cases it is impossible to exclude *a priori* anything. This is the rule that can be found in Herschel's *A preliminary discourse on the study of natural philosophy*, for instance.

Jevons provided a clear criticism of this method. It is impossible to investigate all possibilities, because they are boundless. When a new unexpected phenomenon is discovered, any circumstance of the environment could, in principle, be essential for its production. It is impossible, however, to vary each of those factors. Besides that, even in the case of a small number of factors, a systematic empirical study would require the investigation of all possible combinations of the independent factors, and this would imply an overwhelming number of different tests.

A random choice of factors for investigation is also inadequate, of course, because one could miss the relevant factors and influences. Only in the case of a phenomenon predicted or suggested by some theory or hypothesis it is possible to select in advance the specific factors that are deemed relevant according to the theory or hypothesis under investigation.

Is it then impossible to plan the research of unexpected new phenomena? No. Jevons pointed out an alternative. According to him, a scientist confronting a new, unexpected phenomenon, should compare it to other known phenomena to establish *analogies*. This comparison should allow the researcher to find out one or several known phenomena similar to the new one. Then one should investigate whether the new phenomenon has properties equivalent to those of the known related phenomena.

Notice that the use of analogies to guide empirical research is not equivalent to the hypothetical-deductive method. An analogy does not imply a provisional belief. To use an analogy it is not necessary to assume that the phenomena are of the same nature: analogies between gravitation, electricity and magnetism have guided the experimental research of those phenomena without any assumption that they had equal causes. In the 18th century it was known that gravitational attraction was proportional to the mass and to the inverse square distance. By analogy, according to Jevons' methodological rule, one should investigate whether electricity and magnetism had equivalent properties.

It seems that Jevons' proposal was a new one. Jevons himself referred to Jeremy Bentham (*Essay on logic*) as his source of inspiration, but Bentham did not propose anything similar to Jevons' ideas. It also seems that his contemporaries did not understand Jevons' ideas. George Gore, for instance, read, commented and praised Jevons' book, but in his book *The art of scientific discovery* he claimed that the correct attitude of the scientist facing new phenomena should be to investigate all possibilities.

This paper will present and discuss Jevons' proposal in the context of late 19th century methodology.[1]

[1] This essay was written for presentation at the 11th International Congress of Logic, Methodology and Philosophy of Science [Section 16. History of Logic, Methodology, and Philosophy of Science],

2. THE PROBLEM: PLANNING EXPERIMENTS WITHOUT A THEORY

When scientific disciplines attains a high degree of development and there are working theories available, most of the experimental research is guided by those theories. However, in some special cases, a phenomenon is studied in a pre-theoretical environment. How can those inquiries be guided? How is it possible to plan observations and experiments when no theory is available?

It might seem that such a situation only occurs when science is in its infancy, but it can happen even within well-developed sciences. Sometimes an unexpected phenomenon is discovered. There are several well-known historical instances of chance discoveries in physics: the discovery of polarisation of light by refraction, the discovery of ultraviolet light, etc. It often occurs that the new phenomenon will be understood in the context of existing theories, even if it was not predicted. In that case, only the discovery of the new phenomenon occurs by chance – its further investigation is guided by theory. There are other cases, however, when the new phenomenon does not fit any existing theory.

Let us consider one famous instance: In 1895 Wilhelm Conrad Röntgen was studying electric discharges in vacuum tubes, when he noticed that a nearby fluorescent plate became bright. The unexpected phenomenon called his attention, and its study led to the discovery of a new kind of invisible penetrating radiation, with peculiar properties. From the very beginning of Röntgen's investigation, it became clear that the new radiation could not be explained by existing theories – it was a puzzle, and was the reason why it was called "X rays".

In this case, as in several other experimental discoveries in science, the researcher was not attempting to test any theory. In investigating something that had not been predicted – something

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that seemed completely new – it would impossible to use theories to plan his experiments. How should a scientist conduct his inquiry in those circumstances? Should he follow an inductive method? Should he do random experiments and observations? This was one of the problems William Stanley Jevons (1835-1882) addressed in his book *The principles of science – a treatise on logic and scientific method* (1874).

3. JEVONS ON SCIENTIFIC METHOD

William Stanley Jevons[2] is well known for his books on Economy and Logic.[3] His work *The principles of science* is his best known contribution to epistemology and scientific method. About half of this book deals with logic: arguments, probability, deduction, induction, etc.[4] The second half of the treatise (starting from book IV – *Inductive investigation* – onward) deals

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[2] There are few biographical studies on Jevons. See Gridgeman (1970) and other works referred there.

[3] Jevons' main works were: *A serious fall in the value of gold* (London, 1863); *Pure logic, or the logic of quality appart from quantity* (London, 1864; second edition in 1890); *The coal question* (London, 1865); *The substitution of similars* (London, 1869; second edition in 1890); *Elementary lessons in logic* (London, 1870); *The theory of political economy* (London, 1871; second edition in 1879); *The principles of science* (London, 1874; second edition in 1877); *Money and the mechanism of exchange* (London, 1875); *Primer on political economy* (London, 1878); *Studies and exercises in deductive logic* (London, 1880); *The State in relation to labour* (London, 1882); and the posthumous works *Methods of social* reform (London, 1883); *Investigations in currency and finance* (London, 1884); *Letters and journal of W. Stanley Jevons* (London, 1886, editado por sua esposa) and *The principles of economics* (London, 1905). Besides those books, Jevons published many articles on several subjects, including meteorology – a subject that strongly attracted him.

[4] This is the best known of Jevons' book. Most historians of philosophy and scientific method only discuss this part of his work. See, for instance, Madden (1966).

with the practice of scientific research. Most of the instances mentioned by Jevons are taken from physics, as was usual in the 19th century.

A large part of Jevons' book is dedicated to the analysis of experimental work. He was well aware that scientists do not follow and should not attempt to follow a Baconian "inductive method" because the bare accumulation of facts does not lead to the development of science. Experimental research is grounded upon theories, hypotheses and analogies, it begins with problems and questions, because without a previous conceptualisation it is impossible to plan an experiment.

This paper will deal with a specific point of Jevons' work: his ideas on the role of analogy in pre-theoretical scientific discovery. This specific point has not called the attention of historians, but it is an essential aspect of Jevons' thought. Indeed, Jevons regarded analogy or the comparison of similars as the fundamental principle of reasoning:

> In 1866 what he regarded as the great and universal principle of all reasoning dawned upon him; and in 1869 he published a sketch of this fundamental doctrine under the title of *The substitution of similars*. He expressed the principle in its simplest form as follows: "Whatever is true of a thing is true of its like," and he worked out in detail its various applications. (Hutchinson, 1947, p. 31)

> [...] The germ of his logical principles of the substitution of similars may be found in the view which he propounded in another letter written in 1861, that "philosophy would be found to consist solely in pointing out the likeness of things". (Hutchinson, 1947, p. 30)

> Jevons' logic of inference was dominated by what he called the substitution of similars, which expressed "the capacity of mutual replacement exiting in any two objects which are like or equivalent to a sufficient degree." This became for him "the great and universal principle of reasoning" from which "all logical processes seem to arrange

> themselves in simple and luminous order". (Gridgeman, 1970, p. 105)

Although this was recognised as a central idea in Jevons' logical work, hitherto the role ascribed by Jevons to the substitution of similars in the scientific method has not been emphasised as it deserves.

Jevons' ideas on this subject are not presented in a closely-knit form in any chapter of his book. The account presented here is a *reconstruction* of Jevons' ideas, using statements scattered throughout his work.

4. JEVONS AND THE ROLE OF CHANCE IN SCIENTIFIC DISCOVERY

Jevons admitted that the discovery of a new scientific phenomenon might be due to accident or chance:

> No small part of the experience actually employed in science is acquired without any distinct purpose. We cannot use the eyes without gathering some facts which may prove useful. A great science has in many cases risen from an accidental observation. (Jevons, 1877, p. 399)[5]

Jevons presented several instances of accidental discovery: Bartholinus and Iceland spar, Galvani and the frog's leg, etc. Those are cases where the researcher was not looking for the phenomenon he discovered. Historical examples can show that chance discoveries do occur. However, Jevons not only presented historical cases: he attempted to justify the *necessity* of accidents for the empirical discovery of new phenomena:

> As a general rule we shall not know in what direction to look for a great body of phenomena widely different from those familiar to us. Chance then must give us the starting

[5] All references in this paper are to the second edition (1877) of *The principles of science*.

> point; but one accidental observation well used may lead us to make thousands of observations in an intentional and organised manner, and thus a science may be gradually worked out from the smallest opening. (Jevons, 1877, p. 400)

I think that this is a correct argument. It would be absurd to think that a scientist could enter his laboratory and think: "Now, I am going to discover a new, unpredictable phenomenon". On the other hand, one cannot assume that the main part of scientific research is due to chance observations. The starting point might be a chance discovery, but after that, scientific investigation is not a random work.

Even chance discoveries are not completely random: it can only occur when the observer has the suitable knowledge allowing him to recognise that the observed fact is meaningful. Besides that, chance discoveries must be followed by an investigation of the new phenomenon, if they are to become useful, and that requires scientific training. According to Jevons:

> If we must attempt to draw a conclusion concerning the part which chance plays in scientific discovery, it must be allowed that it more or less affects the success of all inductive investigation, but becomes less important with the progress of science. Accident may bring a new and valuable combination to the notice of some person who had never expressly searched for a discovery of the kind, and the probabilities are certainly in favour of a discovery being occasionally made in this manner. But the greater the tact and industry with which a physicist applies himself to the study of nature, the greater is the probability that he will meet with fortunate accidents, and will turn them to good account. (Jevons, 1877, p. 532)

After the discovery of a new phenomenon it is necessary to think and talk about it. A scientist will not just inform "I have discovered a new *something*". He will ascribe a name or a simple description to the new phenomenon, and this early step will be guided by similarities to other known phenomena. Here, for the first time, Jevons introduced the use of *analogies*:

> When a phenomenon is of an unusual kind, we cannot even speak of it without using some analogy. Every word implies some resemblance between the thing to which it is applied, and some other thing, which fixes the meaning of the word. (Jevons, 1877, p. 522)

Historical examples are well known: “cells”, cathodic “rays”, electric “fluid”, etc.

5. THE IMPOSSIBILITY OF EXAUSTIVE RANDOM INVESTIGATION

After the finding a new phenomenon, how should it be investigated?

In pre-theoretical research, the scientist must attempt to find the conditions related to the production, repetition or change of the phenomenon – that is, its empirical laws. This is the step Jevons called “inductive investigation”:

> Our object in inductive investigations is to ascertain exactly the group of circumstances or conditions which being present, a certain other group of phenomena will follow. (Jevons, 1877, p. 416)

Can we study all circumstances or conditions that could affect a new phenomenon? Let us suppose that someone noticed for the first time that rubbing two sticks together turns them hot. An “exhaustive” account of the conditions of the observed phenomenon would have to include (Jevons, 1877, p. 416):

- the form, hardness, organic structure and all chemical qualities of the wood;
- the pressure and velocity of the rubbing
- the temperature, pressure, and all the chemical qualities of the surrounding air;

- the proximity of the earth with its attractive and electric powers;
- the temperature and other properties of the persons producing motion;
- the radiation from the sun, and to and from the sky; etc.

If we are facing a *new* phenomenon, how could we exclude the influence of any of those conditions, or even the influence of the colour of the clothes of the scientist? Only if the phenomenon is known it is possible to dismiss the influence of some of the circumstances.

> On *à priori* grounds it is unsafe to assume that any one of these circumstances is without effect, and it is only by experience that we can single out those precise conditions from which the observed heat of friction proceeds. (Jevons, 1877, pp. 416-7)

This is the first difficulty of experimental research in the pre-theoretical situation: there are infinite circumstances that could (in principle) affect the phenomenon and it is impossible to study infinite circumstances.

Even if it were possible to select a finite number of conditions that could affect the phenomenon, a second problem would arise: “The great difficulty of experiment arises from the fact that we must not assume the conditions to be independent” (Jevons, 1877, pp. 417). Suppose we want to test the influence of four factors *A*, *B*, *C*, *D* upon the phenomenon *P*. Suppose that **A** stands for the presence of factor *A*, and **a** stands for its absence. It would be necessary to observe whether *P* occurs or does not occur under all possible combinations such as **ABCD**, **aBCD**, **AbCD**, **abCD**, **ABcD**, etc.

> The effect of the absence of each condition should be tried both in the presence and absence of every other condition, and every selection of those conditions. Perfect and exhaustive experimentation would, in short, consist in examining natural phenomena in all their possible combinations and registering

> all relations between conditions and results which are found capable of existence. (Jevons, 1877, pp. 417-8)

Is it *possible* to do this kind of exhaustive experimental analysis? Jevons remarked that even in the case of a finite number of conditions, the systematic research of all combinations is impossible, because the number of cases to be tested would increase according to an exponential law:

> The reader will perceive, however, that such exhaustive investigation is practically impossible, because the number of requisite experiments would be immensely great. Four antecedents only would require sixteen experiments; twelve antecedents would require 4096, and the number increases as the powers of two. [...] It is at this point that logical rules and forms begin to fail in giving aid. The logical rule is – Try all possible combinations; but this being impracticable, the experimentalist necessarily abandons strict logical method, and trusts to his own insight. (Jevons, 1877, p. 418)

Is this "insight" something that defies any understanding? According to Jevons there are no precise rules that could guide the experimenter, in this case:

> This work of inductive investigation cannot be guided by any system of precise and infallible rules, like those of deductive reasoning. There is, in fact, nothing to which we can apply rules of method, because the laws of nature must be in our possession before we can treat them. If there were any rule of inductive method, it would direct us to make an exhaustive arrangement of facts in all possible orders. (Jevons, 1877, p. 504)

> We may be obliged to trust to the casual detection of coincidences in those branches of knowledge where we are deprived of the aid of any guiding notions; but a little reflection will show the utter insufficiency of haphazard experiment, when applied to investigations of a complicated

> nature. [...] When considering the subject of combinations and permutations, it became apparent that we could never cope with the possible variety of nature. An exhaustive examination of the possible metallic alloys, or chemical compounds, was found to be out of the question (Jevons, 1877, p. 505)

Jevons' argument might appear so straightforward that it should have occurred to everyone else. That was not the case. Let us first consider the opinion of another famous 19th century methodologist: John Herschel. According to Herschel, when a new fact is described it would be necessary to include *all the circumstances* of its occurrence, and then one would need to study which are relevant or otherwise:

> The circumstances, then, which accompany any observed fact, are main features in its observation, at least until it is ascertained by sufficient experience what circumstances have nothing to do with it, and might therefore have been left unobserved without sacrificing *the fact*. In observing and recording a fact, therefore, altogether new, we ought not to omit any circumstance capable of being noted, lest some one of the omitted circumstances should be essentially connected with the fact, and its omission should, therefore, reduce the implied statement of a *law of nature* to the mere record of an *historical event*. (Herschel, 1966, p. 120, § 111)

So, Jevons was not describing "common sense epistemology". Although his views may accord with our "common sense", they were not obvious or consensual. Nevertheless, Jevons did not present his approach as a new analysis. He stated that his opinion was the result of a gradual reaction against the method prescribed by Francis Bacon:

> It would be an interesting work, but one which I cannot undertake, to trace out the gradual reaction which has taken place in recent times against the purely empirical or Baconian theory of induction. Francis Bacon, seeing the futility of the

> scholastic logic, which had long been predominant, asserted that the accumulation of facts and the orderly abstraction of axioms, or general laws from them, constituted the true method of induction. [...]
>
> Nevertheless Bacon's method, as far as we can gather the meaning of the main portions of his writings, would correspond to the process of empirically collecting facts and exhaustively classify them, to which I alluded[6]. The value of this method may be estimated historically by the fact that it has not been followed by any of the great masters of science (Jevons, 1877, pp. 506-7)

In principle, if we are facing a new phenomenon, no possibility can be excluded *a priori*, but scientists do manage to investigate new phenomena and they never analyse all possibilities. How do they do that?

One might immediately recall the hypothetical-deductive method: instead of investigating *all* possibilities, the scientist formulates hypotheses and only tests the consequences of those hypotheses. In the Introduction he wrote for the Dover edition of *The principles of science* Nagel called the attention of the readers to Jevons' approach to the use of hypotheses in scientific research (Nagel, 1958, pp. xlix-li). However, Nagel did not pay attention to another question: How are hypotheses formulated? In the pre-theoretical context there is an infinite number of possible hypotheses – indeed, it is possible to frame hypothetical relations that would contemplate all possible combinations of circumstances around the phenomenon. If the choice of hypotheses is not blind or random, what can guide their choice?

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[6] Jevons described here a common view on Bacon's method. It is possible however to find in Bacon's work another less conspicuous approach, suggesting the careful use of analogies: "There is no proceeding in invention of knowledge but by similitude" (see Park, 1984, p. 297).

6. ANALOGY AS A SOURCE OF WORKING HYPOTHESES

Jevons clearly pointed out that the pre-theoretical investigation should be guided by analogies, grounded upon the scientist's experience and "intuition":

> The reader will perceive, however, that such exhaustive investigation is practically impossible [...]. The result is that the experimenter has to fall back upon his own tact and experience in selecting those experiments which are most likely to yield him significant facts. It is at this point that logical rules and forms begin to fail in giving aid. The logical rule is – Try all possible combinations; but this being impracticable, the experimentalist necessarily abandons strict logical method, and trusts to his own insight. Analogy, as we shall see, gives some assistance, and attention should be concentrated on those kinds of conditions which have been found important in like cases. But we are now entirely in the region of probability, and the experimenter, while he is confidently pursuing what he thinks the right clue, may be overlooking the one condition of importance. (Jevons, 1877, p. 418)

> As natural science progresses, physicists gain a kind of insight and tact in judging what qualities of a substance are likely to be concerned in any class of phenomena. (Jevons, 1877, p. 422)

There is no safe rule to exclude any given condition or combination of conditions. However, it is impossible to study all the infinite possibilities. The researcher must choose, and he does choose, taking into account his "tact", "experience", "insight", using analogies to guide his work. Instead of contemplating facts with his mind void of ideas, as required by the Baconian method, it is necessary to use working hypotheses:

> In later years Professor Huxley has strongly insisted upon the value of hypothesis. When he advocates the use of "working hypotheses" he means no doubt that any hypothesis is better than none, and that we cannot avoid being guided in our observations by some hypothesis or other. (Jevons, 1877, p. 509)

Of course, the use of hypotheses is not a new idea, but Jevons' analysis of the origin of hypotheses seems new.

7. JEVONS' CONCEPT OF 'ANALOGY'

What does it mean to say that two phenomena present an analogy? Jevons did not present an explicit definition of this concept in *The principles of science*, but from the very beginning of the book he emphasises the role of analogies and comparisons in all kinds of inferences:

> The fundamental action of our reasoning faculties consists in inferring or carrying to a new instance of a phenomenon whatever we have previously known of its like, analogue, equivalent or equal. Sameness or identity presents itself in all degrees, and is known under various names; but the great rule of inference embraces all degrees, and affirms that *so far as there exists sameness, identity or likeness, what is true of one thing will be true of the other*. (Jevons, 1877, p. 9)[7]

Analogy is a special (imperfect) case of the *substitution of similars*, which Jevons regarded as the most important rule of inference:

> The one supreme rule of inference consists, as I have said, in the direction to affirm of anything whatever is known of its like, equal or equivalent. The *Substitution of Similars* is a phrase which seems aptly to express the capacity of mutual replacement existing in any two objects which are like or

[7] "The universal principle of all reasoning, as I have asserted, is that which allows us to substitute like for like" (Jevons, 1877, p. 162).

> equivalent to a sufficient degree. It is matter for further investigation to ascertain when and for what purposes a degree of similarity less than complete identity is sufficient to warrant substitution. (Jevons, 1877, p. 17)

At another place Jevons elucidated what it means to reason by analogy:

> In reasoning by analogy, the, we observe that two objects A B C D E ... and A' B' C' D' E' ... have many like qualities, as indicated by the identity of the letters, and we infer that, since the first has another quality, X, we shall discover this quality in the second case by sufficiently close examination. As Laplace says, – "Analogy is founded on the probability that similar things have causes of the same kind, and produce the same effects. The more perfect this similarity, the greater is this probability". (Jevons, 1877, p. 597)

In the case of a chance discovery, the unexpected observation of a new phenomenon will evoke, by association, several similar phenomena. Analogy will guide the search for other features of the new phenomenon.

8. THE ANALYSIS OF SIMILARITIES

According to Jevons, when the experimenter is confronted with a new phenomenon, he should use analogic reasoning to suggest hypotheses; then, he should test them:

> It is before the glance of the philosophic mind that facts must display their meaning, and fall into logic order. The natural philosopher must therefore have, in the first place, a mind of impressionable character, which is affected by the slightest exceptional phenomenon. His associating and identifying powers must be great, that is, a strange fact must suggest to his mind whatever of like nature has previously come within his experience. His imagination must be active, and bring before his mind multitudes of relations in which the unexplained facts may possibly stand with regard to each

> other, or to more common facts. Sure and vigorous powers of deductive reasoning must them come into play, and enable him to infer what will happen under each supposed condition. Lastly, and above all, there must be the love of certainty leading him diligently and with perfect candour, to compare his speculations with the test of fact and experiment. (Jevons, 1877, p. 577)

Hypotheses used in pre-theoretical investigation cannot be deduced from any previous set of established propositions. They are *suggested* by analogy, from former knowledge. After that, it is necessary to test the hypotheses.

> If the views upheld in this work be correct, all inductive investigation consists in the marriage of hypothesis and experiment. When facts are in our possession, we frame an hypothesis to explain their relations, and by the success of this explanation is the value of the hypothesis to be judged. In the invention and treatment of such hypotheses, we must avail ourselves of the whole body of science already accumulated, and when once we have obtained a probable hypothesis, we must not rest until we have verified it by comparison with new facts. We must endeavour by deductive reasoning to anticipate such phenomena, especially those of a singular and exceptional nature, as would happen if the hypothesis be true. Out of the infinite number of experiments which are possible, theory[8] must lead us to select those critical ones which are suitable for confirming or negating our anticipation. (Jevons, 1877, p. 504)

> The true course of inductive procedure is that which has yielded all the more lofty results of science. It consists in *Anticipating Nature*, in the sense of forming hypotheses as to the laws which are probably in operation; and then observing whether the combinations of phenomena are such as would follow from the laws supposed. The investigator begins with

[8] In a pre-theoretical context, the "probable hypotheses" are obtained by analogy, according to Jevons.

> facts and ends with them. He uses facts to suggest probable hypotheses; deducing other facts which would happen if a particular hypothesis is true, he proceeds to test the truth of his notion by fresh observations. If any result prove different from what he expects, it leads him to modify or to abandon his hypothesis; but every new fact may give some new suggestion as to the laws in action. Even if the result in any case agrees with his anticipations, he does not regard it as finally confirmatory of his theory, but proceeds to test the truth of the theory by new deductions and new trials. (Jevons, 1877, p. 509)
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> In such a process the investigator is assisted by the whole body of science previously accumulated. He may employ analogy, as I shall point out, to guide him in the choice of hypotheses. The manifold connections between one science and another give him clues to the kind of laws to be expected, and out of the infinite number of possible hypotheses he selects those which are, as far as can be foreseen at the moment, most probable. Each experiment, therefore, which he performs is that most likely to throw light upon his subject, and even if it frustrate his first views, it tends to put him in possession of the correct clue. (Jevons, 1877, pp. 509-510)

It is possible to read in those quotes just an apology of the hypothetical-deductive method. I would like to stress, however, Jevons' views on the *use of analogy in the invention of hypotheses*. Jevons himself acknowledged that previous authors had proposed this idea:

> [...] As Boscovich truly said, we are to understand by hypotheses "not fictions altogether arbitrary, but suppositions conformable to experience or analogy". It follows that every hypothesis worthy of consideration must suggest some likeness, analogy, or common law, acting in two or more things. (Jevons, 1877, p. 512)

However, it seems that no other author, before or after Jevons, gave so much emphasis to analogy.

9. UNCERTAINTY OF WORKING HYPOTHESES

Jevons was aware that hypotheses suggested by analogy are just working instruments and that they are open to error. However, they are useful and even necessary in the experimental investigation of nature:

> There can be no doubt that discovery is most frequently accomplished by following up hints received from analogy, as Jeremy Bentham remarked[9]. Whenever a phenomenon is perceived, the first impulse of the mind is to connect it with the most nearly similar phenomenon. If we could ever meet a thing wholly *sui generis*, presenting no analogy to anything else, we should be incapable of investigating its nature, except by purely haphazard trial. The probability of success by such a process is so slight, that it is preferable to follow up the faintest clue. As I have pointed out already (p. 418), the possible experiments are almost infinite in number, and very numerous also are the hypotheses upon which we may proceed. Now it is self-evident that, however slightly superior the probability of success by one course of procedure may be over another, the most probable one should always be adopted first. (Jevons, 1877, p. 629)

As hypotheses are uncertain, instead of fixing his mind upon a single one, the researcher should investigate a large number of hypotheses:

> It would be an error to suppose that the great discoverer seizes at once upon the truth, or has any unerring method of divining it. In all probability the errors of the great mind exceed in number those of the less vigorous one. Fertility of imagination and abundance of guesses at truth are among the first requisites of discovery; but the erroneous guesses must be many times as numerous as those which prove well founded. The weakest analogies, the most whimsical notions,

[9] Here Jevons referred to Bentham's *Essay on logic*: (Bentham, 1843, vol. 8, p. 276).

> the most apparently absurd theories, may pass through the teeming brain, and no record remain of more than the hundredth part. There is nothing really absurd except that which proves contrary to logic and experience. The truest theories involve suppositions which are inconceivable, and no limit can really be placed to the freedom of hypothesis. (Jevons, 1877, p. 577)

Since the procedure of invention of hypotheses using analogies does not provide any warranty as to their certainty, the researcher should develop rigorous test of those hypotheses:

> Summing up, then, it would seem as if the mind of the great discoverer must combine contradictory attributes. He must be fertile in theories and hypotheses, and yet full of facts and precise results of experience. He must entertain the feeblest analogies and the merest guesses at truth, and yet he must hold them as worthless till they are verified in experiment. When there are any grounds of probability he must hold tenaciously to an old opinion, and yet he must be prepared at any moment to relinquish it when a clearly contradictory fact is encountered. (Jevons, 1877, pp. 592-593)

In the specific case of pre-theoretical experimental investigation, the scientist should therefore frame several hypotheses concerning the properties of the new phenomenon, using analogies about known phenomena. Then, he should submit the hypotheses to a careful experimental investigation. In this way, before a *theory* is reached, the new phenomenon is progressively understood, because, according to Jevons, the general sense of explanation is the search for similarities between the new and the known (Jevons, 1877, p. 533).

Reasoning by analogy can suggest an indefinite number of properties that could be investigated. The associations that will actually occur to a particular researcher during this phase of his inquiry will depend on his background and on his current interests. Heath stated that, according to Jevons, it would be necessary to test all conceivable hypotheses (Heath, 1967, p.

261). That was not Jevons' ideal. According to him, a scientist only needs to check the particular conjectures that occurred to him from the analogies that spontaneously arose in his mind.

10. JEREMY BENTHAM ON ANALOGY AND DISCOVERY

It seems that Jevons' proposal concerning the use of analogy in scientific research was a new one. Jevons himself referred to Jeremy Bentham (*Essay on logic*) as his source of inspiration, but Bentham did not propose anything similar to Jevons' ideas. Jevons referred to the second section of chapter 10 (Bentham, 1843, pp. 275-279 – "On the art of invention") of Bentham's book. In this section Bentham describes "helps applicable to arts in general without exception or distinction", divided in 10 hints or aid to memory (*memento*). Two of those rules mention analogy:

> *Memento 5.* For means and instruments, employ analogy. *Analogias undique indagato.*
>
> *Memento 6.* In your look-out for analogies, for surveying that quarter of the field of thought and action to which the art in question belongs, employ the logical ladders made of nest of aggregates, placed in logical sub-alternation. *In analogiarum indagationes scalis logicis utere.* (Bentham, 1843, p. 276)

Bentham explained the use of analogy as an analysis of genera and species: whatever is true of a genus, should be true of each species belonging to that genus; and whatever is true of a species belonging to a genus *might be true* of the genus and of other species of the same genus.

> *Fifth and Sixth Mementos*: The mode and use of applying these *subalternation scales* are as follows, viz.:
>
> I. Application in the *descending line.*
>
> With the exception of such words as are names of individual objects, take any one of the material words that

> present themselves as belonging to the subject, not being the name of an individual alone, this word will be the name of a *sort* of objects, the name, (say) of an aggregate. If the aggregate be the denomination of a *genus*, think of the several species which, by their respective names, present themselves as being contained under it. Whatsoever is predicated of the genus, will, in so far as it is truly predicated, be, with equal truth, predicable of all these several species.
>
> II. Application in the *ascending line.*
>
> In like manner look out for the name of the next superior genus; with reference to which, the genus in question is but a species, and observe, try, or conjecture, whether that which beyond doubt, has been found predicable with truth of the whole of this species, be, or promises to be, with like truth predicable of the whole, or any other part of the aggregate, designated by the name of that genus. (Bentham, 1843, p. 278)

The application of Bentham's "subalternation scale in the ascending line" might be regarded as a kind of analogical reasoning. However, immediately after the above quoted elucidation, Bentham added:

> It is in the instance of the physical department of the field of thought and action, and more particularly to the chemical district of that department, that the applicability of this memento is most conspicuous. Upon every subject, try, or at least, think of trying, every operation; to every subject in the character of a menstruum, apply every subject in the character of a solvent, and so on. (Bentham, 1843, p. 278)

Now, Bentham proposed to test every possibility – an impossible method, according to Jevons. Not only did Bentham think that the use of analogical thinking would entail this endless search, but he even raised this combinatorial method to the status of a new rule:

> *Memento 9. Quodlibet cum quolibet*. To everything forget not to apply anything. Suppose that of an indefinite multitude of objects, which in consideration of certain properties or qualities, in respect of which they are found or supposed to agree, and certain others, in respect of which they have been found or supposed to disagree, having all of them been placed in one or other of two classes, some article belonging to the one class has, with success, (i.e. with some new effect, which either has been found to be, or affords a prospect of being found to be, advantageous,) been applied, no matter in what manner, nor to what purpose in particular, to some article belonging to the other class; in like manner, frame a general resolution not to be departed from in any instance, but for some special cause, (applying to that instance,) to apply to each article belonging to the one class every article belonging to the other. (Bentham, 1843, p. 276)

Therefore, in Bentham's account an essential feature of Jevons' approach is lacking: the clear statement that it is impossible to investigate every possibility.

11. GORE AND THE METHOD OF EXPERIMENTAL INVESTIGATION

It seems that his contemporaries did not understand Jevons' ideas. Let us analyse one relevant case: Gore's reaction to Jevons' proposals.

In 1878 the chemist George Gore (1826-1908)[10] published his book *The art of scientific discovery or the general conditions and methods of research in physics and chemistry*. In the Preface to this work he cited twice, among other useful books, Jevons *Principles of science* (Gore, 1878, p. vi and p. x – footnote 2). He also acknowledged Jevons' help in correcting part of his book (*ibid*., p. xiii). Besides that, in several parts of his work Gore approvingly cited Jevons' book, and never

[10] There is a short biographical notice on George Gore in the *Dictionary of Scientific Biography*: Jones, 1970.

criticised him. It seems, therefore, that Gore accepted Jevons' ideas.

At several points of his book Gore does present an interpretation of the scientific method that seems inspired by Jevons' book. He stressed the utility of comparison and analogy as an aid to discovery (Gore, 1878, pp. 327-331) and as one of the sources of hypotheses (*ibid.*, pp. 366-7). However, a few pages later, he claimed that the correct attitude of the scientist facing new phenomena should be to investigate all possibilities:

> The power, activity, and variety of the imagination may be considerably increased by practising the formation of hypotheses, in the manner already described, on every available opportunity. This practice may be greatly assisted by the use of a table of classified series of leading ideas of the various sciences, and associating each of these ideas in succession with that of the phenomenon under consideration, and then forming questions respecting it by asking in succession what effect will each have upon the particular phenomenon. The following fragment of such a table will show what I mean: – What will be the effect of gravity, pressure, motion, heat, light, electricity, magnetism, chemical affinity; and of varying time of action, direction, and strength of each of these; also the effect of conduction, radiation, refraction, reflection, and polarisation of heat upon it. And so on through all the chief phenomena of all the forces of nature in succession; and also asking what will be the effect of different classes of elementary substances, metals, metalloids, &c., and all the separate elementary substances and their compounds in succession. Instead of such a table, a copious index of any good book on physical and chemical science may be employed for the purpose. In this way even a student of science may suggest a large number of new questions respecting any phenomenon. (Gore, 1878, pp. 369-70)

The method described by Gore is the kind of blind combinatorial investigation that was criticised by Jevons. Thus, one of the essential features of Jevons' methodological analysis was overlooked by Gore.

12. THE EPISTEMOLOGICAL STATUS OF ANALOGY IN DISCOVERY

Up to this point I have attempted to describe Jevons' ideas and to stress his originality. Of course, I do think that Jevons' proposal is a relevant contribution to the scientific method – otherwise I would not have chosen to write on this subject. However, before closing this paper let me add some critical comments on Jevons' views on analogy.

From a historical point of view, the concept of 'analogy' was born in mathematics where it meant an equality between ratios or proportions (Lloyd, 1973, p. 60).[11] Afterward this word was used in several different senses (Hesse, 1967). Although there is a wide range of analogy concepts, let us assume the following statement as a reasonable account of most recent uses of this word:

- *Two objects A and B of any kind are analogous if there are parts, properties or relations that are similar or equal in both A and B (that is, if they have some equivalent features) and if, beside that, they have some difference.*

If two objects are analogous, this similarity *suggests* that they might have other equivalent features:

> The examination of likeness is useful with a view both to inductive arguments and to hypothetical reasonings, and also with a view to the rendering of definitions. [...] It is useful for hypothetical reasonings because it is a general opinion that among similars what is true of one is true also of the rest. If,

[11] Notice that even in ancient Greek thought analogy was also regarded as a method of suggesting explanations of natural phenomena (Lloyd, 1973, p. 63).

> then, with regard to any of them we are well supplied with matter for discussion, we shall secure a preliminary admission that however it is in these cases, so it is also in the case before us [...] (Aristotle, *Topics*, book I, chapter 18, 108^b 6-16)

'Reasoning by analogy' consists on inferring an unknown similarity between two objects, from a known analogy between them. Of course, reasoning by analogy is not demonstrative. What does it produce, then? Jevons supposed that it leads to *hypotheses*, and so does Carnap:

> The evidence known to us is the fact that individuals *b* and *c* agree in certain properties and, in addition, that *b* has a further property; thereupon we consider the hypothesis that *c* too has this property. (Carnap, 1962, p. 569)

Carnap and most of other authors regard the result produced by analogy as *likely or probable hypotheses*. The greater the initially known similarity between the two objects, the greater will be the probability of the hypothesis. As shown above, Jevons also suggested a probabilistic interpretation for reasoning by analogy.

Other authors – such as Norwood Hanson – who also accepted that analogy has an important role in the formulation of new hypotheses supposed that the process of discovery consisted on the formulation of *plausible* hypotheses: previous knowledge would lead a scientist to think that the hypothesis is probable (Hanson, 1958, p. 1074).

However, as shown by Mary Hesse, this concept is highly problematical. Any analogy involves not only similarities but also differences. Knowledge of those differences should also be taken into account when the probability of the hypothesis is to be evaluated, but it is very difficult to find out a viable way of doing this (Hesse, 1964).

Indeed, let us start from the supposition that *A* and *B* agree in the properties *m*, *n*, *p*, *q* and disagree in the properties *t*, *v*, *w*.[12] Given this knowledge, what is the probability that *A* and *B* agree in every property? Of course, the probability is null, and therefore it is impossible to assume that *A* and *B* agree in a new property *x*.[13] Now, if the new property *x* is completely independent of the properties *m*, *n*, *p*, *q*, *t*, *v*, *w*, it is impossible to find out the probability of *x* belonging to *B*, given that it belongs to *A*. It seems impossible to frame an acceptable concept of probability that could be applied to analogous reasoning.

The difficulty of applying the concept of probability to the conclusions of arguments by analogy could be regarded as a fatal blemish of Jevons' view. However, most of his ideas might be retained if analogies are regarded under another point of view.

Instead of interpreting analogy as a kind of inference producing a *proposition* (something that might be regarded as true or false, or more or less probable), let us embrace another approach: analogy will be regarded as the source of *rules of action* of a special kind. I propose that reasoning by analogy in the context of pre-theoretical scientific research can be described by two rules:

- *Given a new phenomenon, it is desirable to establish analogies between the new phenomenon and other known phenomena.*

[12] In any real-world situation, two different objects will disagree in an infinite number of ways, but let us suppose that we only know that they disagree in a finite number of features.
[13] If we only knew that *A* and *B* agree in some properties, it would be possible, according to Carnap, to ascribe a probability between 0 and 1 to the statement that *A* and *B* agree in every property, and therefore the hypothesis that *A* and *B* would agree in a new property *x* would be different from zero.

- *If we know that two phenomena A and B are analogous and we also know that A has a feature p and we do not know whether B has a similar feature or not, it is desirable to find out whether B has that feature or not.*

So, according to this proposal, analogical reasoning will not lead to state that *B* has the property *p*. It will lead to an *action*: the scientist should attempt to find out whether *B* has that property of otherwise. The result of reasoning by analogy would not produce *propositions*, in the logical sense, but *desiderata* that could guide research[14]. The analysis of similarities and differences between *A* and *B* shows that some information is lacking (we do not know whether *p* applies to *B* or not) and the researcher is led to fill this gap[15]. This is not equivalent to a hypothesis proper, because a hypothesis is a proposition that is regarded as probable. When a scientist is guided by the above-described rule of action, it is completely indifferent whether *p* applies to *B* or not. Analogy cannot lead a scientist to believe that "*p* applies to *B*" is true or probable and therefore he should not defend that he will likely find the property *p* to apply to *B*. However, without applying any truth-value or probability to the proposition "*p* applies to *B*", the above described rule directs the effort of the scientist to choose between "*p* applies to *B*" or "*p* does not apply to *B*".

The *logical* value of this rule of action is null, because the result of the reasoning by analogy would amount to a tautology: "either *p* applies to *B* or *p* does not apply to *B*". However, the *methodological* value of reasoning by analogy is very high,

[14] Reasoning by analogy could also be described as a way to arrive to *questions* such as this: "Does B have the property p?".

[15] A *desideratum* is the description of something that is useful or desirable, from the scientific point of view. It describes sufficient (but not necessary) conditions for ascribing positive scientific value to a scientific result. A general analysis of *desiderata* can be found in my PhD thesis: Martins, *Sobre o papel dos* desiderata *na ciência* (1987). See also: Martins, 1980; Martins, 1984.

because it will focus the attention of the scientist upon a few specific features of the phenomenon, instead of asking him to analyse an infinity of possibilities.

Notice that a *desideratum* is not a heuristic method. Heuristic procedures can help to find new analogies, but the rules presented here do not provide a way to find an analogy – they only state that it is *desirable* to establish analogies, that is, analogies have a positive scientific value.

Except for this feature – the epistemological status of analogical reasoning – I think that the view presented by Jevons is both a nice account of actual scientific practice[16] and a useful methodological guide for the experimental investigation of new phenomena in a pre-theoretical context.

13. FINAL REMARKS

This paper discussed the role of analogy in the process of scientific discovery and experimental investigation in a pre-theoretical context, following Jevons' work. The paper did not attempt to discuss all kinds of analogy, nor every kind of process of discovery and research. Its aim was not to discuss the whole of Jevons' contribution to scientific method and epistemology, but to deal with a specific point of his work.

Jevons' analysis suggest that the discovery of a completely new phenomenon is due to chance, but soon afterwards some assumptions must provide a guidance to the research – otherwise, observations and experiments would occur at random, and that would seldom lead to significant results. It is impossible to study all the factors that could possibly affect a give phenomenon, and hence the attention of the researcher should be focused upon a small number of features. This choice, in a pre-theoretical context, must be guided by analogies.

[16] In this paper I have not attempted to compare Jevons' analysis to the actual scientific pratice. In another paper, however, I have shown that the discovery and early investigation of X rays followed a method corresponding to Jevons' ideas (Martins, 1998).

Jevons' seminal work was not derived from former methodological accounts. It was at variance with Herschel's ideas, and was not derived from Bentham's work – notwithstanding Jevons' own remarks on his debt to that author. Jevons ideas were not straightforward and were not understood by contemporary authors, such as Gore.

Contrary to traditional analyses, this paper ascribes a peculiar epistemological status to analogies used in that kind of investigation: they are interpreted as originating *desiderata*, instead of probable hypotheses. According to this interpretation, analogies are not the source of probable or plausible hypotheses, but are used to focus the attention of the scientist upon a few features of the new phenomenon, in such a way as to avoid random or endless experimental inquiries.

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