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Shifting forensic science focus from means to purpose: A path forward for the discipline?

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ABSTRACT

Forensic science is facing a persistent crisis that is often addressed by organizational responses, with a strong focus on the improvement and standardisation of means and processes. However, organisations and processes are highly dependent on the political, economical and legal structures in which they operate. This may explain why most proposed solutions had difficulties in addressing the crisis up to now, as they could hardly be applied transversally to all forensic science models. Moreover, new tools and technologies are continuously developed by a quasi-infinite number of different scientific disciplines, thus leading to further diversity and fragmentation of forensic science. In this paper, it is proposed to shift the focus from means to purpose and consider forensic science current challenges in terms of discipline, before addressing organisations' specific issues. As a distinct discipline, forensic science can refocus research and development on shared principles and purposes, such as reconstructing, monitoring, and preventing crime and security issues. This focus change will facilitate a better understanding of the trace as the object of study of forensic science and eventually lead to a more impactful and long-lasting effect. This approach will also foster the development of a forensic science culture (instead of a primarily technological culture) unified by purpose rather than means through more relevant education and research.

1. Introduction

Forensic science has been challenged for more than a decade [1–6]. Many different issues have been identified such as backlogs [7,8], quality management [9–13], bias mitigation [14,15], objective evaluation of the meaning of evidence [16,17], communication [18–20], involvement with (crime scene) investigation and intelligence processes [21–23]. While many solutions to address these issues have been proposed over the years, the 'forensic science crisis' seems intractable [24].

Overall, there is little consensus on how forensic science can be characterised or defined [12,25–28]. Because of this situation, the question arises as to whether there are sufficient common principles to consider it as a specific discipline, and what these principles may be [6,20,29]. The relatively poor depiction of forensic science as a discipline means that, when the topic is discussed, it is often unclear whether the arguments presented apply to the *discipline* in general or more particularly to forensic *organisation* (e.g., laboratories). Further, the poor recognition of forensic science as a discipline may give the impression that it can almost solely be viewed and improved through the organisation prism. It may actually be easier to tackle organisational challenges than poorly defined fundamental issues. However, when developing forensic science mainly as an organisation, we tend to focus on means and processes [5,13]. As these two elements are highly dependent on the local political and legal structures that essentially vary between countries, jurisdiction and organisations, it is difficult to identify and agree upon measures that are 'universal' and effective in the long term. The perception of a never-ending crisis suggests that it is time to look into the problem from a different perspective, i.e more through the lens of the discipline and less through organisational factors.

For this reason, we attempt, in this paper, to refocus the discussion on the purpose of forensic science as a discipline i.e., on the **contribution of traces**[1] **to the reconstruction, monitoring and prevention of crime and security issues** [5,20–22,30–32]**:**

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[1] A trace is defined here in the forensic science perspective as a *vestige or mark of a presence, an existence or an action of someone or something in a location or space that did not belong to that space initially* (Margot, 2017).

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1) Traces are collected and analysed to reconstruct past events and infer about their source (e.g. semen allowing inferences about a potential sexual activity and the person at the source of the extracted DNA profile [33]).
2) Traces are continuously collected to monitor situations and detect new tendencies (e.g. wastewater and drug analysis allowing the monitoring of illicit substances consumption over time [34]).
3) Traces are stored in databanks and analysed to detect problems (e.g. shoemarks allowing detection of series and prevention of future events by targeted surveillance [21]).

We first present critical historical developments that help understand why and how forensic tools have been developed through different scientific disciplines. We then discuss how this situation led to a fragmentation of forensic science into an infinite number of possible subdisciplines and processes as well as to an ill-fitted model based on enabling disciplines rather than traces. By refocusing on the identified purpose of forensic science as a discipline, we propose an alternative model of forensic science relying on fundamental disciplinary principles and a shared nomenclature, cemented by a common culture. A better understanding of the trace and its potential to contribute to a variety of shared purposes will provide a solid and transversal basis to guide education, research and development and thus ensure future long-term improvements in forensic science.

2. Historical development of forensic science

It might be useful at this stage to take a step back in history and understand the origins of forensic science. Is it born from investigative requirements, legal needs or scientific observations? While these three drivers have played a significant role in the development of forensic science, the use of traces in investigations is undoubtedly as old as humanity itself. For example, traces such as footmarks and faeces have long been used for hunting or assessing danger [35]. Forensic science is thus born from the observation and needs arising from the investigation of criminal events, the trial being the last step of the judicial process. Indeed, readily visible traces, such as blood, sole marks, fingermarks and handwriting have long been used by police investigators. However, the advent of latent or more complex traces that may sometimes only exist at the molecular level (e.g. latent fingermarks on difficult surfaces or in compromised environment, latent biological traces containing DNA) has increasingly required technical knowledge from other disciplines to develop tools to extract useful information from them [36]. And because traces can be ‘anything’ (physical or virtual, highly transient or more persistent), forensic science developed through many specialized tools and disciplines, some more established than others and progress tended to be viewed through the lens of a particular tool or discipline rather than its core purpose or function, that is **contributing to the investigation of crimes** and other harmful events to society [5,13,30].

Historically, if one excludes police investigators, medical doctors[2] were pioneers in forensic science (investigating death and related traces, such as wounds and blood). Forensic or legal medicine is exclusively taught as a specialisation of medical education programs, and medical doctors still represent a substantial portion of the forensic practitioners (and researchers). Chemistry[3] and physics later gained importance in investigations with the development of toxicology, photography, dactyloscopy and microscopy [37]. Disciplines such as law[4] and psychology, also made significant contributions to the development of forensic science in parallel to criminology [4], particularly in the field of questioned documents[5]. The end of the last century brought a major change in forensic science practice with the introduction of DNA analysis in the investigation of crimes. Thus, biology[6] took an increasingly central position in forensic science services, followed, more recently, by the rapid digital transformation of society (including the criminal landscape), inducing the need to again redistribute resources to include digital expertise in investigations and trials[7] [22,38,39].

This evolution highlights that the needs arising from the examination of traces in police and judicial practice have mainly been answered by other disciplines in often loosely or entirely unconnected endeavours, thus logically yielding a divided applied discipline guided by technical developments rather than a common scientific theory and purpose(s) [6]. Historical development has previously been proposed as an inspiration for future development [20], but it may also be partly at the root of some of the current problems. The added-value of science has been mainly seen as a continuous increase in sophisticated tools becoming sometimes an end in themselves (i.e. technology-oriented development), often overruling the importance of appropriate scientific reasoning to solve actual problems (i.e. purpose-oriented development) [5,6,13,40].

3. Current models of forensic science

Nowadays, the dominant forensic science *organisation* model (at least as discussed in the literature) seems to be a laboratory with the (almost exclusive) purpose of producing “evidence”[8] [22]. While some traces, mostly marks, are still largely examined by police services (e.g. fingermarks, sole and tyre marks), other traces are systematically sent to forensic science laboratories that are physically, and often financially, separated from the police (e.g. DNA and gunshot residue). Some of these laboratories work as (public or private) business entities producing a service (e.g. for police services and justice systems) [41]. The organisation of forensic laboratories is not standardised across the world, and the employed scientists and managers are generally educated in other basic disciplines [42]. With increasing size and advanced technology, the structures become more complex, and difficulties in maintaining a sufficient level of coordination arise between the specialities [30]. This issue is well illustrated by the Organization of Scientific Area

[2] For example, Alexandre Lacassagne (1843–1924) was a forensic doctor and the professor of Edmond Locard (1877–1966), who himself had a multidisciplinary curriculum mixing science, law and medicine.

[3] For example, Archibald R. Reiss (1875–1929) and Paul L. Kirk (1902–1970) were both chemists. Reiss was particularly interested in photography and investigation, while Kirk was specialised in microscopy and identification questions.

[4] For example, Hans G.A. Gross (1947–1915) was a criminal lawyer who introduced the term of “Kriminalistik” and participated to the development of the concept of “profiling”.

[5] Handwriting on questioned documents is still often examined by trained lawyers and psychologists, and interestingly may have lead to one of the first forensic science crisis. The renowned Dreyfus case is often used to illustrate the risk of errors based on faulty and biased examination (see https://www.maths.ed.ac.uk/~v1ranick/dreyfus.htm,last access: July 2021).

[6] For example, Stuart S. Kind (1925–2003) studied biology and chemistry and started his career as a forensic biologist.

[7] Some progress is brought by new technology able to detect traces that were already transferred during criminal activities (e.g. microtraces, touch DNA), while others are brought through a transformation of the tools used by society creating new types of traces (e.g. cars, computers, mobile phones, …).

[8] In truth, forensic science do not produce evidence, but study traces as the sign of past activities and presence. The term “trace” has thus been preferentially used in this contribution.

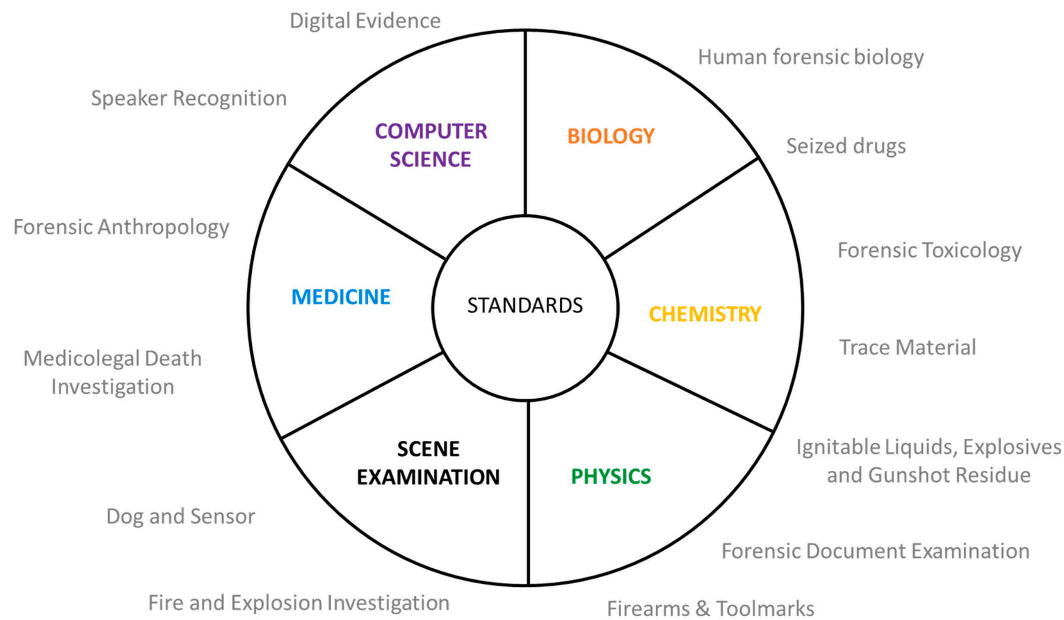

Fig. 1. Typical example of a multidisciplinary organisation of forensic science centred on enabling disciplines and standards (loosely inspired by the OSAC, as well as other forensic institutions organisational structure).

Committees for Forensic Science (OSAC) of the National Institute of Standards and Technology (NIST) in the United States[9]. Apart from scene investigation, the scientific area committees are attributed to enabling scientific disciplines: medicine, physics, chemistry, biology and computer science (see Fig. 1). In each area a set of forensic disciplines sub-committies (22 in total) work to identify and develop forensic science standards.

This can be observed in almost all forensic science organisations, whether networks, laboratories or academia, and highlights a typical issue in forensic science: ***on what criteria do we create and name a new forensic (sub-)discipline?*** Some differences can be highlighted between the OSAC, the European Network of Forensic Institutes (ENFSI) structure[10] and the National Institute of Forensic Science Australia New Zealand (NIFS)[11], illustrating the difficulties in defining a transversal organisational model for forensic science. In terms of subject matter expertise, ENFSI is composed of 17 forensic science working groups, while NIFS is composed of 12 specialist advisory groups. The diversity in the names proposed by these organisations seem to indicate that each time a new skills set is developed, it is added to the organisation as a new forensic sub-discipline, thus complicating and fragmenting further the structures.

Specialities can be named according to traces (e.g. fingermark, toolmarks, gunshot residue), others represent objects (e.g. footwear and tire, firearm), some are linked to other disciplines and specialities (e.g. wildlife, geology, biology, anthropology, toxicology) or type of events (e.g. death, fire, explosion, road accident), and finally, some are based on methods or technology (e.g. imaging technology, dogs and sensors) and processes (e.g. investigation, analysis, identification, interpretation, reporting). This nebulous taxonomy highlights the difficulties in defining forensic science objects of study and purposes. The digital transformation represents an additional challenge for organisations as specialised forensic scientists (traditionally educated in chemistry and biology) cannot efficiently address the new issues generated by this field [22]. Thus, computer scientists are increasingly required to enter the fray of specialists working in forensic science, bringing an additional dimension to an already complicated picture (e.g. forensic information technology, forensic speech and audio analysis, digital imaging, digital evidence). In 1986, Kind suggested that "*concentration on highly sophisticated instruments is the cause of some of our present problems. Large central laboratories are the only ones which can afford expensive instruments, but large central laboratories tend to be a long way from the scene-of-crime and the detective conference. What happens then is that the active enquiring mind of the scientist turns away from the routine examination of parcel contents to the wide academic scientific vistas opened up by the X-ray fluorescence spectrometer, or the organic mass spectrometer and so on. Thus he turns from the problem and focusses his attention on the method. Sometimes he rationalises this by taking the name of this new specialism and putting the word "forensic" before it*" [13].

4. Where is the trace in current forensic science models?

It should also be noted that current structures often result in the examination of some type of traces being fragmented across different sections as **most traces are inherently interdisciplinary**. For example, fingermarks are of a biochemical nature and are composed of ridge details forming patterns. Biology, chemistry, physics, mathematics and psychology fundamental knowledge play a role in their detection, analysis, comparison and evaluation. In small organisations, the DNA section include specialists in biology and statistics. At the same time, they will increasingly be separated in larger organisations, not the least due to the lack of space to host them in physically close offices. Indeed, the structure of organisations is sometimes also influenced and constrained by the design of the hosting buildings and management requirements [22]. In parallel, the aspiration to share processes and methods leads to the creation of additional sections supporting other groups such as "analytical chemistry", "statistics" or "quality". This demonstrates that the means rather than purposes are seen as linking elements between forensic sub-disciplines.

These problems are well illustrated by *forensic document examination* defined as a physics/pattern interpretation discipline in the OSAC structure, while it is separated in two working groups by ENFSI : *documents* and *handwriting*. In fact, a questioned document can be encountered in a variety of crimes, and is the support of multiple traces such as

[9] https://www.nist.gov/osac/osac-organizational-structure (last access: July 2021)
[10] https://enfsi.eu/about-enfsi/structure/ (last access: July 2021)
[11] https://www.anzpaa.org.au/forensic-science/resources/sags (last access: July 2021)

ink, handwriting, linguistic content, latent writings and even fingermarks and DNA. Typically, ink, toner and paper examination will be handled by the "physics" or "chemistry" sections, while a separate section will often handle handwriting. In some countries, handwriting examination is performed by psychologists and experts are often essentially trained in-house. The written content of the document will be handled by a linguist (when one is available in the organisation) [43] and digital specialists (e.g. content of Tweets or Whatsapp messages) [44]. The increasing examination of contested digital signatures also requires knowledge in qualitative and quantitative handwriting comparison, including the extraction and treatment of data produced onscreen rather than paper [45]. The examination of security documents (such as banknotes and identity cards) are generally handled by border controls and police laboratories. Finally, optical examinations are visually non-destructive and can be carried out before fingermark detection or DNA sampling. However, the risk of contamination is not negligible [46]. Thus, priority must be decided on a case-to-case basis depending on the purposes and potential of each element, highlighting the importance of facilitated communication and coordination between the different responsible sections. This was well recognised by the Australian Federal Police (AFP) when the opportunity arose to restructure their forensic science laboratory using a consultancy-based model focused on problem-solving (e.g. shared examination and communication spaces) rather than compartimentalised sub-disciplines, tools and processes [22]. An Example of such interdisciplinary organisation centered on the trace and purpose is illustrated in Fig. 2.

This fragmentation is not limited to documents, and may also expose the difficulties faced by different specialists when collaborating in solving problems, including a reluctance to step out of their comfort zone [13]. For example, firearm traces include physics (e.g. striae on the projectiles, ballistics) and chemistry (e.g. gunshot residue). Marks on projectiles and cartridges are examined by firearm examiners often employed by Police services, separated from the laboratory. Statisticians are also increasingly required to handle the complex comparison and reconstruction algorithms[12]. On the other hand, gunshot residue is

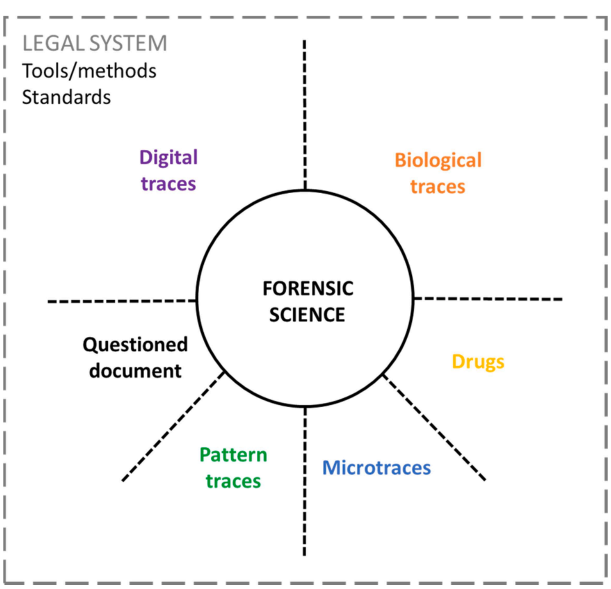

Fig. 2. Example of interdisciplinary organisation of forensic science centered on the trace and purpose (inspired by the AFP forensic science laboratory [22]). While not central, tools and standards are still part of the system.

examined in the laboratory context by experts currently specialised in scanning electron miscroscopy (a tool developed to analyse *inorganic* residue), while *organic* residue analysis necessitates other sophisticated tools such as liquid or gas chromatography [47]. While these tools require specialised knowledge, they are also often situated in different "sections" of forensic laboratories (e.g. drugs or explosives) and thus are generally neither validated nor easily accessible for organic gunshot analysis. In other words, to meet its purpose, the forensic investigation of a single firearm incident may require the collaboration of at least three different specialties. Thus, the focus becomes the development, sustainability and standardisation of the tools and processes available to a particular group rather than adapting to search the best solutions to address the questions arising from the case (i.e., organisational needs override the discipline purpose).

These observations tend to confirm that defining and structuring forensic science through other disciplines and tools does not reflect the multifaceted nature and potential of the trace [24,30] (see case study 1). The organisation of forensic science in sub-disciplines, promoted by the managerial need to structure, unfortunately promotes an increased focus on processes and technology borrowed from a (theoretically infinite) number of different disciplines in multi-disciplinary, but mainly disconnected, "forensic" endeavours. Even part of the same process tend to become fragmented hampering an iterative approach to problems (e.g. separation of investigation and evaluation stages [21]). Thus, a problem or specificity at one end of the process will be difficult to detect and address in subsequent stages [27]. While the prefix **multi**-disciplinary indicates that "many" disciplines are involved, **inter**-disciplinary highlights the need of interactions "between" the involved disciplines. These clarifications may help define how different (forensic) scientists and stakeholders view forensic science. The actual dominant model (illustrated in Fig. 1) may (unintentionally) forward a "multi"-disciplinary approach of forensic science borrowing fundamentals and processes from a multitude of other disciplines in loosely connected endeavours[13], thus resulting in a patchwork of standardised processes rather than a federated discipline using a holistic approach based on fundamental principles and well defined purpose(s) [30,40].

Case study 1: The multifaceted nature and potential of traces to answer forensic science purposes.

In 2010, a woman went missing in Canada. The crime scene investigators found tyre marks and a sole mark outside her house. These traces initially helped to identify Colonel Russel Williams as a potential suspect as the car he was driving presented similar tyre pattern [48]. *During the police interrogation, a shoe mark from the scene as well as a reproduction of Russel Williams' shoe sole were presented to him and were pivotal to his cooperating to quickly find the body of the victim*[14]. *Later, DNA and digital traces were collected to confirm William's implication in the murder. While DNA profiles have a better potential to confirm the identity of a suspect than tyre and shoe marks, they do not bring much information to quickly localise a suspect previously unknow to the police services. On the other hand, tyre and shoe marks present very visual and straightforward patterns. They are thus particularly relevant in the first stages of the investigation to localise potential suspects* [49] *or to guide an interrogation to quickly obtain more information. The Yorkshire ripper crimes investigation (England, 1975–1980) also shows how clues can be used to guide the localisation of a suspect. Tyre marks found in three cases were used to extrapolate the type of vehicle driven by the offender, thus significantly reducing the population of potential suspects. Combined with other information, this might have helped an earlier localisation of the suspect* [50]. *The investigation of the Pembrokeshire murders*

[12] https://www.nist.gov/programs-projects/forensic-topography-and-surface-metrology (last access: July 2021)

[13] It may indeed be particularly difficult for a chemist and a digital scientist to share methods and collaborate on processes, while common purpose(s) and principles may greatly facilitate the interactions.

[14] https://www.youtube.com/watch?v=bsLbDzkIy3A (see around the 35th min., last access : July 2021)

(1985–1989) illustrates well the importance of a multi-trace purpose oriented approach. Angela Gallop reports how the consideration of fibres helped solve the case, including locating DNA traces[15]*. In the Claremont cases in Australia (1995–1997), fibres from a car carpet allowed linking the murders and eventually also helped identifying the owner of the car as the author of the murders*[16].

*Thus, too much focus on one type of trace and process (*e.g. *the analysis of DNA traces) or one type of purpose (*e.g. *source identification) may promote fragmentation and be detrimental to an integrated use of traces as clues aiming at reconstructing, monitoring and preventing harms. Indeed, traces are not only useful to localise or confirm the identity of persons of interests (who? what?), but also to reconstruct chronologies and activities (how? where? when?) and detected serial crimes* [31,50,51]*. This is particularly true when considering the broad information content provided by digital traces* [22,52].

5. Refocusing research and development on the discipline

Following up from the discussion above, it is very important to clarify that forensic science research and development is addressed very differently under the organisation and discipline prisms. In each of these propositions, forensic science is facing different (if somewhat overlapping) issues. For example, the issue of work overload and backlogs is mainly an organisation issue that can be addressed using management tools [7] common to other organisations such as hospitals[17]. Of course, it can also be addressed using scientific reasoning (e.g. triage based on forensic purpose and relevance [53–55]). On the other hand, the issue of lack of cohesion may primarily be a discipline issue (i.e. lack of shared principles), and questions the very existence of forensic science as a discipline [29,30]. It is however often addressed by organisations, rarely in terms of structure (see Fig. 1), but prevalently through the definition of standards and best practices aiming at unifying the practical implementation of science in a forensic setting. However, the large lists of entities developing standards and the number of different standards (even for one type of trace) may indicate that there is less cohesion than what was originally intended by these endeavours[18].

Moreover, while organisations (such as but not limited to forensic science laboratories) mainly focus on processes and technologies, they are also largely dependent on political, economical, legal and physical structures. Forensic science organisations are operating in complex systems involving many different stakeholders such as police officers and magistrates in a variety of evolving models (and are by far not limited to the model presented in Figs. 1 and 2). Addressing forensic science challenges under the organisation and process prisms is thus particularly challenging as problems and solutions may be highly dependent on contextual particularities (e.g. common law vs regulatory law systems). While we can argue on the best configurations (e.g. privatised vs. police laboratories), some solutions are simply not easily implementable in some political or legal structures [4,41]. Thus, it seems that a top-down approach, in which forensic science is structured and defined by politics, organisations and other enabling disciplines [42] within complex justice systems involving many stakeholders may not be the best approach to develop a unified forensic science discipline, but may on the contrary further fragmentation and tension within the discipline (Fig. 3) [21,23,27,30].

For example, the need to improve quality in forensic science has mainly been addressed by organisations and other disciplines with a strong focus on standardisation [9,13,28]. On the other hand, quality is also highly dependent on adequate reasoning and problem-solving skills, together with a good understanding on the particularities of the trace, as main object of study of forensic science [5,10,12,20,56] (see case study 2). These are essential elements of forensic science as a discipline, and enable the definition and development of a body of knowledge and principles that are more permanent and universal than organisations and processes. These should thus be considered first to build a strong basis on which other complementary measures to improve the quality of processes can be added. Margot also observed that "*Before we introduce structural controls like standards (often a poor replacement for competence) and ethics, forensic science needs a sound scientific structure*" [57]. This was also recognised by Mnookin et al. ten years ago: "*At present, most university-based forensic education is far more focused on training future practitioners than on training students to engage in fundamental research*" [26]. Most notably, Kirk already claimed in 1963 [6] that "*for the most part, progress has been technical rather than fundamental, practical rather than theoretical, transient rather than permanent*". Following these (recurrent) observations, we suggest to refocus forensic science development on the discipline, its object of study (i.e. the trace) and its purpose(s) before the quality of processes and standardisation can be adequately addressed under the organisation prism (i.e., practice).

Case study 2: The need of complementary solutions to address contamination risks in forensic science

The resolution of the Heilbronn phantom mystery highlighted a recurrent "laboratory" error [58,59]*. Between 1993 and 2009, the DNA profile of a woman was found on several crime scenes in Germany, Austria and France: murders, burglaries, robberies, organized crimes…the eluding suspect committed all kind of crimes. Often, other authors were arrested and convicted for those crimes, but never revealed any useful information about the "phantom". Moreover, the profile was sometimes found on objects unrelated to the reconstructed actions. Eventually, it was determined that the female DNA came from a woman involved in the manufacture of the cotton swabs* [58].

Subsequent studies further warned about the multiple risks of contaminations along the whole chain of sampling and analysis, particularly when small amounts of DNA are detected [59]*. Most scientists would also (rightly) suggest that a more systematic "blank" swab analysis might have highlighted the problem much earlier (indeed, blank material and background analysis are key aspects of forensic science). However, if only parts of the swabs were contaminated, the DNA may still have been found as relevant in some cases. For some of the complex cases, in which this trace was a central clue, the contamination profile may have led the investigation on the wrong track, thus decreasing the chances of resolution (error type II). Blind confidence in the DNA infallible "gold standard" may have delayed the resolution of the Heilbronn mystery. While standard procedures and quality controls (here of the material used) is essential in forensic laboratories, contaminations will always occur from time to time due to the continuously decreasing limit of detection of the implemented method* [46,60]*. Thus, it seems important to consider other mitigation measures in parallel to quality systems. These will also account for contamination occurring before the police intervention and crime scene investigation.*

In contamination cases, isolating forensic scientists from the investigation

[15] https://www.forensic-access.co.uk/news/interviews/dr-sheila-willis-digs-into-professor-angela-gallop-s-background-and-thoughts-on-the-future-of-forensics/ and https://www.dailymotion.com/video/x7yptxb (last access: July 2021).

[16] https://www.abc.net.au/news/2020–04-23/why-fibre-evidence-is-crucial-in-claremont-serial-killings-trial/12150528 (last access: July 2021).

[17] The parallel with the COVID-19 crisis can illustrate the fact that hospital overload is not per se a discipline issue (i.e., it will not influence fundamental medical research on the development of an adequate treatment). However, it can be addressed by the medical discipline to help develop triage strategies based on scientific criteria (i.e., the chance of successful treatment in a particular case).

[18] List of standard bodies can be found at: https://www.nist.gov/osac/access-standards , https://enfsi.eu/documents/, https://www.nist.gov/standardsgov/designation-requirements-australia (last access: July 2021).

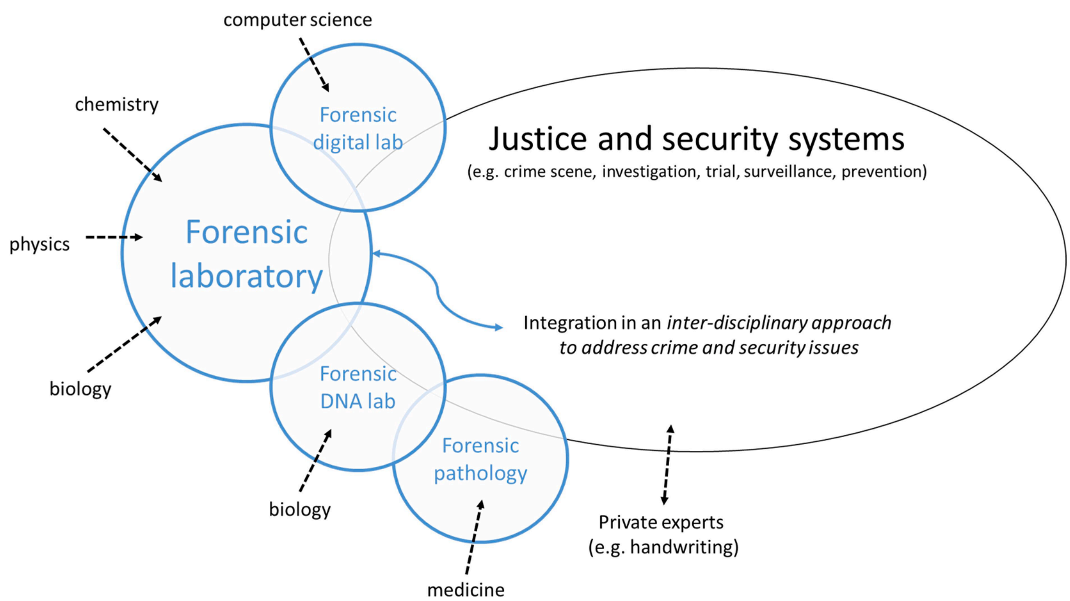

Fig. 3. . Illustration of forensic science as a service-provider to justice and security systems. Shaping (forensic) science by a top-down approach (from organisations to discipline(s)) leads to a very context-dependent and uncoordinated contribution of science to crime and security issues. In this model, crime scene is not even considered to be part of the forensic science service system while invariably being at the origin of any inquiry.

context to avoid bias would not help detect and address the error. Indeed, the DNA profiles were correctly interpreted. Limiting communication might further disrupt the detection of the contamination and hinder a global analysis of all cases[19] [61] (e.g. *the "Heilbronn" cases were different in many aspects such as space, time and MO). On the other hand, a case-based multi-clue approach might help detect the irrelevance of the DNA profile in the investigation (*e.g. *the DNA was found on objects unrelated to the investigated event)*[5]. *Most cases were resolved without interference from this DNA trace, and this finally led to the discovery of the contamination source* [58]. *The wrongful conviction of Farah Jama is another case illustrating the risk of poorly integrating forensic clues with other available information, including contextual information and knowledge about the transfer and persistence of traces (including contamination issues)* [27,62]. *These considerations are best addressed by the discipline with a clear understanding of the investigation, monitoring or prevention purpose(s) of traces. They should systematically be implemented together with other important quality measures such as process standardisation and control* [10,12].

6. Towards more purpose and relevance in forensic science

As already advocated by Kirk more than 50 years ago, it is necessary to refocus forensic science on the definition of a *goal, so that we may all talk about the same thing and move in the same direction* [6]. The same was again suggested by De Forest in 1999 [5]: "*However, the stress that has been placed on accuracy and doing "the job right" has too often been at the expense of relevance. We seem to be drifting away from appreciating the need to also "do the right job". Doing the former doesn't mean we can ignore the latter*." More than 20 years later, the 'scientificity' of forensic science processes continues to be strongly debated (*doing the job right*), while its object of study remains too rarely addressed (*doing the right job*) [5,32,63,64]. However, *doing the job right* will only be useful if you are *doing the right job*. Thus, it is important to understand first the discipline's objects of study (the purpose) before improving the quality of the implemented tools (the means). From a simple practical perspective, forensic scientists need to be aware of more than the discriminating power or the limits of reliable measurement of a technique, they also need **knowledge of the trace** itself and how it is expected to behave in given scenarios (see case study 1 and 2).

As previously mentioned, forensic science organisation and discipline actually share a common main purpose: **contributing to the reconstruction, monitoring and prevention of crime and security issues**. While case specific purposes should be defined together with the different stakeholders, scientific research and development must mainly be carried out from within a discipline in a scientific (bottom-up) rather than politic or economic (top-down) approach in order to be relevant and efficient [26,57]. The distinction between organisation and discipline is particularly important here as their aims may differ in particularities (see case study 3).

Case study 3 – Business structure may interfere with the some of the discipline's purposes

Forensic laboratories provide services (e.g. for police and judicial organisations) and have to work within allocated ressources (e.g. subvention, profit, staff, instrumentation, time, …). While several reasons justify the distancing of forensic science from the investigation (including scientific independence), an important conflict of interests of such models should also be acknowledged: decreasing criminal activity (an important purpose of any society) may be counterproductive to any business plan based on the production of "evidence" for the police and the court. Thus, being too efficient or widening the purpose of forensic science to the monitoring and prevention of security issues may endanger the current main model of forensic science organisation [22,23]. *However, the need for evidence-providing specialists in laboratories seem to be shifting to the need for forensic scientists able to quickly adapt to evolving security issues, operating in the field and better integrating information extracted from multiple type of traces including digital ones. These challenges will be better tackled with a well defined discipline as a persistent basis on which organisation, processes and methods can be built and adapted when the situation evolves.*

The development of forensic practice within organisations is of course heavily constrained by legal, economic and politic frameworks, while science fundamentals remain solely affected by the law of nature[20]

[19] The impediments to share data have also been identified early as a promoter of "linkage blindness" hampering the resolution of serial crimes (Egger, 1984) or the prevention of terrorist acts (see The 9/11 Commission Report).

[20] These scientific laws are of course not limited to the laws of physics, but may also be of a human nature.

(leading to possibilities and limitations that cannot be defined only under a purely legal or political prism) [4,20]. **Thus, it is only by addressing forensic science as a discipline (rather than disciplines [30]) that transversal principles, knowledge and nomenclature suited to the defined objective(s) can be developed** [6,26,57,65]. This, in turn, can only be reached by the development of a forensic science culture developed by research and forwarded by education within (and thus, more relevant to) the discipline. Margot already suggested ten years ago that research in forensic science is sorely needed, but it should address primarily forensic science questions—not questions relating to the application of chemistry, biology, statistics, or psychology. This is how a discipline is built and progresses, and this is where academics should focus their questions [57]. Margot also questioned in another paper: Why do we have medical schools and shouldn't we have forensic science schools: the overall approach (diagnosis, clinical picture, epidemiology, etc) is just as complex with crime scenes as with body functions [4]. And clearly medicine is also assisted by many other disciplines in the development of tools and processes (e.g. statistics and biological analysis are routinely implemented in diagnostics to caracterise risks and detect indicators of health problems, respectively).

Development of forensic science as a discipline has the potential to have a more impactful and long-lasting effect than sole focus on organisations, processes and technologies, as these constantly evolve over time and space [22]. It is sound to continue collaboration with science at large to develop novel tools and quality procedures, as well as with organisations (e.g. forensic laboratories, but also police services, justice systems or security agencies) to keep working on relevant purposes. However, if forensic science fundamentals are only considered from the perspective of other disciplines (e.g. biology, statistics, cognitive science, management…), this will lead to the observation that only "science" is needed and what makes it "forensic" is merely its application to legal matters[21]. Then, what makes forensic science a distinct discipline from applied chemistry or biology?

While acknowledging fundamentals borrowed from other disciplines (e.g. chemistry, biology, statistics or human factors), it is essential to define and recognise fundamentals in a forensic science perspective [29]. It has been suggested that the reconstruction of past events requires different forms of inference than the traditional experimental science (e.g. physics, chemistry, biology) and may be more related to a medical diagnostic or historial reconstruction process [27,32,66]. Several authors also suggested that the trace is a central element of forensic science [19,20,67][22]. The increasing use of the term "traceability" illustrates well the importance of "traces" in the reconstruction, monitoring and prediction of past, present or future events, respectively. While every country has its own legal system and terminology explaining a somewhat different usage of the words trace, sign, clue and evidence, the distinction is particularly important to better understand the continuum of information conveyed by a trace (see Fig. 4) [57,68,69].

Indeed, it may be misleading to think that investigators immediately find 'evidence' at the crime scene. They will first look for traces relevant to the event being investigated. Many observed traces at a crime scene may be contaminations of the scene (e.g. shoemark from a resident or paramedics attending the scene). The crime scene investigators will search for relevant (sometimes latent) **traces**, that are hypothesised to be **signs** of a presence or an action of the event being investigated. At this point, there is still a high degree of unknowns and uncertainties; for example, it may be unknown if a death is the result of an accident, suicide or homicide, or how many people attended the scene. Thus, traces resulting from several alternative hypotheses and actors will be looked for. Once information is inferred from these signs, then the traces become **clues**. The extracted information may be used for several purposes (i.e., reconstruction of the event, localisation of a suspect, identification of a suspect, linking several events, informing policy-making…) [21,70]. If/when the information is presented in Court, it becomes **evidence** (the term "proof" has recently been suggested as an alternative for this concept [69]). A lot of contributions in the literature implicitly presume that collected traces will be binary, either 'evidence' or 'meaningless'. This misunderstanding may have promoted errors, as a trace such as DNA (often used to identify the person at its source) may have been the results of contamination or pollution rather than resulting from the criminal activity (see case study 2). Contamination has been previously defined as the result of legitimate activity, or secondary transfer at the crime scene before or after the crime occurred. Pollution is a particular type of contamination resulting from the intervention of the first respondents (e.g. medical team, fire brigade personnel) and investigators (e.g. police officers, crime scene attendants, laboratory staff) [20]. The risk of pollution can be minimised by the use of quality management guidelines and standard operating procedures, while most contaminations are out of the control of the forensic scientists and represent the background noise of the scene. In many cases, they cannot be avoided and are inherent to the notion of the trace.

However, the forensic science community continues to predominantly address the technical aspects of the analysis, comparison and evaluation of traces, forgetting that the obtained outputs (i.e. results) will not only be influenced by the quality of processes, but also by the initial inputs (i.e. the traces, which creation remain uncontrolled and uncontrollable). Thus, the main driver for the development of forensic science should actually not reside in the standardisation of processes (borrowed from other disciplines). It should rather focus on a better understanding of basic forensic theory and principles (including trace transfer, persistence and prevalence). Following these observations, we suggest that it is time to **resituate forensic science object of study, the trace and its relevance (i.e. purpose) at the centre of the forensic science research and development**. As the starting point of an investigation, crime scene investigation should be considered as (if not more) important that the laboratory [23,27]. Maintaining a continuous development and improvement of tools in collaboration with other disciplines and in compliance with the legal frameworks in place remains important but should be secondary and adaptable.

This agenda cannot be adequately achieved by organisations (constraint by the systems in which they operate) nor by other disciplines (constraint by their own standards). The main driver should come from within the discipline by **developing a forensic science culture based on the contribution of the trace to the study of crimes** and other security issues [19,20,26,30,57]. A good example of such endeavours is the Sydney declaration[23]. Several forensic scientists coming from different countries across the world recently proposed a definition of forensic science and seven fundamental principles. The role of dedicated academic research and education (also focused on purpose) is essential in building and transferring shared principles, knowledge and nomenclature.

7. Conclusion and perspectives

The usefulness of forensic science is widely recognised as forensic laboratories and services are a mainstay of the criminal justice system across the world. However, no global consensus exists about what these laboratories should do, for who and how. For example, several reports indicate that forensic science usefulness in court remains very limited

[21] It is interesting to note that forensic medicine is also referred to as legal medicine, giving the impression that both terms are synonyms. However, the etymology of forensic is attributed to the Latin word forum referring to the public place where people met for trade, political, security and economic affairs, including but not limited to legal proceedings.

[22] See Sydney declaration at: https://iafs2023.com.au/virtualevent/ (last access: July 2021)

[23] https://iafs2023.com.au/virtualevent/ (last access: July 2021)

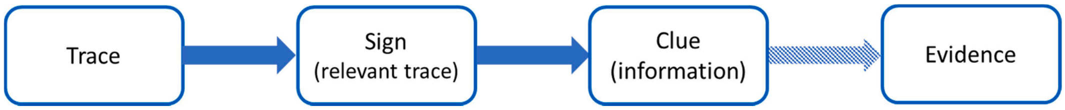

Fig. 4. . Schematic representation of the evolution of the trace to a sign (when its potential for information is recognised) to a clue (when useful information is inferred from the trace) to evidence (if/when the retrieved information is used as evidence in Court). Clues have multiple usages as vectors of information in forensic science and should not be viewed only as evidence.

[5,22,51] and is occasionally highly controversial [1,3,71]. Suggestions are regularly proposed to develop and improve forensic science through increased harmonisation of practice, fundamental research and education [1,6,26,72,73]. Despite these propositions, the crisis forensic science is facing proves to be persistent and may also be strongly fueled by the constant evolution of society, judicial systems, technologies and criminal tendencies (e.g. digital transformation [22,23]). This paper investigated and proposed a complementary, if not alternative, path forward by contrasting the forensic science means and purposes under the prism of the discipline (i.e., forensic science) rather than the organisation (i.e., practice).

We first showed that, over the years, forensic science developments have mainly focused on tools borrowed from and regulated by external disciplines and stakeholders; only minimal consideration has been given to the forensic science purpose and discipline [5,6]. We then highlighted the complex, varied and divided nature of forensic science organisations (including academia), leading to increased fragmentation of the discipline in an infinite number of possible sub-specialities (e.g. forensic medicine, forensic biology, digital forensics, forensic geology, forensic linguistics, etc.). This compartmentalisation explains why some trace types are often examined by different, sometimes uncoordinated, specialists, hampering a more integrated (or holistic) approach to the investigated problems. Harmonisation of these disparate means and sub-disciplines has mainly been attempted through standardisation of processes.

However, if not impossible, it is difficult to develop and unify forensic science through constantly evolving technologies and processes applied by organisations operating in very different spatio-temporal contexts and cultures (and potentially answering other purposes). Suppose we continue focusing on means and processes (viewed as important under a managerial prism). In that case, the key questions arising from purpose will not be addressed by research. Knowledge transfer via education will continue to be almost solely focused on more transient aspects addressed by other disciplines' fundamentals (e.g. technology, processes).

In (re)defining forensic science as a distinct discipline, studying traces (e.g. how, where and when material transfer) with an explicit and common purpose, we can potentially have a more impactful and long-lasting effect. This would further develop a forensic science culture around three primary identified purposes: **the contribution of traces to (1) shed light on past events, (2) monitor criminality/security issues and (3) prevent future harms**. Thus, we propose that shifting the forensic science focus from means to a purpose, i.e. reinitiating development on the discipline and its fundamental principles, will provide a basis on which organisation (s) and current practice(s) can more adequately evolve.

In summary, we argue that better defined forensic science purposes and principles can be shared by and hence transcend organisations, processes and sub-disciplines, ultimately providing a solid and transversal basis to guide future relevant improvements beyond solutions tried to date.

CRediT authorship contribution statement

Claude Roux: Conceptualization, Investigation, Writing - original draft, Writing - review & editing. **Sheila Willis:** Conceptualization, Investigation, Writing - original draft, Writing - review & editing. **Céline Weyermann:** Conceptualization, Investigation, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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