This is an Accepted Manuscript of an article published by Taylor & Francis in Australian Journal of Forensic Sciences on 18 May 2011, available online: http://www.tandfonline.com/10.1080/00450618.2011.555416.

Forensic Science – A True Science ?

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Since Kirk's 1963 article 'Ontogeny of Criminalistics'[1], forensic scientists have upheld a specific body of knowledge based on two fundamental postulates, Locard's exchange principle and Kirk's concept of individuality. The criteria of reliability and admissibility for scientific proof discussed by the Daubert decision (Daubert v. Merrell Dow Pharm. Inc., 509 U.S. 579 (1993)) and its progeny (Kumho Tire v. Carmichael, 526 U.S. 137 (1999) and Gen. Elec. Co. v. Joiner, 522 U.S. 136 (1997)) is a problem of procedure and launched a perceptual revolution of forensic science in the USA for jurists[2,3], but also introduced a debate within forensic science after broad attacks claiming a lack of scientific foundations of much of forensic science practice. This led to various responses[4,5], most of which are based on the North American perspective, where most experts' opinion are, by the very nature of the system, allegations in support of one or the other side of the argument. If this lack of independence is probably at the root of many of the current difficulties, it also questioned the very nature and development of forensic practice by its scientists.

It is of interest to note that both communities generally paid attention only to Kirk's principle application and its consequence of claimed individualizations, focusing mainly on error rate and antagonistic peer-reviews between academics and practitioners. Locard's principle, however, was little questioned : “As much as the Locard transfer theory has been invoked, no peer-reviewed literature exists that proffers it, tests it, or refutes it. It is axiomatic in forensic science ; it is accepted as true without proof”[6a].

This focus on the methodology does not necessarily address the epistemological view of science first requested in Daubert, which quoted Popper's philosophy of science as being only any body of knowledge that is falsifiable at principle, not methodology level[7,8]. Moreover, this limited view of science from the perspective of the law has introduced much confusion between science and evidence[9], the first being a structured process to obtain data and knowledge, the second being the way this knowledge may help understand a situation and clarify its context..

Forensic scientists have failed to address this confusion as scientists, for the most part, and have tried to answer challenges within the legal framework, rather than within their own epistemological roots. This leads to the essential question whether forensic science’s founding principles are a source of valid knowledge for societies' benefits. Surely less important in its legal consequence (“absence of evidence is not evidence of absence”[10]), does not Locard's principle form the base of our science ? Do we have to fear its testing ? Can't we expect a better recognition of crime scene management, which deserves the status as the first stage of forensic science[11-14]? Wouldn't such open-ended basic research fulfill the forensic scientists' ambition to qualify their practice as scientific from a philosophical point of view ?

I – A late identification of the fundamental principles of criminalistics.

a) A progressive definition of criminalistics (Gross, Reiss, Locard, Kirk).

The German word 'Kriminalistik' was coined at the end of the nineteenth century by Hans Gross (1847–1915), an Austrian criminal legal specialist, who described the contribution of methods and techniques to criminal investigations[15,16]. Explicitly referencing scientific disciplines of the time (anthropology, dactyloscopy, biology, medicine, etc.), it complemented the more social and juridical aspects of criminology. Gross claimed that 'Kriminalistik' , the use of a scientific method in crime investigation, constituted the essential method for investigative magistrates (that are found in continental laws). In its method, not only would the silent witness (physical evidence) be interrogated, but also human witnesses using new knowledge brought by such authors as Freud.

Simultaneously, police activity introduced part of this methodology to help its investigative needs. It was labeled “technical and scientific policing”, and slowly asserted itself as a separate discipline by its practice. Criminalistics was initiated within police agency infrastructures first by Bertillon in Paris. Its methods attempted to establish scientific facts[17] and its driving force was to achieve individualization[18]. Interestingly, a few years later, Locard (1877–1966)[19,20] created the "first" official police laboratory, but it was not part of a traditional police organization as it was set up within the Court of Justice in Lyon. Whereas the former would provide mostly investigative leads and methods for identification, the latter would look at the potential to provide expertise and an evaluative potential for scientists in the court.. As a sign of the acceptance of forensic science as a separate discipline, an academic chair was created at the beginning of the twentieth century in Lausanne led by Rodolphe-Archibald Reiss (1875–1929). The creation of this position combined both the views of Bertillon and Locard within a law department, just as proposed by Gross. This enlightened vision was not repeated in other countries and the discipline has developed into three separate-but-related approaches: legal methodology (Gross), investigation and identification by police agencies (Bertillon), and finally analysis and evaluative expert opinions within specialised laboratories (Locard). Obviously, this last aspect is the one under the strongest attacks in US courts[21]. Unfortunately, this fragmented view is shared by many forensic practitioners - and reinforced through education and orientation in multiple professions - and the rich combination of potential interdisciplinary insights and strength is lost or ignored.

Today, traditional definitions keep these strange associations distinct from becoming a specific discipline: forensic science. For example, criminalistics is defined as « the profession and scientific discipline directed toward the recognition, identification, individualization and evaluation of physical evidence by application of the natural sciences to law-science matters »[22], which leans to scientific applications inherent to natural sciences, and to technologies resulting from chemistry, biology and physics rather than scientific principles dedicated to understanding the information content of traces. The trace detection – evidence valuation should lead the need for scientific methodology and technology, not the other way around.

Forensic science is then, foremost, an interdisciplinary endeavor at both doctrinal and practical levels, digging opportunely into other sciences and techniques, to find out valuable information that may help identify a source or an activity described by their traces (remnants of a presence or an activity). Traces act as memory fragments resulting from events, just like puzzle pieces to reconstruct a short term history. Depending on the context, different scientific tools may be put into action with the result being some pertinent information for the "historical case" represented by the past criminal event.

Restricting forensic science to the science of individualization[1], isolates and restricts the discipline's epistemological process to a narrow application which has its limitations and does not offer the breadth and richness of information that can be obtained from material information, from intelligence and security[23,24], investigations and reconstructions, to court evidence interpretations.

Despite the major influence of so many different practitioners identified as chemists, physicians, biologists, physicists - rarely or later as criminalists - like Francis Galton (1822–1911), Alexandre Lacassagne (1843-1924), Karl Landsteiner (1848–1963), Albert Osborn (1858–1946), Salvatore Ottolenghi (1861-1934), Alfredo Niceforo (1876-1960), Calvin Goddard (1891-1955), can forensic science claim a scientific status in its own right? The human mind is constantly attempting to produce simple, unified and coherent representations of nature since at least the scientific revolution of the eighteenth century, and because “all science rest on simple principles”[1], forensic science should lay on a minimum of fundamental, primary, or general laws or truths, possibly axiomatic, from which others are derived. Obviously, Locard's trace exchange and Kirk's individuality ones are sufficient to define the profession at the outset.

b) The different versions of Locard's principle.

Although Locard did not initially identify his 1920 claim as a general law, i.e. a principle[25], it asserts:

> “La vérité est que nul ne peut agir avec l'intensité que suppose l'action criminelle sans

laisser des marques multiples de son passage. [...]. Les indices dont je veux montrer ici l'emploi sont de deux ordres : Tantôt le malfaiteur a laissé sur les lieux les marques de son passage, tantôt, par une action inverse, il a emporté sur son corps ou sur ses vêtements les indices de son séjour ou de son geste"[19],

translated as

"The truth is that none can act with the intensity induced by criminal activities without leaving multiple traces of his passing. [...] The clues I want to speak of here are of two kinds: Sometimes the perpetrator leaves traces at a scene by his actions; sometimes, alternatively, he picked up on his clothes or his body traces of his location or presence".

If *A study in Scarlet*, the first Conan Doyle's novel featuring Sherlock Holmes in 1887, is presented as Locard's reference of his claim[26], this scientific hypothesis[27] appeared as soon as 1911 with Reiss :

"Dans presque tous les cas, les auteurs d'un vol avec effraction laissent sur les lieux des traces » et « les traces peuvent être de deux sortes: Elles peuvent consister en empreintes de toute nature ou en déplacements, fractures, ou dépôt d'une matière"[28],

translated as :

"In almost every cases, perpetrators of a breaking and entering burglary leave traces on the scene" and "these traces are of two kinds : they can be made of prints of any nature or displacements, breaks or deposit of a matter".

As Locard often recognised the influence of Gross on his own thinking, this may also go back to the Austrian jurist.

The notion of this fundamental idea constituting a separate science[29] appears first in the 30's, once translated in an American review[30]. It is of interest to notice here the original criminological and probabilistic wording of the principle : the criminal violence is explicit as a condition of the trace being left without being sure of its certain presence: "After a crime has been committed, the perpetrator may leave behind or take with him, physical evidence"[31]. Notably, it can be expressed in other ways:

- **Criminological and deterministic:** The human activity, not necessary violent, always leaves traces with certainty, as "[w]hen a man commits a crime he always leaves something at the scene that was not there before, and carries away something that was not on him when he arrived"[32]. This formulation is similar to Kirk's (1902–1970) re-wording of Locard's principle : "Wherever he [the perpetrator] steps, whatever he touches, whatever he leaves, even unconsciously, will serve as a silent witness against him. Not only his fingerprints or his footprints, but his hair, the fibers from his clothes, the glass he breaks, the tool mark he leaves, the paint he scratches, the blood or semen he deposits or collects. All of these and more, bear mute witness against him. This is evidence that does not forget. It is not confused by the excitement of the moment. It is not absent because human witnesses are. It is factual evidence. Physical evidence cannot be wrong, it cannot perjure itself, it cannot be wholly absent. Only human failure to find it, study and understand it, can diminish its value”[33].

- **Sociological and deterministic:** The criminal violence is not necessary as the mere human presence is enough, as “tout homme laisse, de son passage, des traces visibles ou invisibles que la chimie fera apparaître”[34] translated as “any man leaves on his way visible or invisible traces that chemistry will let appear” ; or “[i]t is not possible to come in contact with an environment without changing in it some small way, whether by adding to it or taking something away.”[35]; or “[n]o matter where people walk or what they touch, they will leave something of themselves or their environment at the scene or will take something away from the scene”[36].
- **Universal and probabilistic:** The generalization erases any criminological, sociological and human factor, as “ [w]hen two items come in contact with one another there is a potential for transfer of either substance or pattern”[37a].
- **Universal and deterministic:** The wording carries the weight of a general law of nature: “every contact leaves a trace”[38-41], with a conventionalist dimension spreading to other fields than physical trace, as “[i]n essence every contact leaves a trace, which is one of the fundamental principles of forensic science. Images that have been directly captured at a crime scene can be used as evidence. In this case the trace consists of the radiated and reflected photons from the objects at the scene”[42] ; or “les développements scientifiques ont largement aidé les enquêteurs pour retrouver des traces qui autrefois seraient [sic] encore perdues. Il suffit de penser au téléphone portable,...”[43], (“the scientific developments largely helped investigators to find back traces which would have been lost in the past. One can think about mobile phone, ...”).

This list upsets the acceptance of Locard's principle as a uniform idea or concept, itself leaning towards either intuition and conventionalism[44], or a necessary hypothetical generalization[27].

c) A methodological focus on Kirk's principle.

Kirk's principle claims “[e]very object of our Universe is unique”[1]. It could originate from Quételet's (1796-1874) statement around 1830 saying “deux corps ne peuvent être exactement identiques” (“two bodies can not be exactly identical”), by application of the theory of probabilities to anthropometry. It improperly[45] generalizes a more or less strong induction[46a]. Indeed, this weakness is the source of many sometimes virulent critiques about its scientific relevance, and hence its legal admissibility[5, 47-49]. If these critiques are legitimate, if not justified, they bring a cumbersome burden to individualization's inventor, who put forward a philosophical - but not scientific – truth:

> "A thing is identical with itself, because it is an object with a separate existence, independent of all other objects, no matter how similar. Two objects might be similar that no test could be devised to tell them apart, but they would never be identical with each other. A situation such as this, in which no test can distinguish between two objects, is only a philosophical abstraction ; it is unthinkable in the real world. If it existed, it could be defined as an *identity of properties* ; that is, every corresponding measurable property of each of two objects would be found to be the same. Even so it would fall short of the philosophical concept of identity in that one set of properties, *time* and *space*, must be different. With separate existence, two objects could not at the same time occupy the same space. Thus, the philosophical concept has its real counterpart in the physical world.
>
> As a practical matter, the idea that two objects might have a totally identical set of properties is not realistic, and the scientist will always have to accept the alternate concept that every object in the universe is in some meaningful or measurable manner different from every other object in the universe, regardless of the degree of similarity between them."[50].

This may underline the mostly comparative nature of forensic examinations and the need for discriminating power, whatever the precision and accuracy of the measurement.

This philosophical concept appeals directly to the logical atomism of Wittgenstein (1889-1951), who said in 1922 "[s]aying that two things are identical is devoid of sense, and saying that a thing is identical to itself is saying nothing at all" ([d]ire que deux choses sont identiques est dépourvu de sens, et dire d'une chose qu'elle est identique à elle-même c'est ne rien dire du tout"[51]). Indeed, notwithstanding the inescapable different coordinates in the spatial dimension of two similar things, the daily work of forensic consists of discussing structural (physical, chemical, pattern) dissimilarities, either explainable (supporting a compatible source attribution) or unexplainable (leading to a conclusion of different sources or different history/taphonomy), which can easily be conceived as falsifying experiences to Kirk's principle. Within Popperian epistemology[7,52], the very fact that one is able to conceive such experiments leads to the scientific nature of the law itself ; hence, ironically, our more than a century of criminalistic practice would tend to support the philosophical Kirk's principle as being epistemologically acceptable as scientific.

Briefly speaking, the thesis that Kirk's principle passes Popper's falsifiability criterion can be upheld and deserves a scientific status according to the understanding of what constitutes science by American courts under Daubert. Nevertheless, the concept of identity is more complex than this sweeping generalization. Indeed, properties may be permanent like the biological identity of DNA and fingerprints, transitory or ephemeral (for instance with age or localization), a single entity may have different names ((such as pharmaceutical medicines sold under brand and generic trademarks) or different entities may share the same identifier (any brand name or model within a brand, for instance). This complexity ultimately leads to a concept of identifiers or characteristics that, when combined, will reduce a potential source population by linking the identifier to a subject or object within that population (essentially, set theory). Reducing the concept of identity to its ultimate result – individualization - is what causes many problems for the forensic science community. It should be clear that any factor that will reduce a population is a useful factor. Confusion has appeared here because many authors focus on the technique (discrimination power of a method, in general) rather than on the identifier and its reduction factor within the population concerned[53]. As soon as the population is not a closed set the notion of identity can only be expressed in terms of probability based on the discrimination power of the method and the known or perceived variability of the identifiers. Therefore, forensic science is relegated to statistical interpretations[54].

d) Locard exchange as a scientific principle.

Establishing the scientific nature of Locard's principle would consolidate forensic science as a scientific endeavor, not only for courtrooms, but more importantly as part of human scientific knowledge. The ideas surrounding admissibility, falsifiability and error rate have been confused by the current debates, as the Daubert court, quoting Popper and Hempel, mixed falsifiability and testability "[T]he criterion of the scientific status of a theory is its falsifiability, or refutability, or testability"[55]. Indeed, if one looks at general theory, "[s]cientific methodology today is based on generating hypotheses and testing them to see if they can be falsified; indeed, this methodology is what distinguishes science from other fields of human inquiry."[55]. But to be clear about the levels of science to be addressed, the Daubert Court stressed that "the focus should be solely on the principles and methodologies employed", with principles addressed before methodologies.

Just like the identification process, the concept of exchange attributed to Locard is very complex and difficult to address by traditional scientists. The observed results of an exchange may have diverse causes and their likelihood can only be measured or estimated in relation to proposed alternatives i.e. the uncertainty does not rely that much on the methodologies used but rather on the alternative propositions made[56-59] as well as the complexity of nuanced or poorly understood variables. This combines an inference process resulting from observation (of subjective probabilistic nature) followed by a decision based on direct stated effects and most scientists are uncomfortable with this process[60]. Yet most of 20th century science and discoveries have followed this path[61-65]. Examples of such discoveries would include Einstein's relativity theory and, perhaps more importantly, Heisenberg and the "uncertainty principle" associated to his name.

Locard's exchange combines the question of the identity of the source of transferred material (or signal or pattern) and the question of the activity that led to the transfer and the modification through time of the resulting transfer (persistence)[66]. This historical reconstruction process led to extensive research into transfer experiments (within and inter variability depending on various situations, glass[67], fibres[68], GSR[69], drugs[70], paint[71], among others), studying factors affecting donor capability and acceptor capability both of which combine physical and chemical factors that may be complex. Nevertheless, all experiments showed conditions under which measurable transfers do, in fact, occur. Further experiments showed the effect of time and activity on the loss of transferred entities with characteristic logarithmic curves. Analogous studies of evidence transfer are presently conducted in the DNA[72-74].

Knowing the universality of transfer and loss through time, traces will be produced through legitimate contacts as much as through the investigated or alleged contacts. This led to multiple contamination studies (background level or noise level) and, importantly, target material studies to determine whether an observation could result by chance only or by a specified contact[37]. Fibers being a relevant model, since the seminal work started in 1975 by Pounds and Smalldon[75-77], these studies have been found to be reproducible, most uncertainties arising from circumstances and not from methodologies used in the analysis[78-83]. Surprisingly, since Daubert, most discussions turn around error rates in the methodologies!

In our view, the question of admissibility of the evidence is not a scientific question, but purely a legal one[84-90]: The observations made and the inferences made according to circumstantial alternatives afford the court information that it would not have otherwise[*]. A forensic scientist should be able to describe how changes in circumstances will affect the value of what was observed but this will always remain probabilistic because time is not symmetrical (one cannot go back in time and reproduce the single event) and the reality of the event can only be inferred. Locard's exchange principle offers reliable information about past events, the highest uncertainty arising from the reality of alleged circumstances, for which the Case assessment and interpretation (CAI) model offers one scientific methodological solution[91-93].

The main problem of most expert opinion in accusatory systems lies in the fact that experts statements/opinions are offered by the prosecution or the defense and provide evidence on proximate causality rather than a balanced view of observed effects given alternative causes. This

*In the US, see Federal Rule of Evidence 702: “If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise, if (1) the testimony is based upon sufficient facts or data, (2) the testimony is the product of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case.”

was the prototypical mistake highlighted by Poincaré in the Dreyfus case in 1904[94,95] and seeps into or through most known cases of judicial errors.

Following the demonstration of our two testable axioms which support specifically what we like to call forensic science, a more general and philosophical question may be raised as to what constitutes a science and whether forensic science can claim such a status. Indeed, accepting the rules issued by the Daubert hearing calling for an epistemological approach, one can even find philosophical and historical models pertaining to the case at hand.

Certainly, Popper is a favorite philosopher of science, particularly within legal circles, but many others have attempted to define science and many theories co-exist, searching for a Grail represented by a universal definition, much like looking for one answer to the meaning of life. A short overview of theories is persuasive in showing that forensic science is a science by almost any point of view.

II – Is forensic science scientific ?

Philosophical discipline on its own since only the end of the 19th Century[96], epistemology, which merges with the theory of knowledge, aims to answer three main questions: What is knowledge ? Through which method can it be ascertained ? What is its cogency ?

As Daubert's first request targets the last question, all induced legal or even forensic reflexions are focusing only on the second one. As lessons from first inventors and philosophers could be learned on the ontological issue of our forensic principles, Popper rightly addressed the problem of the justification of any theory, introducing the demarcation's criteria of falsifiability to distinguish science from metaphysics (or pure belief not sustained by facts). But this logical approach is not immune to pragmatist critiques, letting appear Popper's falsifiability as a severe threshold (remember that Kirk's Principle passed the test!), and through which Locard's Principle could be analyzed.

This part will propose the readers markers to question the epistemological admissibility of Locard's Principle, through historical reflexions and a logical reasoning.

a) From Aristotelian deductivism to Popperian falsificationism : First lessons to be learned.

As the “[s]ystematic knowledge of the physical or material world gained through observation and experimentation”[97], science refers to a system of acquiring knowledge (the scientific method), involving human reasoning with the goal of deriving theories from observable facts[98,99].

Although denying[100] the oft told story that modern science was born in the early seventeenth century, when the strategy of taking the facts from observation seriously was adopted, it is nevertheless true that deduction, called also Aristotelian syllogism, was for a long time considered as the unique available inference to reach conclusions about the natural world observations[101]. Premisses, like the Bible authority, were undisputed before Copernicus (1473-1543) heliocentric system and Galileo's (1564-1642) laws of motion research[102], which both induced 200 years of heated debate about the role of experiment (e.g. see Descartes (1596–1650) who did not require for any experiments but rather a universal doubt in the face of any knowledge). This acceptance liberated two main currents of inductivist thought, British empiricism in Bacon's (1561 - 1626) track[103] (John Locke, George Berkeley, David Hume) and continental positivism, both of them settling induction at the heart of the growth of knowledge by way of sense perception[104,105]. Indeed, if Locard's Principle is today elevated as a foundation of forensic science, it is mainly due to its century conscious and claimed inductive corroboration of the original Locard's statement by forensic scientists, accepted today as a premise ("Every contact leaves a trace").

Within the different approaches of science by these two different inductivist schools (illustrated by Newton's (1643-1727) *Principia mathematica* opposite of Descartes' (1596-1650) *Principia Philosophiae*, in which there is scarcely any mathematics[106]), the empiricist methodology seemed to have much success, because it led to the Scientific revolution[107]. But it rarely questioned the scientific foundations of human knowledge[108] and David Hume (1711–1776) introduced a logical pessimism for this methodology to establish general laws of nature[45].

In that pessimistic atmosphere, Kant's (1724-1804) a priori and synthetic universal principle of cause, which states that any repetitive occurrence or observation is governed by causal regularities[109], appears as an attempt to save inductivism, but is rejected today by philosophers of science[110,111]. It is then hard to invoke it as the rational ground fitting any observable fact.

Searching for a methodological rule with identified thinking process able to infer new theories, the Vienna school is a philosophical trend of empiricists combining the inductivist logic and the confirmation theory. Their ambition aims to build an organized and formalized knowledge depending on Ludwig Wittgenstein's (1889–1951) and Bertrand Russell's (1872–1970) logic[51,112]. Agreeing with this general critique of metaphysics, close to the Vienna Circle, Popper (1902-1994) could not completely subscribe to this movement[113], as he could not agree to a process, ready to accept a logical statement without imperatively testing it[52], and unable to reject Marxism, Adler's or Freud's psychoanalysis as self-declared sciences through their social or human predictive powers.

On the opposite, impressed by the risk said to have been taken by Einstein as he asked to set aside his relativity theory if the sun rays curvature was not observed during the1919 eclipse, Popper applied the *modus tollens* logical rule to demonstrate that scientific certainties are always negative at the end. Hence, theories understood as speculative and tentative conjectures have to be falsifiable or refutable to be accepted as scientific, meaning open to rigorous and ruthless experiments showing repetitive anomalies leading to reject it. The more a theory will resist to such experiments, the more it would be corroborated, but it could never be verified. The eliminated theories should be replaced by further speculative conjectures : science progresses by trial and error, by conjectures and refutations[114]. Falsificationism supplants inductivism as the logical approach involved in the growth of science, as highly falsifiable theories should be preferred to less falsifiable ones. Within these rules, “every contact leaves a trace” is preferable as any other previous formulation of Locard's principle, as being the most falsifiable statement.

But falsificationism is not really an alternative to inductivism for at least five reasons :

- It better compares alternative competing theories, selecting the more falsifiable - yet not falsified - one. Falsification seeks only constant improvements in science rather than demonstrations of truth.

- A theory which has survived tests, could only said be be corroborated by facts until subsequent tests, but never claimed as being the available law governing the facts under study.

- How could a discipline, whose principles do not remain unchallenged long enough, make significant progress for practical and philosophical work to be done ?

- It cannot solve the Duhem (1861–1916) / Quine (1908-2000) thesis[115,116] claiming that if a theory is to be experimentally tested, then more will be involved than those statements that constitute the theory under test : the theory will need to be augmented by auxiliary assumptions, such as other laws and theories governing the use of any instruments, different experimental set-up, etc. Hence, no inductively compatible statement can be conclusively falsified, because the possibility cannot be ruled out that some part of the complex testing process, other than the theory under test, is responsible for the erroneous prediction. This position is known as the confirmation holism.

- Finally, no historical study could support this kind of methodology of scientific growth adopted by laboratories or scientists. No examples exist to support this highly theoretical process that should govern scientific research. Even Popper's challenge by Einstein is contested by the anarchistic philosopher of science Paul Feyerabend (1924–1994), when situated in its time[117]. Falsifiability is even falsified by long run evolution of fields like astronomy (from Aristotle to Kepler through Ptolemy, Galileo and Copernicus) or modern physics (from Galileo to Einstein through Newton and Maxwell), which replace the growth of knowledge within a sociological context with no real connection to pure logic[118-120].

Indeed, how can a scientist try to falsify a theory that has become a safe necessary dogmatism[52], without which he would not have supported theories for years, at the first sign of anomaly? Science is, from a practical point of view, highly conservative because of this very notion.

b) From a contested epistemology to new standards of scientific recognition.

The history of science reveals that the evolution and progress of major sciences exhibit a structure that is not captured by the inductivist and falsificationist accounts. This historical view of science had proponents by the end of the nineteenth century, with Pierre Duhem notably supporting a continuous progression of science and a gradual improvement of knowledge[116]. Opposed to this philosophy, Gaston Bachelard (1884–1965) stated that any experimental science evolves through revolutions. The idea of breaches is at the core of Bachelard's epistemology, which professes that new configurations appear and objective knowledge increases, not because problems relevant to the scientific matter are solved, but thanks to victories over internal epistemological obstacles to the very act of knowing[121,122] (general opinion, immediate sensitive experience, personal certainty, etc.).

This approach opens the door to Thomas Kuhn's (1922–1996) scientific revolutions theory to explain the growth of scientific knowledge. In 1962, Kuhn proposed an epistemology that worked against the grain of the then orthodoxy and offered the notion of a paradigm, which described both a common cultural matrix for a scientific community[123] and this community itself[124-126].

The emergence of a paradigm can be complex and scaled on time, but in “very rare occasions [...], collected facts [...] speak with a sufficient clarity without the help of a pre-established theory to allow the apparition of such a paradigm. Such a situation creates the characteristic schools at the first stages of development of a science”[125a]. The analysis of the notion of paradigm[127], defined as the matrix of acquired knowledge for a discipline, foresees more than twenty metaphysical, sociological and structuring forms, the more relevant ones for our purpose are such as a philosophy, a complete tradition, a successful metaphysical speculation, a model, an accepted tool in the common law of a scientific community, a backstage of conceptualization, a standard applied to quasi-metaphysics, an organizational principle which can govern perception itself, a general epistemological viewpoint, a new way of seeing, or something which defines a large part of reality.

Normal science is defined as the routine attempts to articulate a paradigm with the aim of improving the match between it and nature, called “puzzle solving” by Kuhn. The existence of such a paradigm, which is capable of supporting this task, is the character that distinguishes science from other ways of knowing the world. The failure to solve a puzzle is seen as a failure of the scientist rather than an inadequacy of the paradigm[128,129] and puzzles that resist solution are seen as anomalies rather than as falsifications of a paradigm. Once a paradigm has been weakened and undermined by anomalies to such an extent that its proponents lose their confidence in it, the time is ripe for revolution.

A variety of factors are involved in a scientific community judgment[130] of the merits of a paradigm, such as commodity, simplicity, connection with some pressing social need, the ability to solve some kinds of problems, accuracy (in prediction and explanation of facts), consistency (in the face of other explanations), utility for new scientific discoveries, robustness, and even economy. This statement is not contested by other more evolved philosophies of science either trying to accommodate Popper's falsificationism and Kuhn's paradigmatic epistemology like Lakatos research programs, or rejecting any universal method to trace science in human knowledge like Feyerabend's anarchistic theory.

Popper's admirer, Lakatos (1922–1974) tried to fight the implicit relativism introduced by Kuhn through Popper's logic. As such, he claimed that not all parts of a science are on par. Some laws or principles are more fundamental than others, so much that they are not to be blamed for any apparent failure. This hard core of a theory is surrounded by a protective belt, sum of the additional hypotheses protecting the hard core from falsification. The hard core is rendered unfalsifiable by the methodological decisions of the protagonists of the science; the protective belt is targeted to improve the match between predictions and observations of experiments[120,131,132]. This Lakatos' essay to offer a Popper – Kuhn syncretic account of science is unfortunately not supported by any historical example[133]. On the other hand, as “anything goes” in Feyerabend's epistemology, we should not care about the philosophical if not logical validity of our forensic principles. Feyerabend maintains that, because of Kuhn's thesis, scientific efficiency is determined by criteria which belong to the scientific tradition, and can not be considered as objective judges[100,118]. He even rejects Kuhn's social consensus to restore the acceptability of any scientific theory, because he does not think this consensus is capable of distinguishing between science and theology, for instance. Science becomes a dangerous dogma in a modern society, joining Habermas sociology[134] and calling for a separation between state and science.

What remains, after so many dead ends?

Firstly, only controlled experiments can contribute to determine general laws. Secondly, falsificationism is not only a severe logical janitor of the scientific temple, but it also offers a step-by-step methodology to learn from errors, as the scientist is unable to rise up out of his paradigmatic dogmatism. From this report, new experimentalism proposes a methodological way secured by our mathematical statistical tools, betting on experiments to accept our theories: Rejecting the idea that every experiment is a deterministic attempt to answer a question posed by a theory, new experimentalists assert that experimentation can have a life of its own, as we dispose of a range of practical strategies for establishing the reality of experimental effects without needing recourse to large-scale theory[135].

Led by philosophers and historians of science, such as Robert Ackermann, Nancy Cartwright, Allan Franklin, Peter Galison, Ronald Giere, Ian Hacking, and Deborah Mayo, new experimentalists defy both Popper's logic and Kuhn's relativism for a new inductivist model of scientific knowledge[135-141].

This new approach originates from a closer analysis of Sir Arthur Eddington's (1882-1944) and Sir Frank Dyson's (1868–1939) reactions to an unexpected result during the 1919 eclipse, which did not match predictively with Einstein's relativity theory. An experimental series of tests issued from a long debate between both scientists finally demonstrated a failed structure of the mirror assembled to the telescope.

On the methodological level, new experimentalists regret that Popper's error-learning logic was not really fully exploited, as repeatability, reproducibility and observed results constantly support the scientific method. For instance, nothing was clearly done to analyze the different error types, our capability to detect and correct them, as well as studying the reflections they induced[141]. Moreover, error statistics provide an adaptive toolbox to create, shape and learn from experimental data. It allows scientists to study anomalies through instrumental measures, to reject external factors, to evaluate precision, to distinguish real observations from artifacts or background noise, instead of simply rejecting an hypothesis. Hence, experiment permits us to learn from our errors. If false, the theory will fall under experimental insults made under optimized conditions and ultimately replaced by another rational belief.

The new experimentalist strategy collates than rejects both Popper and Kuhn, the former by learning constructively from falsifications of experiments, the latter by identifying normal science with experimentation giving it the ability to detect and accommodate errors, which can prove sufficient to trigger a scientific revolution. The experimental method is reinstated as the bedrock for theory acceptance, able to determine the parameters governing the observation (from initial conditions to observer's bias through artifacts noises) through sample testing with the aim to maximize the factors of occurrence of a law[142]. Falsification, under controlled conditions defined by this recurrent process, appears as the very last test for the logical acceptance of a law.

c) Are our principles philosophically admissible as scientific ?

The study of human reasoning regards explanation and interpretation processes as an integral part of the growth of knowledge. If it could give keys to the rationalist ground of Locard's exchange, as the most probable hypothesis explaining traces found on scenes of crime through abduction[143], this could be based on the observation of human survival! Thousands of years of cynegetic experience and reasoning - acquiring the art of animal detection through the reading of most tiny traces[144] completely support this way of accumulating knowledge. As such, Locard's principle is acceptable as an pragmatic hypothesis corroborated through many thousands of years. In complement at that time, let put aside the probabilistic version of our principles : If probabilism, seen as a comprehensive and unified treatment of induction[145] comes close to be attractive for Bayesian educated[55-58] forensic scientists, this path does not give the expected results for the philosophy of science, which is not interested in probable truth : “[P]robability does not “exist” on its own, independently of the evaluations we make of it mentally or instinctively”[146]. Moreover, laws of probability conjugated with logic of induction (applied on infinite occurrences of the law) are mathematically zeroing the probability of any general law[8,147]. Furthermore, Bayesian supports of a theory confirmation[61-63] can say nothing about prior probabilities and evidence to be fed into Bayes' theorem for this purpose of theory choice, rejoining critics of irrationalism to affect a priori odd to any theory[148-150]. As such, Bayes formula is a tool for decision, not adapted for the logical search of a natural theory. “The theory which attributes degrees of probability to hypotheses seems to originate from a confusion between psychological questions and logical ones”[7a]. Confusion could still remain in our present meta-forensic quest, as our daily forensic questionings are of psychological nature, based on both legal and methodological rules, confronting alternative hypothesis, not claiming the truth of any one of them.

To close the case more generally, are scientists acting as Bayesian agents[151]? Their tests are interested in theories with no a priori probabilistic quantification. Adding that Bayesian reasoning dispenses a confident interval for the corroboration of any law, no theory can ever be said to be accepted by some scientists at a specified margin of error.

After having screened the different paths offered by the very same philosophy of science quoted in Daubert, it looks self-evident that Locard's and Kirk's principles shape the paradigmatic matrix of normal forensic science, in the absence of more powerful alternative theories rendered necessary because of unexplained repetitive anomalies.

One could present the principle of divisible matter as such a theory, since it is the only one alternative presented up to now. But, stating that “[m]atter divides into smaller parts when sufficient force is applied”[6b] does not embrace more singular facts than “every contact leaves a trace” or even any of the criminological formulation of Locard, because crimes include implicitly “sufficient force”. Moreover, how funny is it to observe that electronic traces are taken into account with the general Locard's Principle coming from the 1930's, not by Inman & Rudin's principle of divisible matter at the beginning of the 21st century! Finally, invoking Popper's philosophy to propose a rival theory to replace an acceptable not-falsified one is quite troublesome for at least two reasons : highly falsifiable theories (“every contact leaves a trace”) should be preferred to less falsifiable ones (principle of divisible matter)[7]; a newly proposed theory is acceptable only if it predicts a new kind of phenomenon not touched upon by its rival, which is not the case. Hence, Inman and Rudin's statement of the principle of divisible matter could be relevantly understood as an explanation of Locard's transfer Principle. But the latter is more falsifiable, hence, more interesting, than the former.

It is true that the lack of sensitivity for detection of traces (either due to the human weakness[152], the material at disposal or the projected institutional resource) is an easy solution to reject any falsification of Locard's principle. But why should we bother about the legacy (and not the "scientific-ness") of this principle, as its commodity, its simplicity to be understood, its capacity to embrace all criminal facts[145] , all of them sociological relevant criteria within the scientific and legal communities of interest, have the potential to let jurists and forensic scientists agree on this bridge principle between each ones? As long as the interpretation process proceeds through the CAI model and the information is offered in a balanced (non-partisan) and transparent manner, why would this not be science?

Conclusion

Forensic scientists, have been labeled "craftsmen"[89], have been accused of carrying "a misleading title"[89], of having "no understanding of scientific methodology"[89], of issuing "clearly absurd"[90] or "preposterous"[90] conclusions of individualization, and practicing a marginal, pseudo- if-not-junk science[154,155]. Kirk's and Locard's principles both have the ability to be accepted as scientific laws. They add knowledge that can be measured and used in logic for the sake of the law (if not justice). The "over-claiming"[9,156] of experts must still be questioned, but that is an inferior level of analysis or review of our particular historical science (the more interesting deal with interpretation, already addressed by forensic scientists). Unfortunately, this cohesion of forensic science, both through its paradigmatic principles and the CAI model, seems not to have been caught by the 2009 NAS report, as "the legitimization of practices in the forensic science disciplines must be based on established scientific knowledge, principles and practices"[21a].

Acknowledgements :

The first author would like to thank Prof. Simon A. Cole from the University of California, Irvine, for guidance on some relevant jurists' critics about the present state of art of forensic science, and Karl Harrison from LGC Forensics®, UK, who invited him to renew his arguments about the scientific nature of crime scene management since March 2008.

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