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OVERVIEW

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Towards another paradigm for forensic science?

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Abstract

Daubert skews the contribution of forensic science because it only took into account its Galilean dimension (construction of general predictive models). However, forensic science should better be classified in the historical sciences (clinical approach to reconstruct a past event of presence or activity). We therefore need a complementary approach that integrates the necessarily "clinical" part in the resolution of forensic issues. Such an evolution involves semiotics. While recognizing that the Bayesian way of thinking is the only prescriptive available model for interpretation fitting well in the Galilean paradigm, the complexity of the reconstruction of a past-uncontrolled singular case and the robustness of available relevant data to it, invites consideration of its implementation in a semiotic line of arguments. Indeed, Bayes makes it possible to remain in a single harmonized model integrating both the clinical and Galilean dimensions, but rapidly the complexity of the modeling and its mathematization come up against more qualitative natural and legal reasoning. Two different systems of reasoning at stake are inevitably creating a "bug" that could explain the current forensic crisis and miscarriages of justice. This anomaly is reflected in the issue of transparency (misunderstandings by and between interlocutors on the nature of the expertise, if not science). Peirce offers a path to address the tension between complementary reasoning systems.

This article is categorized under:
- Crime Scene Investigation > Epistemology and Method
- Crime Scene Investigation > From Traces to Intelligence and Evidence
- Crime Scene Investigation > Education and Formation

KEYWORDS

inference, interpretation, semiotics, signification, trace

1 | INTRODUCTION

In a previous, scene-setting article questioning the nature of forensic science worldwide, we described the US Supreme Court's Daubert decision (1993), the NAS and PCAST reports, and the epistemological context of expert evidence (Crispino et al., 2019). We argued that the American Supreme Court has failed to recognize the specificity of the scientific attribute of forensic practice expected in court. Their attempt to adopt an epistemological approach based on

Galilean sciences (either Hempelian testability or Popperian falsification[1]) had significant consequences in legal proceedings, especially in the Common Law world. This failure was foreseeable with regard to the case-based approach (called *casuistique* in French) of the scientific investigation, that is, examination of a particular case in the light of the principles of the relevant discipline, aiming at the individualization of the perpetrator and the singularity of the reconstruction of the case. This peculiarity contrasts with the traditional model of science in search of general laws of nature: "the real difficulty in applying the Galilean model lay in the degree to which a discipline was concerned with the individual. As the features centred more and more on the individual, the more difficult it became to construct a body of rigorously scientific knowledge" (Ginzburg, 1988, p. 97). This misunderstanding about scientific assistance in court could explain why forensic science is regularly questioned about its validity by lawyers and scientists outside the discipline, rarely trained in epistemology. This leads to a misconception, a lack of understanding spreading from the practitioners to their conclusions' recipients, with potentially damaging consequences for the entire judicial system. It is therefore not surprising to note the contradiction maintained by the NAS Report that recognized the fragmentation of the forensic disciplines as a major problem of *forensics* while recommending greater fragmentation via a systematic quality approach in each of its components and greater separation of investigative units from scientific services to protect the scientist from the cognitive biases of investigation and criminal proceedings (Crispino & Roux, 2017; NAS, 2009).

We argue that Ginzburg's evidential paradigm, considered in the human sciences as the model of inference from effects (Thouard, 2007), may assist in defragmenting forensic practice, currently exercised in silos of techniques and disciplines disconnected from each other (Roux et al., 2012). This defragmentation is increasingly seen as necessary in the age of digital transformations currently exerting additional pressure on practice (Casey et al., 2018; Ribaux et al., 2021).

This paper recognizes the significance of the historical approach for reconstructing a singularity by exclusion, discrimination, association, identification or even ultimately or ideally the individualization of a trace at the source of the event investigated (Inman & Rudin, 2001). For this reason, it re-considers the nature of the scientific opinion assisting the trier of fact and proposes to focus on the semiotic dimension of the physical, biological, chemical, and digital trace. Analyzing the solutions offered to the current crisis in this context, this article invites another model of the expression of transparency in forensic science embracing the prescriptive and descriptive dimensions, represented by Bayesian inference and semiotic signification, respectively (Box 1).

BOX 1 Some definitions of terms not necessarily used daily in forensic science

Epistemology of science is a critical study of the principles, the assumptions and the results of the various sciences, intended to determine their logical origin (not psychological), their value and their objective scope (Lalande, 1991, p. 293), that is, a study of "the constitution of valid knowledge" (Piaget, 1967). It is largely based on the history and philosophy of science.

Two other definitions of interest for this paper are needed; semiology and semiotics, both concerned with the study of signs and systems of signification, are two concepts often confused (for example in medicine). The first refers to the European tradition, where the human sciences more readily rely on literary, aesthetic, and philosophical movements (see Saussure, Barthes, Metz, etc.). Linguistics, which was supposed to be only one element, has become its reference, including in the fields of the semiology of the image: the object (text, image, film, etc.) is the main place of meaning and language is the foundation of any sign system. Although its current applications are themselves mainly in the field of communication by images, semiotics founded by Peirce aspires to be anchored in the logic of meaning. Semiotics appears as a science of the functioning of thought, intended to explain how the (human) being catches and interprets its entourage (the environment), creates knowledge and sharing. The sign is then generated and maintained by semiosis, "action, activity of production of new meanings" for oneself or for others (Fisette, 1996, p. 14). Hence, semiotics is the study of the various semiosis (either inner or shared) of beings (restricted to forensic scientists and their stakeholders in this paper).

2 | REFLECTIONS ON SCIENTIFIC OPINION

An expert witness is distinguished from a regular witness by his right, even his duty, to express an opinion on the observations and results in their area of competence, defined as a skill, a knowledge superior to an "ordinary citizen." However, this opinion can only be personal and evolving, running up against social, organizational, cultural irritants that are difficult to express in a statement or expert report, let alone a likelihoods ratio (LR)[2] (ENFSI, 2015; NIFS, 2016). The fact that probability, as the expression of an individual's belief in a proposition, is the only possible tool for quantifying the evidential value of a trace (Lindley, 2013) is beyond dispute. Furthermore, the LR and the underlying Bayesian logic are adequate, and therefore should be the prescriptive model for logically updating beliefs about the evidence provided (Dawid, 2002; Good, 1989a, 1989b; Hahn, 2014). This formalization cannot, however, embrace all the scientific and cognitive challenges raised by traces retrieved from a singular, non-reproducible, generally unobserved past (Dror, 2017; Dror & Pierce, 2020; Gardner et al., 2019; Hamnett & Dror, 2020):

- a trace is typically only a specimen (it is usually unwillingly generated, and its representativeness arises from an intentional, specific, singular choice made by the crime scene officer) and not a sample (random selection, controlled within a homogeneous population), as one cannot know the whole population of existing traces created through the event of interest. It is often partial, incomplete, mixed, contaminated. Hence, it is a specimen. At best, the comparison data are obtained under controlled conditions modeled or subjectively qualified as comparable (the print/reference vs. the mark/trace), that can be occasionally similar, by no means identical to ones collected on the chaotic case (Buzzini et al., 2019; Margot, 2011, 2017; Ribaux, 2014). This observation questions the relevance of reasoning imitating the hypothetical scientific method attributed to Galileo (McMullin, 1996; Nickles, 1996) to inductively support a general theory (Donagan, 1964; Hempel, 2001; Popper, 1973, 1985), while forensic science is case-based. Here the Galilean scientific method, based on the statistical representativeness of the results observed or analyzed, can be seen in conflict with the ontology of the trace: "All naturally occurring materials are heterogeneous. Sampling should not be gambling" (Pierre Gy, cited by Esbensen & Julius, 2009);
- the assessment of the probative value increases in complexity as one moves away from the source identification, which cannot itself be deterministic (Jackson & Biedermann, 2019; Koehler & Saks, 2010; Kwan, 1976; Saks, 2010; Saks & Koehler, 2008; Thornton, 1986). However, is this a sufficient reason to isolate the scientist at source level identification, as crime is situated in time and space, that is, the perpetrator interacts singularly with an immediate and specific environment? It means that the trace only acquires significance through the situational analysis of the generating activity (Pietro et al., 2019; Roux et al., 2015)
- While the hierarchy of scientific evidence recognizes the primacy of publications and results accessible to critical analysis, or even structured data rather than personal experience (Biedermann, Champod, et al., 2016), the relevance of these data, far from being available on all types of traces analyzed, is to be assessed with the singular case at hand. This finding takes on an even more worrying dimension as the defense has no obligation to disclose its strategy at the risk of losing a rhetorical advantage in judgment, implying that the scientist may find themselves evaluating a probative value out of the context of interest to the court (Edmond et al., 2014; Redmayne et al., 2011; Roberts & Stockdale, 2018).

In short, the opinion expressed by the scientist, although the only one capable of quantifying a state of uncertainty, also translates to at least an acceptance that the specimens, the examination, and the scientist's knowledge are adequate to the particular case being treated. This decision to proceed is necessarily partially driven by the heuristics of availability and representativeness (Bar-Hillel, 1982; Kahneman & Tversky, 1982; Tversky & Kahneman, 1982a, 1982b). In the Bayesian approach, the case-based nature of forensic interpretation is integrated as I (background information) in the conditional probability ($P(H|E, I)$ or $P(E|H, I)$). However, this I is manageable in equations when it is kept simple, that is, the case's particular circumstances are easily integrated (Meester, 2020). This is true in the decontextualized flow of comparisons to the trace-print chain (where I is the empty set or close to it). Therefore, scientific neutrality, impartiality, even objectivity rests on the transparency of the scientist's inferential process (Biedermann, 2013). We may then ask whether the desire to formalize evaluation, distinct from the investigation, via the undisputed Bayesian approach, is not also a recognition of the failure or rejection to perceive this human reasoning upstream of the forensic assessment. This may limit the scientific inquiry to simple elementary and recurrent forensic questions that can be modeled in a standardized basic"Galilean" Bayesian model (for instance, the context-free comparison of a trace with a print).

The success of the Bayesian inference networks that structure artificial intelligence (AI) by implementing this logic may constitute convincing arguments for the decision-making of justice and security. At this point, it is interesting to note the semantics used by Judea Pearl, one of its inventors, is similar to the vocabulary of proof: the processes that allow Bayesian networks to answer questions from new knowledge (evidence) bear the name of inference, or update of beliefs (Pearl, 1988). However, the reasoning framework of AI relies on inductive logic, mainly machine learning, which will then proceed to a prediction based on an association algorithm making a statistical decision from a rich base of knowledge data against which the new information will be statistically compared. This view is somewhat in conflict with forensic casuistic, which can only rarely rely on randomization of case-like experiments to draw statistical inferences. Indeed, the reconstruction of the singular case through its specific traces brings a new complexity likely unmanageable by the Bayesian model for different rationalities (investigator, CSO, expert, fact-finder).

Finally, as logical as it may be, this direction formally recognizes the role of the scientist as an auxiliary to the decision-maker (judge, jury), leaving the latter the formal responsibility for the decision. But, the LR, ratio of probabilities, considers only one element in isolation from other traces. However, it can vary from several hundreds of thousands, or even millions, for a genetic trace of good quality to a few hundreds for the majority of traces other than biological, or even of the order of 10 for traces of low quality. As a result, it tends to minimize traces other than biological in a siloed practice of forensic science, which struggles to quantify the cluster of evidence made up of the different traces. Hence, it is not clear how its implementation helps human understanding, and subjective probabilities may not constitute the only model for describing the rational decision in uncertainty (Chateauneuf, 2003; George, 1997; Jaffray, 2003; Picavet, 2003; Saint-Sernin, 2003; Vickers, 2003). Besides, the Bayesian agenda legitimately aims at approaching activity level or multi-trace interpretations. However, it seems to be at the cost of managing complexity. It is raising resistance among academics grounded on different rationalities (Hacking, 1996; Savage, 1971; Simmross, 2014; Simon, 1955; Tribe, 1971), who return naturally to causal patterns in their inferential activities as any human beings (Plous, 1993; Tversky & Kahneman, 1982c). Indeed, a recent review of the literature of psychologists studying the understanding of expert opinions by jurors underlines rationalities and, therefore, different expectations than the mere quantification of an evaluation of the evidence by the LR, moreover rather poorly understood by its recipients (Eldridge, 2019).

Therefore, if the only relevance of the Bayesian inferential framework was to be recognized for transmitting the probative value of the expert opinion, would not it be vital for the scientist to master the modalities of its transmission, but also of its understanding (Lagnado, 2011; Smit et al., 2018)? For example, can we suspect that the LR is interpreted as the proxy of the posterior odds (Martire et al., 2013)?

These human hurdles cannot obscure the limits of an approach that would be exclusively quantitative while impossibly exact since it is by no means a given that applying a Bayesian logic eliminates all the biases linked to our natural inclinations. This is especially the case when analyzing (or perceiving) low or high probabilities (Kahneman, 2011; Pearl & Mackenzie, 2018; Stoney, 1991; Tversky & Kahneman, 1982d, 1982e, 1982f). Besides, an LR over but close to 1 would push towards a conservative reflex to favor the defense hypothesis. Furthermore, we can hypothesize that the complexity of case management, amplified by the combination of traces or interpretation at the activity level, may introduce invisible errors. By analogy, it is now accepted, for example, that there is no such thing as a bug-free computer program. The bug is intrinsic to programming. The computer scientists themselves have given up in the face of this adversary called complexity as it is stronger than them. Why would there be a kind of immunization of forensic experts to this problem, with the expected increase of complexity for questions regarding the activity or the combination of traces, particularly in the context of a singular case?

Finally, scientific opinions are akin to rhetorical arguments, with a conviction degree of belief being stronger with increasing transparency than other testimonies (Fox, 2011). Kind explicitly recognized in 1994 this rhetorical aspect in which the scientist had to engage by maintaining that the third chapter of his judicial paradigmatic resolution of a case, the presentation of the evidence, took a fallacious deductive form, precisely absent in the previous stages. Indeed, deduction, which is the only reasoning ensuring logical certainty of a conclusion, is the best, if not only rationale for acquiring a personal degree of belief or going beyond reasonable doubt (Kind, 1994). Isn't it, therefore, opportune to recognize a specific logic of forensic investigation before searching for a relevant epistemological anchoring, going beyond the artificial investigation/evaluation dichotomy, the latter reducing the value of the trace at an incomplete probabilistic quantification (Baechler et al., 2020)?

3 | EPISTEMOLOGICAL ANCHORING: IN SEARCH OF A LOGIC SPECIFIC TO FORENSIC SCIENCE

Is there a logic specific to forensic science? This question invites a critical look at communication between experts and decision-makers through the mastery of a precise vocabulary, understood by both sides (Champod & Vuille, 2011). This improved communication is believed to help distinguish a poorly understood relative objectivity from a hidden persuasion. However, despite significant and sustained efforts in this area, it appears real progress or evolution is modest at best. Let us quote, for example, the semantic debates still active about the different notions between identification and individualization (Biedermann, Bozza, & Taroni, 2016; Kaye, 2009; Kirk, 1963; Saks & Koehler, 2008), questions relating to so-called imprecise expert conclusions (possible, plausible, could have, consistent with, not excluded, matching with, etc.) (Robertson et al., 2016, Chapter 5), the confusion between an unknown and an independent source (Milot et al., 2020) or between probability and likelihood not only among lawyers but also experts (Crispino et al., 2020). We argue that these ongoing semantic difficulties indicate that different meanings are persistent between actors, making shared interpretations of scientific findings rather utopic.

A forensic semiology that would have to be mastered by the practitioners themselves would then be a prerequisite for better communication between themselves and each other, but also the understanding of many concepts that they handle (Lucena-Molina, 2016). For example, in English, the word evidence confuses the concepts of trace (remnant, residue even unseen or undetected of a presence or an activity), sign (aka Sherlock Holmes' trifles, the trace which signifies something for its beholder), clue (the trace which has a meaning, supporting or not a hypothesis), and proof (the trace that convinces the decision-maker to act accordingly to its meaning for them). The few attempts at adoption in English with such semantic precision are struggling to break through (Houck et al., 2017), even if we observe an exciting development recently on this recognition of the trace, as the elementary entity of forensic science (Morgan et al., 2020; van Beek, 2018; Weyermann & Roux, 2021). This is further illustrated by the OSAC lexicon (https://www.nist.gov/osac/osac-lexicon) that enforced the fragmentation of forensic science into subdisciplines using different vocabularies: the trace is never really defined and even absent from the preferred terms (just like mark, evidence). However, less-defining terms for the discipline like biases, controls, or samples are described. It must, however, be recognized that it is far from being established that this wealth of other languages (e.g., French with trace/signe/indice/preuve, German with Spur/Zeichen/Hinweis/Beweis) is recognized by non-English speakers themselves (Champod & Vuille, 2015).

Yet, the semiological inconsistency is evident by confusing two different semantic categories, an object (the trace) and an inference (the proof). According to the decision theory, the proof is a semiotic sign carrying a decision of action or acting with an accepted risk (to convict, exonerate, engage resources, bomb a village considered hostile, etc.). The proof is a product of abductive and inductive inferences from the trace to the cause. Citing Kind again, the proof is artificially re-built deductively from the cause to the trace, giving a consistent explanation of the reconstruction of the singular case (Kind, 1994).

The misunderstanding of the very notion of trace opens perspectives not only semiological but also semiotic, which could mainly explain the crisis that opened in 2009. By refusing to recognize the processes of meaning specific to forensic science, one can doubt the NAS solutions would make it possible to overcome the exposed and described gridlock. Restricting the use of the trace to comparison with more or less validated empirical data from control populations (fingerprints, DNA, ballistics, even today data by destination issued from social networks) offers the reassuring appearance of a probabilistic normative quantification, which remains anecdotal in the face of the immense variety of the daily inferential uses of these traces (Bitzer et al., 2016; Casey et al., 2019). It is, therefore, somewhat astonishing that these many uses cannot or should not be studied, or even formalized because of a risk of error or uncertainty, that they would produce in the decision-making processes. In contrast, they intrinsically participate in the understanding of the casuistic problem to be solved. The fact that we mostly do not (yet) master their complexity should be seen as secondary.

We argue that refusing an epistemological reflection recognizing the different non-Galilean nature of forensic science will further limit the use of the trace, leading to increasingly ineffective forensic science. As extraordinary as it may be, the semiotic approach to forensic science proposed in this paper would not necessarily be less scientific than the current classical experimental model. While there are "differences between prototypical historical science and classical experimental science vis-à-vis the testing of hypotheses, [t]hese differences represent different patterns of evidential reasoning" that can both be considered scientific (Cleland, 2002).

The semiotic pathway invites a broader reflection addressing the transformation of the trace into a proof (blurred in the English catch-all name "evidence"). This process of signification called semiosis is both specific and internal to the scientist and shared with, or rather reappropriated by, their recipients (investigator, judge, jury, etc.). We find such an

BOX 2 Peirce? What for?

Polymath, logician, Charles Sanders Peirce (1839–1914) left a posthumous work, arguably difficult to read and to follow, hailed as major by Russell and Popper (Anellis, 1995; Popper, 1972). Part of a historical evolution from the sign of the Greek School to the logic of Port-Royal (Foucault, 1966), Peirce's so-called pragmatic philosophy developed as a reaction to European structuralism, carried by philosophers like Descartes and his knowing subject or Kant and the a priori intentions or pure forms of sensibility (Descartes, 1637, 1641; Everaert-Desmedt, 1990; Fisette, 1990; Kant, 1787). Peirce's semiotics aiming at an objectification of meaning, compatible with human understanding (Berkeley, 1710; Hume, 1748; Locke, 1690), invites each discipline to create its own semiotics for the purposes of their own meaning and therefore communication. But this philosophy formalized in the second part of his life cannot be explained without understanding his family mathematical immersion from his earliest childhood or even his 30 years of professional life in the coastal measurements office of the United States, at the time of the avalanche of readings and measurements creating the new science of statistics in the 19th century. Forensic scientists could easily recognize him as the first theorist to support the logarithm odd model of LR as coherent (Aitken, 2018). But Peirce is best known as the first scientist to design a randomized controlled experiment in psychology in 1884. His paradigm of the universe of chance (Peirce, 1958) will result in a theory of statistics laying the philosophical and logical foundation of frequentist hypothesis tests developed 50 years later by K. Pearson. In this context, would not his semiotics be a logical response to the impossibility of statistics, and therefore of probability of responding to casuistry, even by adopting a subjective vision as correctly expressed by Poisson in 1835, namely the (subjective) probability of an (objective) chance (Hacking, 2008)?

approach of deconstruction of meaning in mathematics, medicine, or archaeology (Bloch, 2005; Duval, 2017; Marila, 2015; Nessa, 1996). The first few research works in forensic semiotics testify to the richness of this approach. It transcends the type of traces (physical, chemical, biological, and digital) to analyze better the logic of the interpretation of the trace via its different Interpreters (in the sense of Peirce), that is to say, the habits, heuristics, and biases involved in the semiosis of the various actors, including the scientist developing a communicative argument, significant rather than interpretative (Hazard, 2014, 2016; Papaux, 2018; Pape, 2008; Sauleau, 2020; Schuliar & Crispino, 2013; Sørensen et al., 2017; Voisard, 2020). In short, proof would be the crystallization for a cognitive agent at a given time of a semiosis ad infinitum explicable by Charles Sanders Peirce's semiotics (Peirce, 1994, 1995, 1998) (Box 2).

This reflection on Peirce, logician, statistician, and probabilist, invites us to recognize his questioning concerning the adequacy of probabilities to assess in their own the singularity of the case in question. It justifies the need for transparency (more than robustness or mathematical rigor) throughout exploiting information from traces. At a time of a demanded objectification of court decisions, or the police, of the significance of AI in this field, Peircean semiotics offers a rich reflection on the meaning and manipulation of traces, signs, clues, proofs, all known as evidence.

4 | A FIRST CONTRIBUTION OF THE SEMIOTIC PATHWAY: REFLECTION ON TRANSPARENCY

As it stands, transparency indeed targets the means and instruments used to carry out the expertise, responding to a legitimate need to understand the analytical part of the scientific service (Robertson et al., 2016, p. 86). We also find this conceptual concern in AI, where this quality would be limited to the disclosure of algorithms and analyzed data (Rudin et al., 2020). It is obvious and commendable that the tools and methods implemented for the benefit of security and justice are tested and validated, now formally supervised by quality management, possibly recognized by accreditation and certification (Malkoc & Neuteboom, 2007; Padar et al., 2015). However, while legal transparency is required during the phase of specimens gathering and submission, the scientific process of on-site investigation or the (non-normative) stage of assessment of the singular case investigated seems beyond the reach of normalization, insofar as it is desirable (Ross & Neuteboom, 2020, 2021). Yet this is the phase of most interest to law enforcement, the court, and parties. A formal, purely legal guarantee of evidence integrity, the chain of custody, cannot replace this inferential dimension of the meaning of the trace to solve a problem defining the mission of the forensic scientist. However, the uncertainties specific to this evidence (Trace? Sign? Clue? Proof?) are often much more significant than those resulting from the processes of analysis or even of prescriptive or normative interpretation of the results, supervised, controlled by "quality assurance, crowned by accreditation and certification procedures" (Ditrich, 2018; Hazard et al., 2013). This concentration of efforts on the means rather than on the objectives of the forensic science endeavor questions the understanding of forensic casuistry.

While transparency is considered necessary for a beneficial interaction between science and society (Jasanoff, 2006), expert opinion transparency seems to be cited lately as a specific attribute essential for decision-making by the trier of fact. Is this expected quality implicit or hidden, integrated into nouns more commonly encountered in casework or research such as objectivity, impartiality, neutrality or even scientificity, the capital letters denoting almost platonic ideals? It seems to appear explicitly in forensic science through fingerprint identification (Champod, 2007; Langenburg & Champod, 2011; Stevenage & Pitfield, 2016), to cover today nearly all disciplines (de Puit, 2010; Houck, 2019; Passalacqua et al., 2019). The 2011 R v T hearing could look like a catalyst by blaming (erroneously) this lack of transparency to the expert who expressed the probative value of the association of a sole mark with a suspect shoe imprint using the Bayesian model (Berger et al., 2011; Biedermann et al., 2012; Hamer, 2012; Kaye, 2012; Morrison, 2012; Thompson, 2012). Indeed, in this model of updating beliefs, the LR takes into account all the information that has been communicated to the scientist in the context of the case, but is also implicitly supposed to include those to which they would have had access, either legally or not by their employment position, training, experience or civil life (e.g., information in the press) (Dror, 2020a; Whitman & Koppl, 2010). Even though the debate has remained lively on this decision, it is doubtful that Bayes' theorem, presented as the mathematical quintessence of this transparency, is sufficient to satisfy this expected quality (Aitken et al., 2011; Aitken & Taroni, 2004; Biedermann & Taroni, 2006a, 2002; Dawid, 2002; Dawid et al., 2011; Fenton et al., 2013; Finkelstein & Fairley, 1970; Hahn, 2014; Jackson et al., 2015; Roberts & Aitken, 2014; Robertson et al., 2016; Schaapveld et al., 2019; Sironi et al., 2016; Smit et al., 2016; Taroni et al., 2004). Considering the LR as encompassing implicitly all this information could fall short of labeling transparent any opinion, restricted to the evaluative phase. It leaves aside the reconstruction of the investigated event (fire, explosion, homicide, etc.), or the reasoning on the crime scene. Notwithstanding the artificiality of the investigation/evaluation dichotomy (Baechler et al., 2020), the question seems all the more relevant as Laurin "points 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" (Laurin, 2013).

Apart from a few exceptional cases such as major fire or explosion scenes, the scientist is rarely involved in the investigation strategy or the gathering of traces and analyses to be carried out. Furthermore, the role is sometimes explicitly limited by the legal process. In short, generally, the scientist is limited to the evaluation of their analysis carried out on traces collected by others. If the expert is undoubtedly responsible for communicating their analysis results and for ensuring that these are correctly understood and interpreted, they have few tools to correct the biases of actors upstream of their work, to understand their heuristics, as long as they are indeed interested in this phase. Implicitly, their referral simply carries as a premise the scientific relevance of the trace submitted for analysis, the latter often being conceived as a sample (and not a specimen). However, these upstream decisions necessarily determine the scientific opinion transmitted downstream to the decision-maker, especially if they express themselves on the causes. They are just as limited in managing the difficulties subsequently encountered by the recipients of their opinion, even powerless to demonstrate the errors or fallacies that could be concluded from it, even correctly expressed (Biedermann & Kotsoglou, 2018; Ditrich, 2015; Gennari, 2018; McQuiston-Surrett & Saks, 2009; Thompson et al., 2013; Thompson & Newman, 2015). It is not a question here of relieving the scientist of their responsibility, but questioning the effectiveness and merits of scientific transparency in a vacuum, without integrating the steps of selecting traces or deciding to seek their assistance. As it stands, it does not appear that increased control of the most rational and logical element of the inference chain ensures the robustness of the end-to-end decision-making. Furthermore, it makes the desired shared meaning between the different actors essentially impossible to reach.

Since 2011, the importance of transparency is also recognized by cognitive scientists beholding forensic practices (Dror et al., 2011), and more systematically from 2014 onwards (15 publications cited in Edmond et al., 2017; Cooper & Meterko, 2019, the references cited throughout this article and Charlton et al., 2010; Dror, 2009, 2012a, 2012b, 2013a, 2013b, 2015, 2016, 2018, , 2020b; Dror & Cole, 2010; Dror & Pierce, 2020; Dror et al., 2015, 2018; Jeanguenat et al., 2017; Kellman et al., 2014; Mattijssen et al., 2016; Murrie et al., 2019; Nakhaeizadeh et al., 2014). An exceptional focus is even noticeable where transparency as an operational request is cited 30 times in a single publication in 2019[3] (Almazrouei et al., 2019).

This observation is in opposition to the 2009 NAS report in which the word transparency is mentioned only twice, with reference moreover to the article by Champod (2007), cited above (NAS, 2009). It supports the need to better study and understands the professional and social environment in which forensic science is carried out, that is, the behavior specific to its administrations, defined as “the art of getting things done” (Simon, 1997). Indeed, it could also explain the possible institutional and operational difficulties to implement specific proposals from Dror and his colleagues (e.g., forensic managers, joint experts, linear sequential unmasking, or the separation of laboratories from prosecution authorities) (Dror et al., 2015). In short, the social constraints surrounding the practice of forensic science require significant and constant transparency to understand the extent of the gap between the operational situation and the scientific ideal perceived (by the scientist or stakeholders).

It, therefore, seems a little simplistic to consider the forensic scientist as a simple instrumental, analytical link in the judicial or police chain while stigmatizing their influence on the trial (among other things, by the rule of exclusion in adversarial proceedings). This position also excludes the structuring economic and professional context in which the scientist operates (Aepli et al., 2011; Lawless, 2010, 2011; Lawless & Williams, 2010; Ribaux et al., 2017; Simon, 1997). It is interesting to note that, nowadays, expert mandates are often allocated only after agreeing on the cost. On the other hand, does not expertise tend towards (private) bargaining when, on occasions experts would not accept the mission and conditions requested by their party, the latter preferring searching for another one? Can we deny that the expert debtor of a party has little interest in losing their favor, while their clients will stretch the conclusions to win the conviction of the decision-maker (Edmond, 2020)?

Notwithstanding the problems of ethics and deontology, which are not limited to scientists (Margot, 2011), idealizing their performance is also to deny the human sensitivity of this actor. A historical example illustrates this dilemma: in 1840, Orfila, French forensic pathologist, chemist, Dean of the Faculty of Medicine of Paris, Toxicologist of the Emperor, will abandon his duties as a forensic expert before the Assize Courts the day after the sentencing to the prison of Marie Capelle, wife of Lafarge, found guilty of poisoning her husband with arsenic despite her constant denials. He will take responsibility for it: “I was asked to say whether Lafarge's body contained arsenic and not to say whether Madame Lafarge was guilty or innocent” (Anonymous, 2012; Salomon, 2013).

Concluding this last section, it seems questionable that transparency can be restricted to a currently non-existent semantics common to physical, chemical, biological, and digital traces or encompassed in a prescriptive interpretation process. Traces, their analysis, and result outcomes have first and foremost meanings that call for going beyond a forensic semiology to broader semiotics studying the different perceptions and expressions of evidence.

5 | CONCLUSION

In this paper, we have argued that a semiotic approach to forensic science could offer an unexplored avenue in research into the understanding of evidence in general, forensic evidence in particular, integrating probability as an argument in the process of signification, that is, a traces semiosis. As quoted by Tillers (2011, p. 260), “Although human inference is a rational and logical activity, human inference—i.e., the inferential activity of the human organism—involves not just (let alone only, or even mainly) explicit ratiocinative processes. Inference is one of the activities of a sentient human organism (the same is true of non-human organisms). The human organism, though sentient, is ‘rational’ to its core: Logic—a complex logic or a set of logics—is embedded in the human organism and regulates its activities.”

Peirce, recognized as a pioneer in the field of statistical induction, had already perceived the permeability of probability in all aspects of our lives (Hacking, 2008), including its limits in the interpretation of the singularity. A semiotic approach could help us to re-establish a logic specific to forensic science integrating probability and human understanding, because it offers a good representation of the reasoning actually carried out, able to take into account heuristics and biases within the Interpretant undersign, even within a prescriptive opinion (it could help frame the reality of the reasoning while respecting the what should be done normative dimension):

- it makes it possible to clearly express, step by step the semiosis of the trace depending of the agent (police officer, investigator, forensic scientist, trier of fact, etc.), hence to contribute to the transparency of the reasoning actually carried out;
- it makes it possible to discuss the entities by the signs they send back, by the relations between them and it makes it possible to express chronologies, in a qualitative way, in a process of inquiry and interpretation which starts from a disorganized, confused situation and leads gradually towards a more formalized and quantitative expression: one can only speak of statistics and probabilities once the questions have been well expressed. The probability comes next if it makes sense with respect to the singularity of the case.

As quoted by Ginzburg, "At this point, then, there were two possible approaches: to sacrifice understanding of the individual element in order to achieve a more or less rigorous and more or less mathematical standard of generalization; or to try to develop, however tentatively, an alternative model based on an understanding of the individual which would (in some way yet to be worked out) be scientific" (Ginzburg, 1988, pp. 97–98).

The first approach has attracted significant interest over the last 30 years through the Bayesian approach, obviously largely perfectible facing "features centred more and more on the individual [...] to construct a body of rigorously scientific knowledge" (see introduction). Ginzburg's alternative approach has remained relatively uncharted, and we argue that semiotics could offer the tools to progress in this direction. Furthermore, it appears that semiotic research would make it possible to envisage a coherent meta-analytic path of bringing together the two research axes currently dominant in forensic interpretation, namely the prescriptive normative axis of Bayesian modeling and the descriptive axis raising awareness of bias in the expression of a transparent opinion.

At the very least, this paper re-considered the nature of the scientific opinion assisting the trier of fact and highlighted that we should pay more attention to the forensic science semiotic dimension to forward the discipline, which is more than simply paying close attention to words and their symbolic meanings.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

AUTHOR CONTRIBUTIONS

Frank Crispino: Conceptualization (lead); formal analysis (lead); investigation (lead); methodology (lead); project administration (lead); supervision (lead); writing – original draft (lead). **Celine Weyermann:** Formal analysis (equal); investigation (equal); methodology (supporting); validation (supporting); writing – original draft (equal). **Olivier Delémont:** Formal analysis (supporting); investigation (supporting); validation (supporting); writing – original draft (equal). **Claude Roux:** Formal analysis (supporting); investigation (supporting); project administration (supporting); validation (equal); writing – original draft (equal); writing – review and editing (equal). **Olivier Ribaux:** Formal analysis (equal); investigation (supporting); methodology (equal); supervision (equal); validation (equal); writing – original draft (equal); writing – review and editing (equal).

ENDNOTES

[1] The Daubert judgment explicitly cites Hempel ("[T] he statements constituting a scientific explanation must be capable of empirical test") and Popper ("[T] he criterion of the scientific status of a theory is its falsifiability, or refutability, or testability") to distinguish "science from other fields of human inquiry."

[2] We are assuming here the plurial at likelihoods, because the LR is the ratio of two likelihoods of two opposite causes having observed the effects (traces).

[3] It is anecdotal, but also interesting to note here that this sudden exacerbation of transparency is visibly linked to the professional and research interests of the first author, a high-ranking officer of a police force in the Arab Emirates, while the first author of this article, himself a former senior operational officer in France, has been concerned about this issue for more than 25 years.

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