Journal Pre-proof

Towards a forensic semiotics

Frank CRISPINO

PII: S0379-0738(24)00049-5

DOI: https://doi.org/10.1016/j.forsciint.2024.111968

Reference: FSI111968

To appear in: *Forensic Science International*

Received date: 25 October 2023
Revised date: 18 December 2023
Accepted date: 12 February 2024

Please cite this article as: Frank CRISPINO, Towards a forensic semiotics, *Forensic Science International,* (2024) doi:https://doi.org/10.1016/j.forsciint.2024.111968

Towards a forensic semiotics

Title : Towards a forensic semiotics

Author : Frank CRISPINO, PhD, MPhil

Affiliations :

UQTR, Forensic Science Research Group, Director

UQTR, International Center for Comparative Criminology, Researcher

Acknowledgements :

As the author takes full responsibility for the condensed and abstruse part of this paper, he owes a debt to his usual conspirators for their advices to help make it more readable. Thanks to Olivier Delémont, Olivier Ribaux and Celine Weyermann

Declarations of interest: none

Complete address :

Université du Québec à Trois-Rivières (UQTR)

3351 Boulevard des Forges

Chemistry, biochemistry and physics Dpt

Trois-Rivières (QC) G9A 5H7, Canada

Highlights

- Quality management and legal criteria fall short of embracing the epistemology of forensic science.
- Are the Bayesian prescriptive and the descriptive cognitive approaches irreconcilable?

- Peirce semiotics seems an unexplored rich avenue that could merge both approaches and serve the various communities forensic science is providing.
- The Sydney Declaration recognizes this capacity throughout its principles.

Abstract

For years, forensic science has been criticized for its lack of scientific foundations, explaining its methodological drawbacks. Notwithstanding recommendations to upgrade quality management and counter cognitive biases, the ontology of the trace and the very nature of forensic science amplified by its decision context is rarely invoked as sources of inescapable errors. Understanding what (forensic) science is could even reconcile the prescriptive approach and the descriptive cognitive reality, through an unexplored pathway, Peirce's semiotics. The implementation of a semiotic line of arguments could concur to the transparency of scientific opinions for security and justice purposes, with rich potentialities in sight.

Keywords: Trace; interpretation; meaning; semiotics; Peirce; epistemic probability.

The Sydney Declaration aims to revisit the essence of forensic science through its foundational basis, beyond organizations, technicalities or protocols [1]. Indeed, for years, forensic science has been criticized not only for its methodological drawbacks, but also its lack of scientific foundations [2, 3]. Through introducing four non-exhaustive criteria to help the decision-maker identify scientific knowledge, the 1993 USSC Daubert hearing illustrated this legal concern about its epistemological nature [4], although Honorable Judge Rehnquist's minority opinion questioned the competency of judges to define science. Standard operating procedures, quality management and bias identification as solutions advanced by the 2009 NAS Report are still falling short of addressing the philosophy relevant to forensic science [5]. One could even question the current understanding of (forensic) science by both scientists and its stakeholders: Forensic science fundamental principles are asserted but seem insufficient to provide a reliable implementation of science addressing security and justice questions [6]. Indeed, what are those fundamental principles? Locard's exchange one, far from being "Every contact leaves a trace", is of sociological nature [6, 7]. Kirk's individuality principle, at least traceable to 1922 Wittgenstein Tractacus Philosophicus (5.5303) is philosophical [7, 8]. Locard's exchange and Kirk's individualization principles define a complete tradition within forensics, a set of techniques and methods focused on court questions, a reduction of forensic science [9]. They constitute a model to theorize the crime scene and the perceived forensic scientist tasks, hence, tools accepted in the common law by its scientific community. They could be seen as a norm applied to quasi-metaphysics, as both are philosophical and govern perception itself. All those descriptions constitute a Kuhnian paradigm, i.e. a general epistemological point of view of a scientific discipline, here forensic science [10, 11]. Nevertheless, unable to be tested to Popper's severe demarcation criterion of falsifiability, distinguishing science from pseudo-science [12], some are entitled to claim that they are not scientific [7, 13].

As the accountability of bad science in the courtroom is usually laid on individual scientific shoulders, at best structurally supported by a lack of independence with consequential occurring biases from experts, couldn't errors be inescapable, due both to the ontology of the trace and the very nature of forensic science amplified by its decision context (part 1)? Shouldn't the conflict between the scientific prescriptive approach and the descriptive cognitive reality allow for a better understanding not only of what science is about, but also for a way to acknowledge and even reconcile both approaches (part 2)? With regards to the philosophical journey he took as a leading logician at the very first hours of statistical studies, couldn't Peirce's semiotics offer an unexplored solution (part 3)?

Part 1 – State of the (perceived) art of forensic science

Although junk science was clinched in the courtroom by Huber in 1991, one could easily find such worries as early as 1904, with Poincaré criticizing Bertillon's expertise as poor reasoning on false data [14]. Even earlier in 1840, Orfila relieved of any expert duty after Mrs. Lafarge was found guilty of poisoning her husband, was upset to have been possibly misunderstood by the jury about his arsenic identification in Mr. Lafarge's body, as it was not his responsibility "to say whether Madame Lafarge was guilty or innocent" [15].

Indeed, forensic science could appear as an easy scapegoat for wrongful convictions, and high-profile cases produce easy anchors to this perception (Dreyfus, Omar Raddad in France, Azaria Chamberlain, Farah Jama in Australia, Louise Reynolds, Leighton Hay in Canada, McKie, Easton in the UK, JonBenet Ramsey, Mayfield in the US, to cite only a few). But, when one observes each case, it is uncommon, even if so frequently presented, imputable to individual forensic bad practice. Indeed, a more general picture emerges than expected. It is undeniable that a compromised chain of custody or an inadequately trained examiner not applying accepted standards of the discipline can put at odds the legal admissibility of evidence. It is not rejected that some disciplines rely on unrobust empirical findings (which is partly the task of the Court to check), or that a forensic scientist, or an independent expert outside the administrative control of public laboratories, could provide an unsound interpretation. However, the main picture is more about probative evidence overlooked at the crime scene, police investigators not detecting, ignoring or misusing relevant forensic traces, prosecutors mischaracterizing evidence, let aside judges admitting testimony that does not conform to rules of evidence [16, 17]. Following the seminal Brandon Mayfield's miscarriage of justice 13 years after Huber's Junk Science in the Courtroom in 1991 [2], did national recommendations calling for separation and independence of labs from police forces and prosecution authorities enforced by norms, accreditation, certification to ensure precision, accuracy, confidence (NAS, Hart House, PCAST reports) [18-20] correct this perception? Then, how does this explain the new denunciations of Fabricant's 2022 Junk Science, focusing on bite marks, hair and bloodstains, but also damaging arson reconstruction, fibers and fingermark identification, to cite a few [3]? One can argue that, after 14 years, we are only halfway to implementing the NAS recommendations. But looking at the UK, it is likely further than 50% of this journey has been made with the establishment of the Forensic Science Regulator (FSR) in 2007, before the dismantling of the Forensic Science Service (2010) and the privatization of the market, that should have supported quality management harmonization, impartiality, accuracy, and costs benefit through a forensic profit-driven marketplace [21-23]. Despite a clear engagement by the FSR with a broad variety of stakeholders, it is hard to celebrate

a new efficient forensic science provision. Reading the yearly Forensic Science Regulator reports since then, it is apparent that it still faces incomplete accreditation and lack of compliance, the legislature's unwillingness to enforce its power, entitlement of courts to accept any evidence from non-accredited experts or laboratories. The icing on the cake is an increase of less-qualified forensic workers in police services due to budget decreases and inability to support the police investigative and intelligence-led initial screening and selection of exhibits, which speeds the collapse of the forensic free market, hence increasing its case-by-case costs [24]. Without throwing out the baby with the bath water, wouldn't it be useful to ask what forensic science is, by focusing on its fundamental, theoretical and permanent attributes? Let's face it: science will always be part of the investigation. Thus, the question is who will implement it? A police officer using a portable NIR instrument, an AI (Artificial Intelligence) specialist for stylometry, or a forensic scientist understanding forensic principles, their strengths and limits? Back in 1963, Paul Kirk has already raised the issue: "With all the progress that has been made in this field, on a wide front, careful examination shows that for the most part, progress has been technical rather than permanent" [25]. It is even more relevant today at a time where digital transformation is reshaping the contextual environment of scientific investigation [26, 27]?

Back to basics, science is the "systematic study of the structure and behavior of the physical and natural world through observation, experimentation, and the testing of theories against the evidence obtained" (Oxford dictionary). Science is split into scientific disciplines (also called "sciences" or "fields of science"), that are subdivisions of science and branches of knowledge that use a rigorous and systematic method to study a particular area of knowledge. Forensic science aims to reconstruct singular circumstances of a past event through its uncontrolled offspring specimens, called traces [28]. Instead of being predictive of a general law or theory through Galilean (aka well designed and controlled) experimentation to interpret samples, it is retrodictive towards a singular unobserved event from an uncontrolled, degraded, often mixed specimen [29, 30]. Its lack of statistical representativeness introduces a native uncertainty, amplified by the inferences to explain it [31], with the danger of "recounting past events in the light of what appears to us to give them a logical meaning after the fact" [32, p209]. The forensic scientist is only a surrogate, an auxiliary of the trier of fact who is the only one in charge to transform thinking into action (sentencing, allocating investigative resources, etc.), i.e. accepting evidence as a proof. Instead of evidence, proof is "an artifice established by a recognized method which allows a proposition to be the subject of a belief" (Encyclopedia Universalis). How does forensic science address this challenge of reliability of belief for the trier of fact while solving a problem of high complexity due to human decisions throughout [33]?

2 – Prescriptive vs. descriptive approach

The middle of the 19th century marked the avalanche of figures, the scientific frenzy of measuring and recording everything, announcing the birth of statistics [34]. But Galton, the first theorist in the field, quickly recognized that the correlation is independent of the cause. His best student, Pearson, rejected any causality in the conclusions of this new science [35]. The difference between the probability of causes and that of effects was the subject of a most subtle theorization by Henri Poincaré from 1902, moreover, implemented during the second Dreyfus revision trial at the Court of Cassation (French Supreme Court) (1904) : « It often happens that instead of trying to guess an event based on a more or less imperfect knowledge of the law, we know the events

and try to guess the law; that instead of deducing the effects from the causes, we want to deduce the causes from the effects. These are the so-called problems of probability of causes, the most interesting from the point of view of their scientific applications » [36, p221-222]. Its objectification by the urn model, i.e. his proposal of a bijection between frequentist (also called objective) and epistemic (personal) probability opened the door to the recognition of probabilities as “states of mind, not states of nature” [37], necessarily subjective and conditional [38], that one could trace back in 1835 to Poisson: probability is the ('subjective') probability of an ('objective') probability, or, better, “*la probabilité d’une chance*” [34, p99].

The table was set to implement a scientific approach to solve a singular problem from an unobserved past, or “finding an explanation without conflict with the state of knowledge” [39, p17]. Indeed, Bayes theorem is the only logical solution to deductively upgrade belief through knowledge [40-42], leading to the so-called prescriptive approach [43, 44]. Add in quality management through controlled experiments (or today AI calibration), and one could think they are heading to the Holy Grail of an objective safe heaven [45], despite the warning of statisticians themselves: “All our analysis provides is a set of tools and you have to relate them to the circumstances you face, which is no easy task. What our analysis does is to provide a framework for our thoughts” [42, p241]. As quality management does not address this inference process [46, 47], cognitive scientists convincingly argue that not only do we tend to apply causal thinking inappropriately to situations that require probabilistic reasoning, while even aware scientists easily err with figures they provide [48, 49], that echo in the various fallacies denounced in forensic science [50-52]. Such a questioning of the prescriptive approach by the descriptive one could even be felt as an open conflict: “Rather than award a Nobel Prize to someone who correctly shows how bad we are at decision making, we should support research into coherent decision making” [53, p373, undoubtedly targeting Kahneman].

Although the Daubert hearing tried to define science (a pretension opposed by Judge Rehnquist’s minority opinion), this never-ending debate would not be solved by jurists and lawyers: “It is a utopia to suggest that these scientific difficulties we face are going to be corrected by the court. Judges don't have the expertise for that. We don't even know how to ask the right question. It is not a lack of will; it is that most of us are misinformed” [54]. One could even fear the sounding board of the contradictory adversarial system: “In the adversarial system, once you get to court, your mission is to win. So, you're not doing anything that would help the other party. In such a system, you are not looking for scientific truth. This work must have been done by the scientists” [54], as Rocher, dean of the Law faculty of the University of Sherbrooke, one of the best Canadian education academy in this field, asserted in 1998 : “As for current students, I have often found that most of those who enroll in law have avoided science education in high school and college” [55], or Laurin pointed to a “raft of yet unaddressed issues concerning the meaning of scientific integrity and reliability in the context of investigative decisions that are by and large committed to the discretion of decidedly unscientific actors” [56, p1118]. It raises up the gain and loss of a better capturing the most secured processes of the investigative and justice processes (“It costs something to reduce errors, and it costs more and more to get rid of each error as there are fewer of them left” [57, p1007]). This aligns with Goldstein's warning that "all bureaucracies risk becoming so preoccupied with running their organizations and getting so involved in their

methods of operating that they lose sight of their primary purposes for which they were created" [58, p236-237].

Can anything emerge from this field of ruins? Is it possible to find a research axis to reconcile both sides [59]?

3 – An unexplored avenue

Charles sanders Peirce (1839-1914) is born into a puritan, severely religious family from New England. His father was a mathematician and astronomer, professor at Harvard [60]. As an American polyglot (including Ancient Greek) scientist, logician, Charles belongs to those collectors of figures described by Hacking at the mid-19th century [34]. He is the first one to frame a random control test in 1884 for psychological studies and to "elicit subjective or personal probabilities, determining that these probabilities varied approximately linearly with the log odds" [34, p211]. He immediately rejects the consequences of such an inapplicable subjective use of statistics. His "Values in a universe of chance" (1880) is the philosophical and logical foundation of Galton's frequentist school [61]. So why did Peirce, a polymath, author of numerous theorems in formal logic, turned into philosophy and a full theory of signs after 30 years of quantitative practice, discovered only after his death through his correspondence with an English suffragette and feminist, Lady Welby, herself interested by logic and epistemology? We have to wait for the publication of the first two volumes of the Collected Papers (CP) in 1931-32 to learn that Peirce developed during his life (especially during the period 1860-1910) a cognitivist theory of knowledge that figures and statistics could not solve, called semiotics, in which signs are the center pieces. Indeed, part of the answer could be found at CP 2.690: "How is that that a man can observe one fact and straightway pronounce judgment concerning another different fact not involved in the first?" [62].

The central postulate founding the semiotic project could be reduced to the following assertion: the world is only accessible to us as a representation, in the form of artifacts that we call signs. These artifacts or signs are constructs, "a thing, knowing which, we know something more" (CP 8.332). The real reference world is not directly accessible by intelligence. And the knowledge, understanding, intelligibility of the signs under which the world presents itself to us - and is accessible to us - is achieved by processing or manipulating signs with the help of other signs. Peirce calls semiosis this necessary sequence of signs. It is in this sense that a theory of signs (semiotics) is a cognitivist theory. Peirce's semiotics originality resides in a needed and sufficient triadic decomposition of signs, where the perception of the sign (representamen or ground) leads to another signification (the object) through a necessary Interpretant, which is a function, a resultant, a thought, a judgment. While Peirce never detailed the nature of the Interpretant, summarizing it as the habit, it is not hard to recognize in it the "eight sources of bias" (if so limited…) of Dror, 2020 [51]. Searching in a revered cognitive scientist who never cited Peirce or his semiotics, Hofstadter is a good hit [63]. But it fails to refute it: Aren't Hofstadter's symbols, activated at a level of recursion higher than that of synoptic signals, Peirce's signs? An active symbol is one which "can be triggered in many different ways", hence which can act "in many different ways when awakened" [63, p349]. We should think of a symbol not as a fixed entity, whose "purpose is to try to awaken, or trigger other symbols" [63, p350]. Double down, aren't Hofstadter and Sander analogies, "the fuel and fires of thinking" both part of the Interpretant and

the semiosis modelled by Peirce [64]. Indeed, it is quite difficult to imagine how to better define Peirce's semiotics…

By transparently integrating the human factor in the interpretation process through the Interpretant, Peirce opens the way towards a more qualitative approach of the thought process, or sense making or signification. It helps to express and decode the signification of forensic findings, even considering the complexity of the mathematical expression through the use of (quantitative) probabilities.

Besides rediscovering Aristotle's abduction confounded for years with induction, hence reframing our thought processes to infer scientific explanation [31], Peirce invites us to better understand the logic of meanings. His semiotics is about classification (and meaning) of signs, hence, signification, not hierarchization, about the never-ending game between materialization and abstraction, opening to an algebraization of the semiosis [65, 66]. Previous works in forensic science identified its usefulness [67], and its potential on the crime scene [68, 69], forensic education [70] and decision-making [71]. But many other applications could look relevant for the episteme and doxa of forensic science, as such as:

- Which legal / scientific / cultural / administrative / etc. alchemy transmutes a trace to a proof? From cue (the trace perceived) through clue (the cue with a signification) to proof (the clue carrying away the belief), what are the various semiosis of the forensic scientist, the detective, the police manager (to allocate resources) [72, 73], the legal scholar, the judge, the laypeople? How can the catch-all name evidence decipher this process [74]? "While there is a long history of theorizing about evidence in some contexts, notably law, probability theory, epistemology and historiography, there have been relatively few attempts to make evidence itself the subject of a general theory" [75, p3]. Thinking about evidence "is not about the reasoning of legal experts, such as judges, barristers, or investigators. It is about the reasoning of lay people when confronted with complex bodies of evidence" [76, p185].
- For instance, what do figures, LR (likelihood ratio) mean for a scientist, a lawyer, a layperson? Where do robustness of data, relevance, but also administrative behavior [77] interfere, or frame the Interpretant?
- How could legal, scientific education evolve to upgrade understanding between forensic scientists and stakeholders [78, 79], to decipher rhetorical arguments from scientific ones?
- Has forensic evidence, for instance at its clue level, always to be in real (material) connection with the object it wants to signify (supporting the quest of accuracy, precision enforced through quality management), what Peirce calls Secondness, the universe of existence or actuality? For instance, as a well understood only investigative step that should prefer false positives to let investigators check new hypotheses, shouldn't facial reconstruction question accuracy and precision, while cognitive mechanisms underlying recognition are not yet identified [80, 81]? Indeed, opening the universe of possibilities could be more productive for the recognition process, i.e., the semiosis, that is different between a familiar and non-familiar face [82-84].
- Finally for this paper, once Voisard proposed to distinguish a print from a trace, the former being "a sign from the outside world whose very existence is conventional and

whose referential determination is saturated" [70, p266], when does a trace become a print ? Better, retrospectively when does a print becomes a trace in the eye of the beholder? Then couldn't AI help quantify a priori its quality not limited to imprints of physical traces, but also of DNA electropherograms, chemical spectrograms, digital data collection, addressing the uncertain ontological nature of our traces, overflowing accuracy, completeness, validity, consistency, uniqueness, timeliness, and fitness for the purpose at the time of digital transformations [26, 27, 85]? Assessing the maximum awaited weight of evidence of a trace deriving from this assessed quality could help check the consistency of our inferences, hence of our reconstructions and identifications.

Conclusion

Forensic science challenges are more synthetic (inferences and interpretation) than analytical (the technical breakthrough that will solve crimes, like the fridge that will cool the Earth, or the nuke that will stop the hurricane). Facing tensions between the prescriptive and the descriptive approach of thinking, Peirce's semiotics offer an unexplored pathway to try merging not only both models, but also the various communities that forensic science is providing, partnering with. Tackling not only semantics, but primarily the logic of meaning, through the implementation of a semiotic line of arguments that would concur to the transparency of opinion, even while providing a formal probative value [31, 86]. The Sydney Declaration integrated this promising semiotic approach throughout its seven principles, at least understandably during the investigation process (principles 2 and 3), but is ever overarching it in the last one: "Forensic science outcomes acquire meaning in their context", which addresses the human factor, i.e. both his own semiosis (usually labelled Peirce's second semiosis), and the one shared through communication (first semiosis, closer to semiology).

References.

1. Roux, C., et al., *The Sydney declaration – Revisiting the essence of forensic science through its fundamental principles.* Forensic Science International, 2022. **332**: p. 111182.
2. Huber, P., *Galileo's Revenge : Junk Science in the Courtroom*. 1991, New York: Basic Books.
3. Fabricant, C., *Junk Science and the American Criminal Justice System*. 2022, New York, NY, USA: Akashic Books.
4. Supreme Court of the United States, *William Daubert, et ux., etc., et al., Petitioners v. Merrel Dow Pharmaceuticals, Inc.*, S.C.o.t.U. States, Editor. 1993.
5. Kaye, D., *The good, the bad, the ugly: The NAS report on strengthening forensic science in America.* Science & Justice, 2010. **50**(1): p. 8-11.
6. Crispino, F., et al., *Forensic science - A true science?* Australian Journal of Forensic Sciences, 2011. **43**(2): p. 157-176.
7. Crispino, F., *Le principe de Locard est-il scientifique ? Ou analyse de la scientificité des principes fondamentaux de la criminalistique*, in *Ecole des sciences criminelles*. 2006, Université de Lausanne: Lausanne, Suisse. p. 172.
8. Wittgenstein, L.W., *Tractacus logico-philosophicus*. Tel 311. 1993, Paris, France: Gallimard.

9. Roux, C., F. Crispino, and O. Ribaux, *From Forensics to Forensic Science.* Current Issues in Criminal Justice, 2012. **24**(1): p. 7-24.
10. Kuhn, T., *La structure des révolutions scientifiques*. Champs. 1970, Paris: Flammarion.
11. Masterman, M., *The Nature of a Paradigm*, in *Criticism and the Growth of Knowledge*, I. Lakatos and A. Musgrave, Editors. 1999, Cambridge University Press: Cambridge, UK. p. 59-90.
12. Popper, K., *La logique de la découverte scientifique*. Bibliothèque scientifique. 1973, Paris: Payot. 480.
13. Inman, K. and N. Rudin, *Principles and Practice of Criminalistics. The Profession of Forensic Science*. Protocols in Forensic Science. 2001: CRC Press.
14. Appell, P., J.-G. Darboux, and H. Poincaré, *Rapport du 20 août 1904 de la commission Appell, Darboux, Poincaré lors de la 2ème révision du procès de Dreyfus*. 1904, Cour de Cassation: Paris.
15. Salomon, D. *La toxicologie, la science des poisons au service de l'homme*. Histoire de la médecine 2013 [cited 2020 30/09/2020]; Available from: https://destinationsante.com/la-toxicologie-la-science-des-poisons-au-service-de-lhomme.html.
16. Morgan, J., *Wrongful convictions and claims of false or misleading forensic evidence.* Journal of forensic sciences, 2023. **68**(3): p. 908-961.
17. Morgan, J., *Wrongful Convictions and Forensic Science Errors: Case Studies and Root Causes*. 2023, New York, NY, USA: CRC Press.
18. NAS, *Strengthening forensic science in the United States : a path forward : summary*. 2009, National Academies Press: Washington, DC.
19. Pollanen, M., et al., *Forensic Science in Canada. A Report of Multidisciplinary Discussion*, P. MS, et al., Editors. 2013, Centre for Forensic Science and Medicine: Toronto, ON, Canada. p. 113.
20. PCAST, *Report to the President. Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods*. 2016, Washington DC, USA: President's Council of Advisors on Science and Technology. 160.
21. Lawless, C., *A Curious Reconstruction? The Shaping of 'Marketized' Forensic Science*. 2010, London School of Economics and Political Science. p. 24.
22. Lawless, C., *Policing Markets. The Contested Shaping of Neo-Liberal Forensic Science.* British Journal of Criminology, 2011. **51**: p. 671-689.
23. Lawless, C. and R. Williams, *Helping with inquiries or helping with profits? The trials and tribulations of a technology of forensic reasoning.* Social Studies of Science, 2010. **40**(5): p. 731–755.
24. McCartney, C. and E. Amoako, *The UK Forensic Science Regulator: A Model For Forensic Science Regulation?* Georgia State University Law Review, 2018. **34**(4): p. 945-981.
25. Kirk, P., *The Ontogeny of Criminalistics.* The Journal of Criminal Law, Criminology and Police Science, 1963(54): p. 235-238.
26. Casey, E., O. Ribaux, and C. Roux, *Digital transformations and the viability of forensic science laboratories: Crisis-opportunity through decentralisation.* Forensic Science International, 2018. **289**: p. e24-e25.
27. Ribaux, O., et al., *Digital transformations in forensic science and their impact on policing*, in *Policing in an Age of Reform - An Agenda for Research and Practice*, J. Nolan, F. Crispino, and P. T, Editors. 2021, Palgrave Macmillan: London, UK. p. 173-191.
28. Buzzini, P., B.W. Kammrath, and P. De Forest, *Trace evidence? The term trace from adjective to noun.* WIREs Forensic Sci., 2019. **1**(5).

29. Margot, P., *Traçologie: la trace, vecteur fondamental de la police scientifique.* Revue Internationale de Criminologie et de Police Technique et Scientifique, 2014. **LXVII**(1): p. 72-97.
30. Ristenblatt III, R.R., et al., *Traceology, criminalistics, and forensic science.* Journal of Forensic Sciences, 2022. **67**(1): p. 28-32.
31. Crispino, F., et al., *Is the (traditional) Galilean science paradigm well suited to forensic science?* WIREs Forensic Sci., 2019(1): p. e1349.
32. Taleb, N., Nicholas, *Le Cygne noir. La Puissance de l'imprévisible*. 2008, Paris. France: Les Belles Lettres. 496.
33. Brown, S. and S. Willis, *Complexity in Forensic Science.* Forensic Science Policy & Management: An International Journal, 2010. **1**(4): p. 192-198.
34. Hacking, I., *The Taming of Chance*. 11th ed. Ideas in context. 2008, Cambridge, UK: Cambridge University Press. 264.
35. Pearl, J. and D. Mackenzie, *The Book of Why. The New Science of Cause and Effect*. 2018, New York, NY, USA: Basic Books. 418.
36. Poincaré, H., *La science et l'hypothèse*. Bibliothèue de philosophie scientifique. 1902, Paris, France: Ernest Flammarion.
37. Savage, L.J., *The Elicitation of Personal Probabilities and Expectations*, in *Studies in Subjective Probability (1980)*, H.E. Kyburg, Jr and H.E. Smokler, Editors. 1971, Robert . Krieger Publishing Company: Huntington, NY, USA. p. 149-191.
38. de Finetti, B., *Foresight: Its Logical Laws, Its Subjective Sources*, in *Studies in Subjective Probability (1980)*, H.E. Kyburg, Jr and H.E. Smokler, Editors. 1937, Robert . Krieger Publishing Company: Huntington, NY, USA. p. 59-118.
39. Deutsch, D., *The Beginning of Infinity*. 2012, Westminster, UK: Penguin Books. 496.
40. Good, I.J., *C312: Yet another argument for the explication of weight of evidence.* Journal of Statistical Computation and Simulation, 1989(31): p. 58-59.
41. Good, I.J., *C319: Weight of evidence and a compelling metaprinciple.* Journal of Statistical Computation and Simulation, 1989(31): p. 121-123.
42. Lindley, D., *Understanding Uncertainty*. Wiley-Interscience, ed. Wiley. 2006, Hoboken, NJ, USA: Wiley. 263.
43. ENFSI, *ENFSI Guideline for evaluative reporting in forensic science - Strengthening the Evaluation of Forensic Results across Europe (STEOFRAE)* 2015, European Network of Forensic Science Institutes. p. 128.
44. Robertson, B., G. Vignaux, and C. Berger, *Interpreting Evidence. Evaluating Forensic Science in the Courtroom*. Second ed. 2016, New York, NY, USA: John Wiley & Sons Inc. 214.
45. Morrison, G.S., *Advancing a paradigm shift in evaluation of forensic evidence: The rise of forensic data science.* Forensic Science International: Synergy, 2022. **5**: p. 100270.
46. Crispino, F. and C. Roux, *Forensic-Led Regulation Strategies: Are They Fit for Security Problem-Solving Purposes?*, in *The Routledge International Handbook of Forensic Intelligence and Criminology*, Q. Rossy, et al., Editors. 2017, Routledge: Abingdon, Oxon, UK. p. 65-76.
47. Neuteboom, W., et al., *Quality Management in forensic science: A closer inspection.* Forensic Science International, 2023: p. 111779.
48. Kahneman, D., *Thinking, Fast and Slow*. 2011, New York, NY, USA: Farrar, Strauss and Giroux.
49. Kahneman, D., O. Sibony, and C.R. Sunstein, *Noise: Pourquoi nous faisons des erreurs de jugement et comment les éviter*. 2022, Paris, France: Odile Jacob.

50. Saks, M. and J. Koehler, *The Individualization Fallacy in Forensic Science Evidence.* Vanderbilt Law Review, 2008. **61**(1): p. 199-219.
51. Dror, I.E., *Cognitive and Human Factors in Expert Decision Making: Six Fallacies and the Eight Sources of Bias.* Analytical Chemistry, 2020. **92**(12): p. 7998-8004.
52. Dror, I.E., *The most consistent finding in forensic science is inconsistency.* Journal of Forensic Sciences, 2023. **n/a**(n/a).
53. Lindley, D., *Understanding Uncertainty*. Second edition ed. Wiley, ed. Wiley. 2013, Hoboken, NJ, USA: Wiley. 424.
54. Judge Edwards, H.T., *Judge Harry T. Edwards: How reliable is Forensic Evidence in Court ?*, in *The Real CSI*, G. Gavett, Editor. 2012, Frontline: Boston, MS, USA.
55. Rocher, G. *La problématique des rapports entre le droit et les sciences*. in *L'interaction entre le droit et les sciences expérimentales. La preuve d'expertise*. 1998. Sherbrooke: Revue de droit de l'Université de Sherbrooke.
56. Laurin, J., *Remapping the path forward: toward a systemic view of forensic science reform and oversight.* Texas Law Review, 2013(91): p. 1051-1118.
57. Rosenthal, R., *How Often Are our Numbers Wrong ?* American Psychologist, 1978. **33**(11): p. 1005-1008.
58. Goldstein, H., *Improving Policing: A Problem-Oriented Approach.* Crime & Delinquency, 1979. **25**(2): p. 236-258.
59. Margot, P., *Forensic Science on Trial - What Is the Law of the Land ?* Australian Journal of Forensic Sciences, 2011. **43**(2-3): p. 89-103.
60. Fisette, J., *Introduction à la sémiotique de C.S. Peirce*. 1990, Montréal, Québec (Canada): XYZ éditeur.
61. Peirce, C.S., *Selected Writings (Values in a Universe of Chance)*. 1958, New York, NY, USA: Dover Publications Inc. 446.
62. Peirce, C.S., *The Collected Papers of Charles Sanders Peirce*. 1994, Harvard University Press: Cambridge, USA. p. 2904.
63. Hofstadter, D., *Gödel, Escher, Bach: an eternal Golden Braid*. 1979, New York, NY, USA: Basic Books. 777.
64. Hofstadter, D. and E. Sanders, *Surfaces and Essence : Analogy as the Fuel and Fire of Thinking*. 2013: Basic Books. 592.
65. Marty, R., *L'algèbre des signes : essai de sémiotique scientifique d'après Charles Sanders Peirce*. Foundations of semiotics. 1990, Amsterdam: John Benjamins Publishing Company.
66. Meunier, J.-G., *Computational Semiotics*, ed. B.A.i. Semiotics. 2022, New York, NY, USA: Bloomsbury. 271.
67. Eco, U. and T.A. Sebeok, (Eds), *Dupin, Holmes, Peirce. The Sign of Three* 1988: Indiana University Press. 256.
68. Dulong, R., *La rationalité spécifique de la police technique.* Revue internationale de criminologie et de police technique et scientifique, 2004(3): p. 259-278.
69. Hazard, D., *La pertinence en science forensique; Une (en)quête épistémologique et empirique*, in *Ecole des sciences criminelles. Institut de police scientifique*. 2014, Université de Lausanne: Lausanne. p. 309.
70. Voisard, R., *L'empreinte photographique de l'imagerie judiciaire. De la sémiotique aux applications pédagogiques*, in *Faculté de droit, des sciences criminelles et d'administration publique*. 2020, Université de Lausanne: Lausanne, Suisse. p. 294.
71. Sauleau, C., *Réduire l'aversion pour l'incertitude au procès pénal : Approche stratégique et probabiliste du faisceau d'indices dans l'investigation criminelle*, in *Philosophie des sciences*. 2020, Université de Franche-Comté, France: Besançon. p. 434.

72. Mousseau, V., S. Baechler, and F. Crispino, *Management of crime scene units by Quebec police senior managers: Insight on forensic knowledge and understanding of key stakeholders.* Science & Justice, 2019(59): p. 524-532.
73. Crispino, F., et al., *Forensic science understanding by police managers: New opportunities to re-think its involvement in policing*, in *Policing in an Age of Reform - An Agenda for Research and Practice*, J. Nolan, F. Crispino, and P. T, Editors. 2021, Palgrave Macmillan: London, UK. p. 117-131.
74. Dawid, P., W. Twining, and D.e. Vasilaki, *Evidence, Inference and Enquiry (Proceedings of the British Academy)*. 2011: British Academy. 448.
75. Dawid, P., *Introduction*, in *Evidence, Inference and Enquiry (Proceedings of the British Academy)*, W. Twining, P. Dawid, and D. Vasilaki, Editors. 2011, British Academy: London, UK. p. 1-9.
76. Lagnado, D., *Thinking about Evidence*, in *Evidence, Inference and Enquiry*, P. Dawid, W. Twining, and M. Vasilaki, Editors. 2011, Oxford University Press: London, UK. p. 183-224.
77. Simon, H.A., *Administrative Behavior*. 4 ed. 1997, New York, NY, USA: The Free Press. 368.
78. Champod, C. and J. Vuille, *Des sciences sourdes et une justice aveugle.* Revue internationale de criminologie et de police technique et scientifique, 2015. **LXVIII**(1): p. 67-88.
79. Crispino, F., C. Muehlethaler, and L. Cadola, *Likely is not probable. The need for rigorous and common semantics between scientists and lawyers.* Canadian Journal of Law and Justice, 2020. **2**: p. 116-132.
80. Haig, N.D., *The effect of feature displacement on face recognition.* Perception, 1984. **13**(5): p. 505-512.
81. Abudarham, N. and G. Yovel, *Same critical features are used for identification of familiarized and unfamiliar faces.* Vision Research, 2019(157): p. 105-111.
82. Fisher, G.H. and R.L. Cox, *Recognizing human faces.* Applied Ergonomics, 1975. **6**(2): p. 104-109.
83. Hancock, P.J.B., V. Bruce, and A.M. Burton, *Recognition of unfamiliar faces.* Trends in Cognitive Sciences, 2000. **4**(9): p. 330-337.
84. Young, A.W. and A.M. Burton, *Recognizing Faces.* Current Directions in Psychological Science, 2017. **26**(3): p. 212-217.
85. Horsman, G., *Tool testing and reliability issues in the field of digital forensics.* Digital Investigation, 2019. **28**: p. 163-175.
86. Crispino, F., et al., *Towards another paradigm for forensic science?* . Wiley Interdisciplinary Reviews: Forensic Science., 2021: p. e1441.

Acknowledgements :

As the author takes full responsibility for the condensed and abstruse part of this paper, he owes a debt to his usual conspirators for their advices to help make it more readable. Thanks to Olivier Delémont, Olivier Ribaux and Celine Weyermann.

Declaration of Competing Interest

none