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PERSPECTIVE

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The utility of trace DNA within forensic science for investigative and intelligence purposes

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Abstract

Forensic science not only provides evidence to support criminal investigations, but also contributes to knowledge surrounding criminal phenomena. Forensic scientists are in the unique position to strategically combine information gained from traces to create intelligence that can assist the security space in keeping our communities safe. Research into the use of traces for more than just criminal investigations, with a focus on the greater "utility" of a trace, has pointed to the broader problem-solving potential of traces when more fully exploited. Alongside this, there has continued to be an exponential increase of the use of biological traces for criminal investigations, in particular the collection of trace DNA specimens. The potential for identification, among other information, trace DNA can provide is vast, however much of the previous research has predominately focused on recovery rates which does not provide a holistic view of the value of trace DNA. This paper summarizes the current knowledge on the utility of trace DNA, as well as makes suggestions toward the creation of a decision-making model that can inform scene of crime officers in regards to trace selection and decisions about trace analysis.

This article is categorized under:

Forensic Biology > DNA Databases and Biometrics

Crime Scene Investigation > From Traces to Intelligence and Evidence

KEYWORDS

effectiveness of forensic science, policy, security

1 | INTRODUCTION

Forensic science has struggled to measure its effectiveness, despite being a mainstay of the criminal justice system, which has caused challenges to be made regarding forensic science as well as highlighting the need for a broader understanding of its measure of effectiveness (Bitzer et al., 2017; Julian et al., 2011; Julian & Kelty, 2009; NRC, 2009). In parallel, there has been a refocusing of *the trace* as the bedrock of forensic science (Margot, 2017), with analysis of traces within their broader context being cited as the way forward for forensic science (Jaquet-Chiffelle & Casey, 2021; Roux et al., 2015; Weyermann & Roux, 2021). The *trace* is defined as the vestige or mark remaining and indicating the former

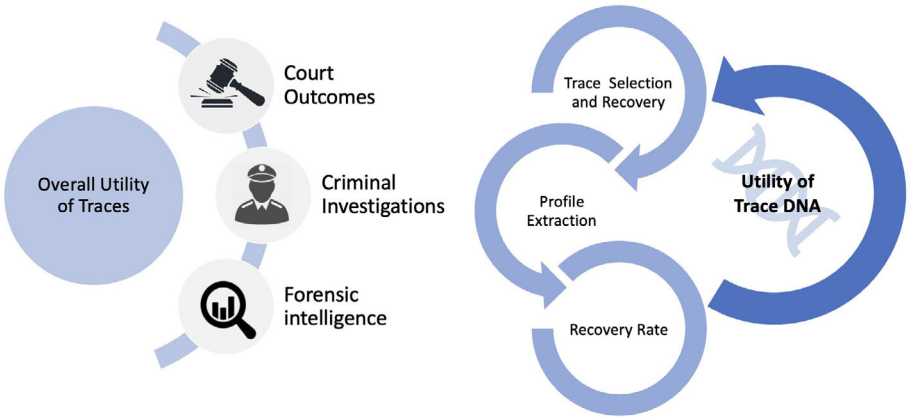

FIGURE 1 Summary of the utility of traces with a particular emphasis on trace DNA.

presence, existence or action of something, a term that applies irrespective of size and/or quantity of marks (Ristenbatt et al., 2022). Many of the attempts to quantify the effectiveness of traces have fallen short possibly due to viewing the value of a trace as purely a support to the criminal justice system (Baskin & Sommers, 2010; Burrows et al., 2005). Instead, traces should be considered in the greater security space, which aims to detect and understand risks as well as any problems that disturb public order and peace, focusing on not only reacting to criminal activity but preventing it to reduce its impact on society (Brodeur & Shearing, 2005).

Viewing traces in the context of the security space allows for the broader problem-solving potential of traces for investigative and intelligence purposes.

DNA, purportedly the gold standard of forensic science, has been the focus of much research surrounding its effectiveness within forensic science (Harbison et al., 2008; Mapes et al., 2016; Prasad et al., 2021; Raymond et al., 2011). The growing reliance on DNA, and in particular trace DNA, has highlighted the lack of a standardized measure or understanding of the value of traces beyond the criminal justice system and in the broader security space (Mapes et al., 2015). However, the problem-solving capacity of DNA traces in general cannot be captured in a singular lateral measure; instead, utility was proposed as an internal indicator of a trace's performance (Bitzer et al., 2015; Bitzer et al., 2016). Utility encapsulates the total value of the information a trace can provide, not only for court outcomes, but also for investigation purposes such as; identification or exclusion of persons of interest, witnesses or victims, corroborating or contradicting a proposed narrative, providing law enforcement with new leads for an investigation or highlighting previously excluded avenues of investigation. Simultaneously a trace may be used for intelligence purposes such as linking scenes or events together to identify a series of crimes, informing on criminal networks working within an area, identifying any patterns of activity or relating factors that link crimes together. The overall utility of traces expands beyond court outcomes and can be summarized in Figure 1. These considerations of utility allow for a greater exploitation of a trace as a whole as well as allowing for improvement in trace selection, recovery and analysis as will be discussed in this article.

2 | FORENSIC SCIENCE AS THE "STUDY OF THE TRACE"

The popularity of forensic science within the public is markedly a result of the boom of CSI television shows, crime dramas and documentaries. Alongside the increasing public interest came a somewhat warped perception of the infallible nature of forensic science (DNA analysis in particular) within popular culture. This perception has been juxtaposed against some very real failings of forensic science (NRC, 2009) creating a huge discrepancy between the public perception of the effectiveness of forensic science and the real world uses and outcomes of the discipline. In the wake of disparagements, a critique of the state of forensic science has been raised (Margot, 2011; Roux et al., 2012), with the questions regarding the reliance on forensic science by the criminal justice system when there is limited empirical evidence determining its effectiveness (Julian & Kelty, 2009; Julian & Kelty, 2015).

Much of the research surrounding forensic science in the past has focused on the aspects of the physical science, rather than the use of forensic science within the criminal investigative process (Julian et al., 2011). The majority of

forensic science research leans into being seen as a Galilean science which means to be concerned with the construction of general and predictive models, however in reality forensic science's principles and potential transcend the traditional Galilean framework and are more concerned with a clinical approach to the reconstruction of an event (Crispino et al., 2019; Crispino et al., 2022). Research has often focused on highly specialized technological advancements in order to further exploit the high identification power of certain traces, such as DNA or fingermarks. This dedicated focus on certain scientific disciplines has contributed to the criticism that forensic science is fragmented or has an appearance of being a "patchwork" of other scientific disciplines (Margot, 2011; NRC, 2009; Roux et al., 2015; Roux et al., 2022; Weyermann & Roux, 2021). Demand for rapid advancements in certain forensic analysis types rises to support the necessary increases in speed of decision making for investigative and intelligence purposes, however, the question of the effectiveness of comparative methodologies, or combination of methodologies is for the most part unanswered (Julian et al., 2011; Julian & Kelty, 2009). Any future advances in forensic science that aim to improve or define new techniques could be more effectively invested in if the value they provide could be more accurately anticipated (Julian et al., 2011).

There has been a resurgence of the "trace" that, by its existence in a location or space where it did not belong initially, becomes a silent witness that must be detected, collected, investigated and understood. It is therefore at the core of forensic science (Margot, 2017). This resurgence has precipitated a movement away from the highly specialized analyses, that in turn often neglect activity and context and mainly focus on the identification power of a trace (Jaquet-Chiffelle & Casey, 2021; Ristenbatt et al., 2022; Roux et al., 2015; Weyermann & Roux, 2021). As technological advancements lead to increases in ability to analyze smaller and smaller amounts of traces, a greater understanding of their significance and better ways to interpret their meaning and communicate different levels of confidence are needed (Walport, 2015), refocusing on the context of the trace. Similarly, several research papers have also highlighted the need to re-focus forensic science with fundamental principles, grounded in the study of the trace, stating that a case-based approach allows for broader use of forensic science as a whole (Margot, 2017; Roux et al., 2012; Roux et al., 2015; Roux et al., 2022; Weyermann & Roux, 2021). This movement toward establishing, or perhaps re-establishing, traceology as the primary purpose of forensic science leads the discipline toward a more coherent set of fundamental principles (Roux et al., 2022).

Forensic science has extreme potential to inform criminal investigations, as well as being used for forensic intelligence and informing proactive policing models. However, the lack of a unified approach in regard to the future of forensic science has limited the ability for the discipline to define and defend its effectiveness. Achieving coherence through standards and quality analysis may be possible, but this may move the analysis away from the context and the relevant questions the traces are supposed to help answer. The focus of laboratories on normalization, accreditation and certification is often used to cover their lack of control over detection, collection, and relevance due to the variability of traces (Roux et al., 2022). Instead, the focus should be on creating a greater understanding of the effectiveness and significance of traces within the broader context of their creation, to give insight for investigations, intelligence and security purposes (Roux et al., 2015). The need to determine the effectiveness of forensic science within investigations as well as its outward uses for intelligence and proactive policing models is aligned with the need to refocus the foundations of forensic science.

3 | UTILITY OF A TRACE

The resurgence of the trace as the bedrock of forensic science has highlighted the need for a better understanding of the use and effectiveness of traces. Different performance indicators have been proposed by studies as a means of measuring the effectiveness of traces and their use within forensic science. For example, one such study proposed the number of identifications that resulted from a trace as a means to measure the effectiveness of forensic science and its databases (Burrows et al., 2005), while another focused on the predictive power of trace processing on case outcomes (Baskin & Sommers, 2010). Both of these proposed indicators are simplified ways of viewing a trace's contribution, with the variability among traces and the multitude of contributing factors to their creation unable to be quantified by a singular ratio (Bitzer et al., 2015).

Instead of using singular ratios to consider the effectiveness of traces, a more holistic measure of utility has been proposed as an internal evaluation indicator of forensic science in investigations to allow for a broader view of traces (Bitzer et al., 2015). The "utility" of a trace was defined as the added value of information to an investigation obtained by the use of a trace (Bitzer, 2016; Bitzer et al., 2015). It was suggested that by observing actual utility a measure of expected or potential utility could be made for traces of this type in the future, leading to a decision-making model to inform scene of crime officers on trace selection (Bitzer, 2016; Bitzer et al., 2015). The benefit of this indicator is that it

is not limited to assessing the value of a trace within an investigation but can be applied to all facets of forensic science, such as the value a trace may have for policing models, crime patterns or other intelligence purposes. The concept of "utility" allows for a more holistic view of the value of information that can be exploited from a trace, avoiding the narrow view of a trace purported in previous research (Baskin & Sommers, 2010; Burrows et al., 2005).

Assessing the utility of traces within their context allows for the multi-dimensional purposes and contributions of forensic science. Trace analysis, though instrumental within the criminal justice system, also provides insight for investigations and crime and criminal mechanisms within a community, which can assist in the creation of policing models (Roux et al., 2022). Proactive policing styles (e.g., intelligence-led or problem-oriented) go beyond traditional reactive law enforcement approaches and aim at crime prevention, harm reduction and crime disruption. The consideration of the utility of traces can significantly support the detection and analysis of repetitive problems, thereby supporting crime prevention initiatives within the broader criminal justice system (Roux et al., 2022). Though a more traditional view of forensic science tends to see the value of traces through the eyes of the criminal justice system, the resurgence of forensic science as the "study of the trace" brings to light the crucial value that traces have for wider security purposes. Failure in the past to acknowledge this is a contributing factor as to why assessments of forensic science have been unable to fully assess the effectiveness of traces (Roux et al., 2022).

4 | THE NEED TO DEFINE THE UTILITY OF DNA

DNA profiling is arguably the gold standard of forensic science, predominantly due to its incredibly high discriminatory identification power (NRC, 2009). DNA profiles can be obtained from biological material (Jeffreys et al., 1985), such as blood, saliva, semen, sweat and trace DNA; trace DNA being defined as DNA that cannot be attributed to an identifiable body fluid (Meakin & Jamieson, 2013) (for a further discussion of this term, see (van Oorschot et al., 2019)). It should be noted that the uses and utility of DNA technology applied within forensic science extend beyond those discussed in this paper; and that uses such as phenotyping and genetic genealogy are not considered in this review of the current understanding of the utility of trace DNA within forensic science.

The uses of routine nuclear DNA profiling within forensic science are multi-dimensional, providing value to investigations and for intelligence purposes. DNA profiling, as noted previously, is highly discriminatory and can be used for the identification or exclusion of persons related to crimes. DNA profiles can be used to assist in the narrowing down or identification of persons of interest, witnesses or victims, in cases where the victim is unknown, as well as the exclusion or exoneration of a suspect who has been mis-identified as a person of interest (van Oorschot et al., 2010). With regards to intelligence, DNA profiling could be crucial in identifying scene to scene links, the pinpointing of which informs patterns that can both assist in solving and connecting multiple criminal investigations, as well as better understanding criminal activities (van Oorschot et al., 2010). The many uses of DNA profiling within investigations and for intelligence purposes can inform policing models to proactively address criminal activity that in turn increase societies' security and safety.

Detection of trace DNA was first published in 1997 (van Oorschot & Jones, 1997). Since then, there has been an exponential increase in the number of trace DNA specimens collected and submitted to laboratories for analysis, comprising half of all specimens submitted for DNA analysis in some jurisdictions (Dziak et al., 2018). The ever-increasing dependence on biological traces within criminal investigations, in particular trace DNA, coupled with the recent emphasis on the underlying broader problem-solving potential of such traces, has highlighted the need for research exploring the utility of trace DNA for investigative and intelligence purposes.

Studies have attempted to evaluate the utility of trace DNA in response to the growing reliance and use of trace DNA profiling (Castella & Mangin, 2008; Dziak et al., 2018; Harbison et al., 2008). Several of these studies identified that there were low recovery rates for DNA profiles being obtained from trace DNA specimens, purporting that among the possible causes of this was potentially poor trace selection by scene of crime officers (Castella & Mangin, 2008; Dziak et al., 2018; Harbison et al., 2008). Though this could be due to several reasons, scene of crime officers may not have a core understanding of the utility of trace DNA. Scene of crime officers primarily choose to collect trace DNA specimens for analysis based on their individual assessment of utility, with a methodology that has been described as little more than "guess and collect" (Margot, 2011). Such a possibility was suggested to be combatted by investigating which categories of trace DNA exhibits were returning profiles more frequently, to provide a framework to assist scene of crime officers by creating a targeted trace collection strategy. One study highlighted that items with "prolonged contact," specifically clothes or surfaces within a vehicle, had the highest rates of DNA profiles obtained (Castella & Mangin, 2008). This conclusion was confirmed by a second

study, stating the "handled items" had the highest rates of DNA profile success (Harbison et al., 2008). The forensic applications for investigators that these studies could provide was noted, with one study noting that items could be prioritized for analysis depending on the specimen type and likelihood to produce a DNA profile (Harbison et al., 2008).

The need for improvements in the decision-making model for scene of crime officers to inform trace collection in criminal investigation was further highlighted when studies reported a high number of trace DNA analyses did not return a profile, again citing possible poor collection strategies as a potential cause (Mapes et al., 2015). Building on this evaluation, Mapes and co-authors (Mapes et al., 2016) investigated exhibit categories with highest and lowest profile success rates, with the goal of building the foundation of a trace collection decision-making model (Mapes et al., 2016). They determined that cigarette ends, balaclavas, head wear, ball caps, collars, sleeve cuffs and socks had the highest DNA profile success rates, while cartridge cases, crowbars, keys, tape, tie wraps and gas cylinders had the lowest DNA profile success rates (Mapes et al., 2016). This confirmed previous research that items with "prolonged contact" had a greater chance of returning a DNA profile (Castella & Mangin, 2008; Dziak et al., 2018; Harbison et al., 2008). They further stipulated that though this information may be used by crime scene officers to assist in trace selection, a case-based approach is still recommended, as it may be justified to collect traces with low success rates for more serious crimes (Mapes et al., 2016).

5 | A MODEL FOR TRACE DNA UTILITY

There has been considerable research into recovery rates of trace DNA on different exhibit types, to help inform scene of crime officers on which item types typically have high recovery rates and therefore which traces to target for analysis (Castella & Mangin, 2008; Dziak et al., 2018; Harbison et al., 2008; Krosch, 2020; Mapes et al., 2015; Prasad et al., 2021). However, the DNA profile recovery rate of an item type does not equate to the overall utility of an exhibit and its surrounding context, particularly as the recovery rates do not consider how a recovered profile can be used within an investigation and for further intelligence purposes. For example, a profile may be successfully recovered from the clothing of a victim of a sexual assault, however if that profile is attributed as having come from the victim, then the utility of that recovered profile is extremely low. Clothing or worn items typically have high recovery rates (Castella & Mangin, 2008; Dziak et al., 2018; Harbison et al., 2008; Mapes et al., 2015; Wong et al., 2019), which lends them toward being targeted for trace collection and examination, however this may not be yielding the most exploitable results for investigations and for intelligence. The possibility of a notable difference between recovery rates and utility should be a factor considered during trace collection. Ideally, a framework considering both recovery rates and utility should be available to scene of crime officers during trace selection, and later when decisions are being made regarding trace analysis, a fact that has been highlighted in previous research (Bitzer, 2016).

A model of trace DNA utility considering different types of items and crimes could be of use to investigators, allowing them to have the best information regarding trace targeting, collection and analysis. Such a model could consider the recovery rates of item types as well as their utility, to hypothesize the theoretical value that each exhibit type has, which has been presented as "expected utility" previously (Bitzer, 2016; Bitzer et al., 2015). Considerations for such a model could be to group utility type into different categories, for example, profiles that can be used to provide key investigative links between a person of interest (POI), a victim or a crime scene, as well as profiles that can be used to exclude a POI, profiles that can corroborate an alleged narrative, and profiles that provide redundant information, that being information that is already known or assumed such as finding a victim's DNA profile on their own clothing. When trace DNA specimens are collected from a crime scene and then profiled, the traces can provide information for that investigation, as well as more holistically increasing our knowledge on the profile recovery rates of that exhibit type and the likely utility of a link provided by that exhibit type collected at a crime scene of that nature, thereby providing feedback for trace detection and collection in the future. An understanding of exhibit type recovery rates and potential utility, along with the potential utility of the trace to investigators or for intelligence purposes, should be considered alongside the investigation of a case, so the broader potential of each trace can be fully exploited as expressed in Figure 2. The detection of potential trace DNA and its collection at the crime scene leads to, but is also informed by, the information those traces provide.

Categorizing utility of exhibits would allow for comparison across exhibit types, such as clothing and worn items, firearms, and steering wheels, that already have published recovery rates, allowing for comparison of recovery rates to the utility of exhibit types. This would assist scene of crime officers and investigators, as they would be aware of both the probability of recovering a profile from an exhibit type and the likelihood that the profile that is recovered will have high utility.

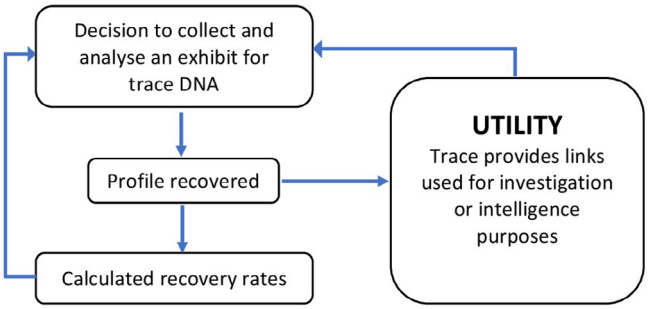

FIGURE 2 Feedback loop of the utility of traces for investigative and intelligence purposes.

In the future, it could be possible to use a quantified threshold of utility as the foundation for such a model, however in the absence of such a calculation, pre-emptive reasoning and recording could be used (Bitzer, 2016). Investigators could pre-emptively record the link they are expecting to gain from a specimen; for example, if they are hoping to link a POI to a scene. Once DNA profiling results have returned, any links gained from a specimen could be compared to those that the investigators were in fact hoping to find. Recording of this nature would allow for analysis of the consistency with which the links investigators are reasonably assuming they will gain from a specimen are actually being found.

Setting a precedent for considering utility as well as recovery rates would have an impact not only on trace collection, but also on the broader trace analysis. Integrating consistent considerations of the utility of a trace would increase the effectiveness of forensic science as a whole, with an expansion of the information gained from traces that can be used for all the purposes of forensic science, that is, intelligence, investigation and court (Bitzer, 2016). Trace collection would also have another layer of reasoning in the field, with scene of crime officers having more information available to them when collecting traces at the scene and when investigators made decisions of which traces to analyze. Further integration of considerations of utility would also likely occur in education programs. Forensic scientists being taught to view the trace as a wealth of information as opposed to a means of identification (a pervasive problem with DNA), will result in an increase in analytical thinking in the next generation of forensic scientists (Morelato et al., 2023). Furthermore, utility of all trace types would be a focus of further research, with the possibility of a decision-making model being created using data from other trace types.

6 | CONCLUSION

This paper discussed the concept of utility when applied to trace DNA. Although the discussion about the utility and the added benefit it can bring to forensic science is largely theoretical at this stage, a number of perspectives should be highlighted. Firstly, though recovery rates can assist in trace selection, a reliance on them may result in the over targeting of exhibit types that may not have high utility. Considerations of the utility of trace DNA as well as reported recovery rates allows for a more holistic view of the value of a trace (Bitzer, 2016). Secondly, research into the utility of trace DNA, as well as other trace types, allows for a more holistic view of the use of traces and can improve outcomes for court, investigations and intelligence purposes. Refocusing on traceology being the bedrock of forensic science as a realignment to the core principles of forensic science, combats against the criticisms of fragmentation across the discipline, and is paramount as forensic science reaffirms itself and its goals. Finally, further research regarding the utility of specific trace types, for example, trace DNA, would assist scene of crime officers in trace selection and decisions to analyze traces, resulting in an increase of the information able to be exploited from trace DNA profiles.

AUTHOR CONTRIBUTIONS

Rachael Hoffmann: Conceptualization (lead); data curation (lead); formal analysis (lead); investigation (equal); visualization (lead); writing – original draft (lead). **Georgina E. Meakin:** Conceptualization (equal); investigation (supporting); supervision (equal); visualization (supporting); writing – review and editing (equal). **Marie Morelato:** Conceptualization (equal); investigation (supporting); supervision (equal); visualization (supporting); writing – review and editing (equal). **Claude Roux:** Conceptualization (equal); investigation (supporting); supervision (equal); visualization (supporting); writing – review and editing (equal).

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Claude Roux is the Editor-in-Chief of the journal and was excluded from the peer-review process and all editorial decisions related to the publication of this article. The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

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

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REFERENCES

Baskin, D., & Sommers, I. (2010). The influence of forensic evidence on the case outcomes of homicide incidents. *Journal of Criminal Justice*, *38*(6), 1141–1149.

Bitzer, S. (2016). *Utility of the Clue. Formalisation of the decision to analyse a trace and insights into the evaluation of the investigative contribution of forensic science*. [Doctoral thesis, Université de Lausanne].

Bitzer, S., Albertini, N., Lock, E., Ribaux, O., & Delémont, O. (2015). Utility of the clue—From assessing the investigative contribution of forensic science to supporting the decision to use traces. *Science & Justice*, *55*(6), 509–513.

Bitzer, S., Margot, P., & Delemont, O. (2017). Is forensic science worth it? *Policing: A Journal of Policy and Practice*, *13*(1), 12–20.

Bitzer, S., Ribaux, O., Albertini, N., & Delémont, O. (2016). To analyse a trace or not? Evaluating the decision-making process in the criminal investigation. *Forensic Science International*, *262*, 1–10.

Brodeur, J.-P., & Shearing, C. (2005). Configuring security and justice. *European Journal of Criminology*, *2*(4), 379–406. https://doi.org/10.1177/1477370805056055

Burrows, J., Tarling, R., Mackie, A., Poole, H., & Hodgson, B. (2005). Forensic science pathfinder project: Evaluating increased forensic activity in two English police forces. *Home Office Online Report*, *46*, 5.

Castella, V., & Mangin, P. (2008). DNA profiling success and relevance of 1739 contact stains from caseworks. *Forensic Science International: Genetics Supplement Series*, *1*(1), 405–407.

Crispino, F., Roux, C., Delémont, O., & Ribaux, O. (2019). Is the (traditional) Galilean science paradigm well suited to forensic science? *Wires Forensic Science*, *1*(6), e1349. https://doi.org/10.1002/wfs2.1349

Crispino, F., Weyermann, C., Delémont, O., Roux, C., & Ribaux, O. (2022). Towards another paradigm for forensic science? *Wires Forensic Science*, *4*(3), e1441. https://doi.org/10.1002/wfs2.1441

Dziak, R., Peneder, A., Buetter, A., & Hageman, C. (2018). Trace DNA sampling success from evidence items commonly encountered in forensic casework. *Journal of Forensic Sciences*, *63*(3), 835–841.

Harbison, S., Fallow, M., & Bushell, D. (2008). An analysis of the success rate of 908 trace DNA samples submitted to the crime sample database unit in New Zealand. *Australian Journal of Forensic Sciences*, *40*(1), 49–53.

Jaquet-Chiffelle, D.-O., & Casey, E. (2021). A formalized model of the trace. *Forensic Science International*, *327*, 110941. https://doi.org/10.1016/j.forsciint.2021.110941

Jeffreys, A. J., Wilson, V., & Thein, S. L. (1985). Hypervariable 'minisatellite' regions in human DNA. *Nature*, *314*(6006), 67–73.

Julian, R., & Kelty, S. (2009). The effectiveness of forensic science in criminal investigations. *Australasian Policing a Journal of Professional Practice and Research*, *1*(2), 10–15. https://doi.org/10.3316/informit.970635406120648

Julian, R., & Kelty, S. F. (2015). Forensic science as "risky business": Identifying key risk factors in the forensic process from crime scene to court. *Journal of Criminological Research, Policy and Practice*, *1*(4), 195–206. https://doi.org/10.1108/JCRPP-09-2015-0044

Julian, R. D., Kelty, S. F., Roux, C., Woodman, P., Robertson, J., Davey, A., Hayes, R., Margot, P., Ross, A., Sibly, H., & White, R. (2011). What is the value of forensic science? An overview of the effectiveness of forensic science in the Australian criminal justice system project. *Australian Journal of Forensic Sciences*, *43*(4), 217–229. https://doi.org/10.1080/00450618.2011.610820

Krosch, M. N. (2020). Variation in forensic DNA profiling success among sampled items and collection methods: A Queensland perspective. *Australian Journal of Forensic Sciences*, *1-14*, 612–625. https://doi.org/10.1080/00450618.2020.1759687

Mapes, A. A., Kloosterman, A. D., & de Poot, C. J. (2015). DNA in the criminal justice system: The DNA success story in perspective. *Journal of Forensic Sciences*, *60*(4), 851–856. https://doi.org/10.1111/1556-4029.12779

Mapes, A. A., Kloosterman, A. D., van Marion, V., & de Poot, C. J. (2016). Knowledge on DNA success rates to optimize the DNA analysis process: From crime scene to laboratory. *Journal of Forensic Sciences*, *61*(4), 1055–1061.

Margot, P. (2011). Forensic science on trial—What is the law of the land? *Australian Journal of Forensic Sciences*, *43*(2–3), 89–103.

Margot, P. (2017). Traceology, the bedrock of forensic science and its associated semantics. In Q. Rossy, D. Décary-Hétu, O. Delémont, & M. Mulone (Eds.), *The Routledge International Handbook of Forensic Intelligence and Criminology* (pp. 33–39). Routledge.

Meakin, G., & Jamieson, A. (2013). DNA transfer: Review and implications for casework. *Forensic Science International: Genetics*, *7*(4), 434–443. https://doi.org/10.1016/j.fsigen.2013.03.013

Morelato, M., Cadola, L., Bérubé, M., Ribaux, O., & Baechler, S. (2023). Forensic intelligence teaching and learning in higher education: An international approach. *Forensic Science International*, *344*, 111575. https://doi.org/10.1016/j.forsciint.2023.111575

NRC. (2009). *Strengthening forensic science in the United States: A path forward*. National Academies Press.

Prasad, E., Atwood, L., van Oorschot, R. A. H., McNevin, D., Barash, M., & Raymond, J. (2021). Trace DNA recovery rates from firearms and ammunition as revealed by casework data. *Australian Journal of Forensic Sciences*, *1-16*, 73–88. https://doi.org/10.1080/00450618.2021.1939783

Raymond, J., van Oorschot, R. A., Walsh, S. J., Gunn, P. R., & Roux, C. P. (2011). How far have we come with trace DNA since 2004? The Australian and New Zealand experience. *Australian Journal of Forensic Sciences*, *43*(4), 231–244.

Ristenbatt, R. R., Hietpas, J., De Forest, P. R., & Margot, P. A. (2022). Traceology, criminalistics, and forensic science. *Journal of Forensic Sciences*, *67*(1), 28–32. https://doi.org/10.1111/1556-4029.14860

Roux, C., Bucht, R., Crispino, F., De Forest, P., Lennard, C., Margot, P., Miranda, M. D., NicDaeid, N., Ribaux, O., Ross, A., & Willis, S. (2022). The Sydney declaration—Revisiting the essence of forensic science through its fundamental principles. *Forensic Science International*, *332*, 111182. https://doi.org/10.1016/j.forsciint.2022.111182

Roux, C., Crispino, F., & Ribaux, O. (2012). From forensics to forensic science. *Current Issues in Criminal Justice*, *24*(1), 7–24.

Roux, C., Talbot-Wright, B., Robertson, J., Crispino, F., & Ribaux, O. (2015). The end of the (forensic science) world as we know it? The example of trace evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1674), 20140260.

van Oorschot, R. A., Ballantyne, K. N., & Mitchell, R. J. (2010). Forensic trace DNA: A review. *Investigative Genetics*, *1*(1), 1–17.

van Oorschot, R. A., & Jones, M. K. (1997). DNA fingerprints from fingerprints. *Nature*, *387*(6635), 767.

van Oorschot, R. A., Szkuta, B., Meakin, G. E., Kokshoorn, B., & Goray, M. (2019). DNA transfer in forensic science: A review. *Forensic Science International: Genetics*, *38*, 140–166.

Walport, M. (2015). Forensic science and beyond: Authenticity, provenance and assurance: Evidence and case studies. The Government Office for Science.

Weyermann, C., & Roux, C. (2021). A different perspective on the forensic science crisis. *Forensic Science International*, *323*, 110779.

Wong, H. Y., Tan, J., Lim, Z. G., Kwok, R., Lim, W., & Syn, C. K.-C. (2019). DNA profiling success rates of commonly submitted crime scene items. *Forensic Science International. Genetics Supplement Series*, *7*(1), 597–599. https://doi.org/10.1016/j.fsigss.2019.10.104

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