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The shifting narrative of uncertainty: a case for the coherent and consistent consideration of uncertainty in forensic science

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ABSTRACT

This review of academic, policy and case law materials identifies current challenges in reaching a coherent understanding of uncertainty in forensic science in terms of articulating a definition, and the types and characteristics of uncertainty. It is identified that there is a shifting narrative characterized by a move from avoiding uncertainty, towards an increasing awareness of its complexity and acceptance of its unavoidable and ineliminable nature at every stage of the forensic science process. Despite this shift, there is still significant progress to be made in order to reach the requisite level of clarity in how uncertainty is understood and conceptualized for the purposes of developing more holistic and effective frameworks for its evaluation and reporting. This review sets out a basis for developing a coherent and consistent understanding of uncertainty in forensic science across institutions and stakeholders.

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Introduction

Uncertainty is inherent to scientific endeavour. In an applied discipline such as forensic science, where theory development must be situated within real-world complexity, rather than exclusively within a pristine laboratory environment, that theory must be able to accommodate greater thresholds of risk and uncertainty. Uncertainty exists in every step of the crime reconstruction process[1,2], from the very trace itself[3–5], to its collection at a crime scene, through to its presentation as intelligence or evidence in court. Uncertainty is therefore always present, particularly due to the inherently uncertain nature of reconstructing past events[6], where there are often gaps in the knowledge and evidence base due to missing data and information[6–8], and the resulting necessity for abductive evidential reasoning[9,10]. For this reason, a forensic science expert is not able to determine with absolute certainty the source of a non-directly individualizing trace material identified at a crime scene[11] to the exclusion of all others, or the activity or offence that generated a trace, pattern or mark.

Even though the prevalence of uncertainty in forensic science is widely acknowledged[2], the narrative constructed around uncertainty and the way it is understood have arguably not kept pace with the developments in other disciplines[12]. Given

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the importance of forensic science evidence in criminal trials[13], it is important that the uncertainties inherent to expert opinions are more fully understood, evaluated, and communicated. However, uncertainty does not necessarily undermine the quality of the evidence or the conclusions of the expert decision-makers, as long as the uncertainty is managed[2,14], or addressed and communicated to the lay decision-makers in a manner that is understandable and transparent[15]. The degree of certainty communicated by experts when providing their findings to a jury has been found to be of significant importance to jurors[16], and it has been argued that the level of certainty provided by experts can enhance the overall understanding of the evidence by jurors[17].

Uncertainty has been recognized as one of the critical issues that can have an impact upon the probative value of the evidence. Unacknowledged uncertainty can potentially lead to the overvaluation of the evidence by jurors[18], whereas its disclosure through appropriate communicative frameworks, can instead assist jurors to evaluate and assign probative weight to specific pieces of forensic science evidence. It has also been argued that the disclosure of uncertainty can also be beneficial for forensic science experts as it can improve best practice[18] by fostering an enhanced environment characterized by reflection, transparency and accountability. The evaluation and communication of uncertainty of science evidence, is therefore, fundamental to achieving a legitimate and fair criminal trial[19].

To communicate the uncertainty associated with forensic science evidence to lay decision-makers, it is important to articulate a clear and coherent conceptualization of uncertainty in forensic science. Without a clear and coherent conceptualization of uncertainty within and across the relevant stakeholder institutions, we cannot identify what exactly needs to be evaluated and hence communicated to lay decision-makers. This article contributes to the efforts of achieving a more consistent understanding of uncertainty in forensic science, by providing an overview of how uncertainty has been articulated and conceptualized by key forensic science stakeholders to date. Perspectives from academia, the courts and policymakers have been synthesized in order to identify three main facets of uncertainty: (i) definition issues, (ii) typological concerns and (iii) characterizations of its nature.

The manuscripts included in this review were selected on the basis of their direct engagement with the topic of uncertainty in forensic science to gain useful insights into how uncertainty in forensic science is conceptually perceived, captured and understood. These were retrieved by using 'uncertainty' and 'forensic science/evidence' as keywords in search for academic and policy documents, while a wider term of 'limitations' was used for case law, due to the limited results yielded from the search of the term 'uncertainty'.

The sample of academic manuscripts, case law and policy reports included in this review were also considered to be valuable examples in reflecting the shift in the narratives deployed by stakeholders with regard to the uncertainty in forensic science. Given the vastness of the topic, the scope of the review was restricted to conceptual understandings of uncertainty, so as to encourage a dialogue that places the emphasis on uncertainty as a holistic, complex phenomenon with nuances that are not always amenable to probabilistic evaluations. As such, discussions around the use of the Bayesian approach and the likelihood ratio, as mechanisms through which to measure uncertainty, were excluded from this study. It is hoped that the insights offered in this paper will allow for the identification, selection, and implementation of valuable practices for effective evaluation and disclosure going forward.

The concept of 'uncertainty' and the way it is understood

Definitions

The consistency and clarity of key terms used in forensic science is a significant concern within the academic community. Inman and Rudin[20], highlight the lack of a single consistent definition for terms such as 'match' and 'consistent with', while Christensen et al.[21] note the multiplicity of ways in which 'error rates' can be defined. It is becoming clear that similar concerns may be raised with regard to the definition of the concept of 'uncertainty' in forensic science.

A definition for the concept of 'uncertainty' in its own right has been elusive, resulting in a largely colloquial understanding of the term. More specifically, uncertainty is usually seen in a sentence followed by a preposition. For example, uncertainty is captured in relation to what it is 'about'[8,22–26], what it is 'regarding'[27], uncertainty 'of' something[9,28,29]or 'as to'[30]. Uncertainty is also used as an adjective to describe an event, knowledge, science or the state of science[30–36]. Definitions are often required to identify the essential attributes of the concept being defined[37]. In forensic science, however, the term 'uncertainty' is often introduced as an attribute, rather than introducing the term by establishing its core elements.

Despite the principally informal understanding of the term 'uncertainty', two potentially useful definitions of this concept in forensic science have been identified. The first from Taroni and Biedermann[25, p.3949, p.3949]

> Human understanding of the past, the present and the future is inevitably incomplete. This implies what is commonly referred to as a state of uncertainty, that is, a situation encountered, by an individual with imperfect knowledge.

A second, more recent, definition from Biedermann and Kotsoglou[38 p.264], is based upon a conceptualization of the term by De Finetti[39] in the field of probabilities and statistics:

> Uncertainty means 'the extent of our knowledge and ignorance' . . . uncertainty relates to an aspect of the real world, although it is not . . . a feature of the world that exists independently of a human observer . . . Uncertainty is all about 'being uncertain about something . . . of the present, past or future.'

Both definitions are tied to what has been termed as the 'problem of uncertainty' – a problem inextricably linked to the reconstruction of past events. However, it is possible to argue that these definitions do not holistically capture the nuanced and complex nature of uncertainty as it arises in every step of the crime reconstruction process.

Nevertheless, these two definitions do identify key components of the term that make a contribution towards demonstrating the essence of the concept of 'uncertainty'; 'incomplete understanding'; 'imperfect knowledge'; and 'extent of knowledge and ignorance', as well as the personally experienced and perceived nature of uncertainty[38]. Moreover, both definitions constitute a significant step towards defining the concept of 'uncertainty' in more explicit terms and shifting the narrative of uncertainty in forensic science towards one that does not rely as much on informal tacit understandings of the concept. They are, therefore, a valuable starting point for conceptualizing, evaluating and communicating uncertainty in forensic science and have the potential to contribute to wider efforts seeking to achieve greater transparency in forensic reporting practices[29,40–42].

Establishing a more holistic definition of uncertainty for forensic science may remain elusive. However, it is clear that there is value in developing the current definitions in a way that assists the integration of uncertainty into the development of forensic science. A more holistic definition that incorporates the nuances necessary for considering uncertainty in forensic science could be adapted from previously articulated definitions of uncertainty as:

> Anything that falls short of determinism[43] (ranging from the available data and evidence base, to the skill and experience of the expert) and which may have an impact on how much, how confidently and what part of the picture is known[44] by the forensic science expert in relation to any stage of the crime reconstruction process.

This adapted definition may also be flexibly modified and applied to the needs of different forensic sub-disciplines, so that it captures the experiences of its distinct experts, while at the same time maintaining a fundamental consistency in the definitional understanding of uncertainty across sub-disciplines.

Confounding of the term: uncertainty and error

The absence of a coherent and consistent understanding of the term ‘uncertainty’ has arguably led to a confounding of the term ‘uncertainty’ with the concept of ‘error’. The lack of a clear distinction between the two terms is not only observed in the field of forensic science but is a common occurrence in the study of other complex systems as well[45]. A prime example in which the boundaries between the two terms, as well as their relationship, were blurred was the seminal report by the National Academy of Science in 2009[29]. Despite numerous calls throughout the report for the development of standardized language to communicate sources of uncertainty[29], the report itself fails to use the term uncertainty in a clear and consistent manner. One section, entitled ‘Uncertainties and Errors’[29, p.116] does not explain the distinction between the two terms but rather focuses on the sources of error and measurement error. Uncertainty is merely mentioned in terms of ‘intervals of uncertainty’[29, p.116], an instrument used to provide a range of numerical values, which can qualify experts’ conclusions in light of potential error sources.

An absence of clarity in the use of these two terms can also be observed in more recent published literature. For example, Kampourakis and McCain[46] suggest that different types of human errors, such as cross-contamination, mislabelling of samples or misinterpretation of results can give rise to uncertainties. They give specific examples of cases where human errors have been committed and go on to conclude that ‘These uncertainties are due to human errors: someone did not take the necessary precautions for avoiding contamination, confusing the samples, or making a bad interpretation of the findings’.[46, p.14]. Even though it is important to acknowledge the possibility of human error or mistake as a source of uncertainty, the way errors have been described in this particular instance indicate a framework of determinism and certainty; knowledge that the necessary precautions had not been taken to avoid contamination, confuse samples or provide 'bad' interpretations. The terms 'error' and 'uncertainty' are further confounded in this instance, as the phenomenon of contamination is presented as something that could be avoided, when in reality it is more akin to an unavoidable form of uncertainty. A better term that could have been used to capture the preventable nature of what Kampourakis and McCain referred to[46] would be pollution. Such a distinction would also ensure that the semiotic boundaries between 'error' and 'uncertainty' can be carefully tread.

The failure to define and separate the terms 'uncertainty' and 'error' does not only obscure semantic clarity and consistency, but it is also an obstacle towards gaining better insights into the relationship of the two concepts. What lies at the heart of the separation of the terms 'uncertainty' and 'error', is the existence or absence of knowledge. Unlike 'uncertainty', which has been described as 'imperfect knowledge'[25,47]or the absence of determinism[44], 'error' is understood as inaccuracy that can be known or identified upon examination[45]. If such inaccuracy – error – is indeed known, as in the examples above, or identified upon examination, then uncertainty could not possibly exist, given that two 'essential attributes' of the definition of 'uncertainty', as identified by Taroni & Biedermann[25] in their definition are 'incomplete understanding' or 'imperfect knowledge'.

It is important to also clarify that the directional relationship between 'errors' and 'uncertainty' is not such that the former gives rise to the latter in all circumstances. In the field of medicine it has been recognized that uncertainty, particularly when it is mismanaged, may be an important contributing factor towards the commission of errors in the decision-making or final conclusions of experts[48,49]. This may indeed be the case in instances of misinterpretation as discussed by Kampourakis and McCain[46]. So instead of just emphasizing that the potential of misinterpretation can give rise to uncertainty regarding the reliability of the conclusions of experts, the reverse may also be true. Uncertainties, such as in the available data or knowledge base, may have been the source of misinterpretation or 'human error' in the first place.

Seeking a segregation of the terms 'uncertainty' and 'error' is even more important in the field of forensic science, where the articulation of 'error' is especially elusive due to the difficulty of establishing a ground truth[1,50]. Furthermore, vague and inconsistent definitions can lead to the 'misuse and misunderstanding' of the terms[51] within different institutional organizations and between them. It may also interfere with the establishment of clear criteria and standards in the identification, management, evaluation and communication of 'uncertainty', which is distinct from the solution and rectification-oriented approaches often adopted as a response to 'errors'. As such, it is crucial that the stakeholders engaging with forensic science evidence work together in identifying or developing a clear definition that captures their different perspectives and which is sufficiently separate from similar terms and phenomena. Such a clear definition has the potential to ensure consistency in understanding, and avoiding the miscommunication between stakeholders, and even provide the basis upon which the most appropriate strategies for uncertainty management can be constructed.

Eliciting the concept of 'uncertainty'

Types or sources of uncertainty

Identifying the different facets of uncertainty is as important as maintaining a consistent definition across different institutions and organizations. The discussion of uncertainty in forensic science presented here is structured around three of the stages of the forensic science process developed by Morgan[6] and draws on the published academic literature that has identified different types and sources of uncertainty relating to forensic science evidence. As such, the materials discussed here are those that directly refer to uncertainty or make direct or explicit links with the concept of uncertainty. Therefore, even though research areas, such as the consideration of evidence dynamics or decision-making, have been very well documented and have implicitly highlighted sources and characteristics of uncertainty, this review only includes those materials that explicitly identify different types and sources of uncertainty.

The terms 'types' and 'sources' are used interchangeably where appropriate, given the absence of a coherent framework of conceptualizing uncertainty in forensic science, that distinguishes between the two terms.

Crime scene

The scene of a crime can be a source of a multitude of uncertainties, including the trace itself, as well as the selection and use of different techniques and their capabilities to detect traces at the scene[52–56]. Yet, a particularly prominent area of explicit discussion with regard to the uncertainties arising at a crime scene is that which is commonly known as 'evidence dynamics'[9,57,58]. The term 'Evidence dynamics', or 'Trace Dynamics' as it is more commonly referred to in recent published literature, refers to those conditions that exist prior to and at the crime scene that may alter the state of or obliterate forensic science materials – traces – that may be relevant to the crime reconstruction process[57]. The complex and changing nature of the crime scene environment, as well as the unpredictable behaviour of first responders upon their arrival at the crime scene, may lead to the change, degradation or possibly contamination of the trace. Such modifications of forensic science materials can give rise to uncertainties in the practices employed by forensic science experts in subsequent analysis[25], as well as their final findings and conclusions[57,59].

Traces found at a crime scene constitute inherently incomplete and imperfect fragments or remnants of an event[4,34]. This inherently fragmented nature of the trace[60,61] as well as its variable quality[2] – contributed to or exacerbated by factors such as the crime scene environment, the detection and collection practices of forensic science materials – can give rise to what is often referred to as 'data uncertainties'. Such uncertainties can also create challenges during subsequent stages of the crime reconstruction process. One such stage, is the stage of evaluation[62], as traces are the fundamental medium for the provision of data and information upon which the decision-making processes of forensic science experts are based. The courts have also indirectly recognized the challenges and limitations that may arise as a result of the uncertainties in the data relied upon by the expert providing opinion evidence[63,64].

Laboratory analysis

Once the forensic science materials have been collected and recorded, these materials are then analysed and evaluated. Sampling uncertainty is a prominent type of uncertainty affecting the analysis and evaluation of forensic science materials. The academic literature has recognized the importance of sampling uncertainty in explicit[65,66]or implicit terms[42]. This type of uncertainty often arises due to the databases (reference sample) that have been constructed to inform the analysis and comparison of traces, marks or patterns retrieved from a crime scene. Given that reference samples cannot capture every single feature of the entire population in question, they are inherently lacking information[66]. More specific concerns have included, the representativeness of footwear sole pattern databases[42]and the impact of sampling upon the uncertainty in the computation of a likelihood ratio for forensic voice comparison[67].

The majority of scientific endeavours rely on the assessment of a sample of a larger entity, yet this practice necessarily makes the findings probabilistic in nature, and introduces uncertainty[66]. As such, providing information on the representativeness of a sample has been outlined as a crucial factor for the validation of measurement-based methods – as opposed to interpretive methods – in the UK[68]. Even though the new draft Statutory Code by the Forensic Science Regulator in the UK suggests that the ability of the sampling process to provide a representative sample shall be considered in the validation of measurement-based methods[68], the reporting of any related uncertainties is not required with regard to forensic science reports or testimonies[69].

The analysis and evaluation of forensic materials, as well as their interpretation in relation to source, activity or offence-level questions, are also heavily depended upon what knowledge is available. Uncertainties relating to knowledge have been by expressed in the academic published literature over the past decade[42,60,70], yet the precise meaning of 'uncertain knowledge', has not been fully articulated, reinforcing perhaps concerns around a colloquial understanding of the term of 'uncertainty'. For example, Kruse[42] concludes that knowledge is limited as a result of the changing nature of data that make up the available databases for footwear sole patterns. Uncertain knowledge is therefore indicative of a state of unawareness or not being in possession of all or the required information[42]. A perhaps broader understanding of knowledge is captured by Mnookin[70] who raises concerns regarding valid forms of knowledge in different forensic sub-disciplines, as a result of absent formalized and standardized methodological procedures, among other factors. Mnookin's understanding of uncertain knowledge may thus be a recognition of the existence of uncertainty within the 'evidence base' underpinning the decision-making of forensic science experts[6] as well as in relation to 'explicit' forms of knowledge, as generated or encoded by the relevant institutions and organizations[7].

The continuum of 'tacit and explicit knowledge' as developed and applied by Morgan[7] to the crime reconstruction process, is particularly useful in locating further uncertainties identified in the literature. For example, the practices adopted by forensic science experts have been a recognized source of uncertainties[22,42]. Uncertainties may exist in the practices that involve greater elements of human subjective decision-making and evaluative interpretation – such as fingerprint examination – in which a blend of tacit and explicit knowledge is generated[42,71]. Uncertainties have also been noted that relate to the precision or accuracy of techniques employed or the instruments used, such as mass spectrometry or DNA analysis[22], which incorporate more 'explicit' forms of knowledge[9]. Such uncertainties are often also referred to as measurement uncertainties.

Measurement and modelling uncertainties are widely recognized by academics and policy makers[68,72,73]. Forensic science experts in the UK are encouraged to include, where relevant, in their report or statement an assessment of what is referred to as 'uncertainty of measurement' which relates to any uncertainty that may exist within the results of an analysis. Uncertainty of measurement can be related to the methods used by the forensic science expert, as well as to any equipment calibration issues[69]. With regard to interpretive or evaluative sub-disciplines, the Forensic Science Regulator also requires an evaluation of measurement uncertainty to be carried out[68]. The Code of Practice goes on to recognize that even though the method through which such an assessment is conducted may differ from measurement-based techniques, uncertainties associated with testing conditions in qualitative-based techniques should nevertheless be subject to evaluation, which could take the form of false-positive or false-negative test results rates[68].

Model uncertainties have also been identified in the published literature even though they have not been as prominent a topic of interest in policy reports, in comparison to measurement uncertainty. Uncertainties in models may be the result of the selection of models, as models are never correct but some are more useful than others[74], hence rendering it unfeasible to select with absolute certainty one model as a better fit over others in converting the available data into probabilities[73]. Uncertainties have also been recognized in terms of the parameters that inform the models[72]. An example is the observation of a particular feature in a population of interest, and the uncertainty arising due to the existence of an incomplete, absent, or inappropriate dataset[72].

Evidence interpretation

More recently, significant attention has been focussed on the inevitability of uncertainty in the judgement and inferences of human decision-makers. Uncertainty has been identified as being present in the decision-making of forensic science experts throughout the crime reconstruction process[1,2,9,75]with the contributing factors being well documented[76]. One key potential factor is the gaps in the knowledge base or evidence base and the resulting necessity for abductive evidential reasoning[47]. Intrinsic and extrinsic factors influencing the decision-making of experts and giving rise to uncertainty have also been noted[75]. Extrinsic factors include the environmental factors that affect the context within which a decision is made, which can lead to the introduction of uncertainty to the decision-making and final findings of experts[9,29,77,78]. Intrinsic factors are also significant. For example, in the judgement of the Court of Appeal in the case of R. v Thomas (B)[79], it was emphasized that expert reports should disclose any relevant information about the expert's experience and expertise, as well as any associated limitations that may have an impact upon the opinion provided to the court. In the academic literature, expertise has increasingly been identified as a prominent issue in giving rise to uncertainty[9]. Decision-making by human actors occurs at every stage of the

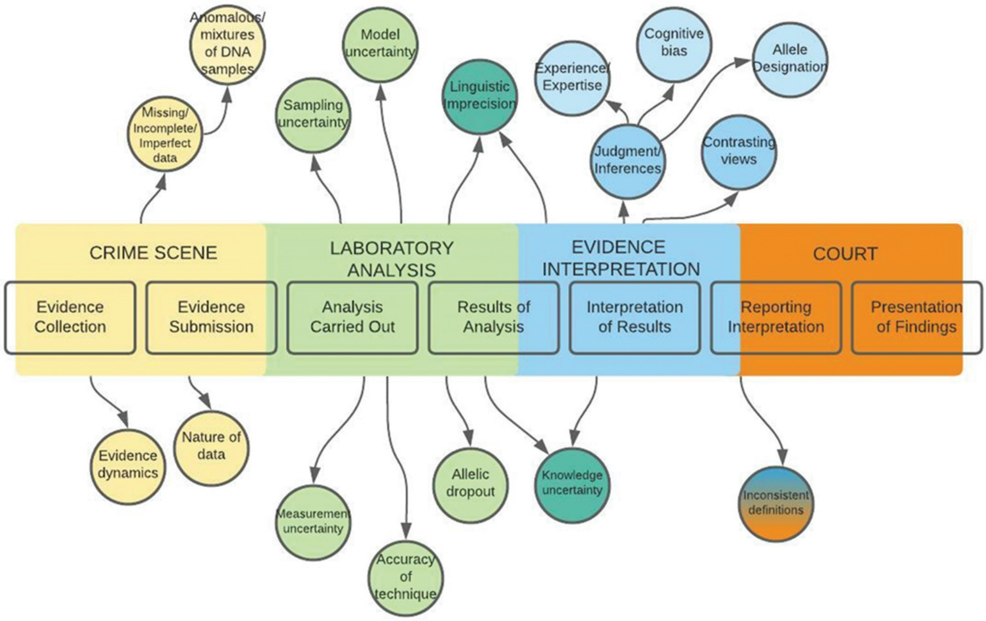

Figure 1. Uncertainty types mapped on forensic science process developed by Morgan et al. (2018).

forensic science process (Figure 1), and as expertise (which incorporates many factors including experience and training) results from both 'tacit' and 'explicit' forms of knowledge[3] uncertainty becomes an integral part of crime reconstruction endeavours.

The uncertainty associated with the judgement and conclusions reached by forensic science experts can also be observed in the variations of forensic science experts' conclusions[61,78]. In the guidance provided by the Court of Appeal in R. v Thomas (B)[79] regarding issues to be included in expert reports, the range of expert opinions that may exist was also listed as an additional factor for inclusion. In so doing, the Court's judgement may have implicitly acknowledged the range of expert views as a source of uncertainty that needs to be disclosed.

Identified types/sources: wider implications

Figure 1 provides a visual representation of the sources of uncertainty as they relate to three stages of the forensic science process[1] identified in this review. The stages in the forensic science process are sequential but are also iterative and highly connected. In a similar fashion, even though the types of uncertainty have been mapped to the stage they primarily relate to, they will also impact other stages of the forensic science process. This is because some sources of uncertainty may arise in one stage but have an impact on a subsequent stage(s). For example, incomplete, missing or imperfect data, such as anomalous or mixtures of DNA samples, can have an impact upon the subsequent stages of analysis and interpretation[80,81]or may exist across multiple stages (i.e. tacit forms of knowledge may impact decisions made about which analysis or analyses are carried out, or on decisions leading to the generation of an evaluative opinion of the significance of the analysis).

Uncertainty is therefore present in every stage of the crime reconstruction process[1,2]. This review of the published academic literature, policy documents and case transcripts has identified the most prominent sources or types of uncertainty. In order to remain reflexive, these sources have been grouped and discussed together according to the terms and definitions used by the original authors.

This is by no means an exhaustive list of all the specific sources of uncertainty that may have been documented across academic, policy and legal work, and a range of other sources exists. Yet, this review seeks to draw attention to the multiple sources or types of uncertainty that have been documented in the published literature, so as to highlight the shifting narrative of how uncertainty has been understood in the field of forensic science. In the last decade there have been increased efforts, especially by the academic community[2], to develop an understanding and conceptualization of uncertainty in terms of its sources and types. Given the large number of sources and types of uncertainty that have been identified, a more coherent and systematic organization of the nature of uncertainty is clearly necessary in order to for uncertainty to be more transparently and robustly managed in crime reconstructions.

Characteristics of uncertainty

During the last decade there has been an increasing awareness of the different characteristics and forms of uncertainty, and the implications for managing uncertainty, whether that is in the form of efforts to reduce, acknowledge, evaluate and/or communicate it. One of the most famous descriptions of the nature of uncertainty in forensic science is the triptych of uncertainty popularized by Donald Rumsfeld, the U.S. Defence Secretary in 2006; that of known knowns, known unknowns and unknown unknowns[82]. According to this triptych, which has been incorporated into academic and policy reform work[9,75,83], there are things that we are aware of knowing, things that we are aware of not knowing, but also things that we are unaware of not knowing. However, Rumsfeld's triptych has been described as the 'simplest' attempt to structuring uncertainty[84] despite the existence of a range of taxonomies of uncertainty that have been developed across a number of other disciplines, such as environmental science[85].

There is therefore value in exploring the narratives that have been adopted by other allied disciplines[12] in seeking to establish a framework that incorporates an understanding of the complexity of the forensic science ecosystem, the necessary risk thresholds that must be incorporated into the scientific process that can be useful within the justice system, and to set out within that framework the nature of uncertainties in forensic science. To achieve this, cooperation between different institutions and stakeholders within forensic science will be critical to develop a framework that reflects and accommodates the competing needs, values, priorities and strategies for forensic science of the different stakeholders.

One aspect of uncertainty that has been widely addressed to date is its inherent nature in science[1,9,25,46,75,86]as well as whether it is reducible or irreducible[9,67,75]. But perhaps the biggest shift in the narrative deployed by forensic science with regard to characterizing uncertainty is in addressing the quantifiable or unquantifiable nature of uncertainty. Until recently, the most popular response to evaluating uncertainty in forensic science has been that of quantification, supported to a great extent by a number of academics and policymakers[29,87]. The measurement of uncertainty was a significant topic of discussion in the National Academy of Science's seminal report[29], while reports and guidance documents of the Forensic Science Regulator have regularly highlighted it[67,88]. In 2011, a number of academics became signatories to a statement that hailed probability theory as 'the only coherent logical foundation' for 'reasoning in the face of uncertainty'[87, p.11]. Similar positions were expressed by the ENFSI[22], the Royal Statistical Society[31,32,36,81]and more recently by Taroni and Biedermann[25] who heralded the use of probabilities, and specifically the application of Bayes theorem, in attempts to discriminate between events or causes, as a staple of science.

This position is indicative of a widely held position that uncertainty should be subject to quantification and measurement. However, this insistence on quantifying and measuring uncertainty indicates a narrative that is unable to incorporate uncertainty that is inherently unquantifiable by nature (i.e. uncertainties arising from the evidence base, or uncertainty as a result of the potential impact of extrinsic factors on the decision-making of forensic science experts). It also runs counter to some definitions of uncertainty that draw a distinction between risk (which is quantifiable) and uncertainty (which is often unquantifiable)[89].

There are signs that this narrative is shifting, with calls being made to address uncertainty in a more holistic manner[2,12,13], so as to capture those uncertainties that may not be amenable to quantification[1,9]. An implicit recognition of the need to adopt qualitative evaluative approaches – that can complement quantitative evaluative instruments – to uncertainty can perhaps be traced to the Law Commission's Report in 2011[83], where it was suggested that the presentation of evidence by forensic science experts should be qualified to 'reflect the uncertainties and gaps in the scientific knowledge'[83, p.129]. More recently, explicit acknowledgements of the need for a more holistic framework have been expressed by academics, such as Martire et al.[78] who question whether the Bayesian subjective probabilities assigned by forensic science experts can capture uncertainty in its entirety. Similarly, Morgan et al.[1], highlighted the need for a holistic evaluative framework of uncertainty, that goes beyond an insistence on quantification, to reflect the decision-making element of the scientific endeavour that plays a central role in crime reconstruction activities, while very recently Roux et al.[2] have been discussing uncertainty in forensic science in terms of a 'continuum'. Interestingly, the UK Forensic Science Regulator recommends that uncertainty should be 'measured' in interpretive based techniques but suggests that this can be done in a similar manner to the quantification of uncertainty in laboratory-based techniques, without providing more concrete advice on how to achieve this, beyond the provision of false-positive and false-negative test result rates[68]. Most recently there have been studies that suggest the value and utilization of qualitative and semi-qualitative tools to communicate the degree of uncertainty in the evaluative interpretation of both digital materials[40] and physical traces[12], even though criticisms have been expressed with regard to the former[38].

Conclusion

It is clear that forensic science faces challenges when it comes to communicating uncertainty and incorporating it into evaluative interpretations in crime reconstructions. This review has identified that these challenges stem, to an extent, from the absence of a holistic definition of uncertainty, as well as from the lack of a systematic and organized collection of the different types and characterization of the nature of uncertainty.

The inherently fragmented, incomplete and thus uncertain nature of the trace itself, may be the root of the conceptual difficulties faced by forensic science, and may indeed place limits on how effective attempts at defining and systematically identifying and collecting the characteristics of a trace may be. Nevertheless, the conceptual narrative of uncertainty in forensic science appears to be shifting, particularly with more detailed identifications of sources or types of uncertainty being observed in academic and policy discussions. Heightened awareness and recognition that some of these sources or types of uncertainty may not always be amenable to quantification and evaluation through the use of probabilities, has also been evident more recently.

The gradual acceptance and open acknowledgement of uncertainty in forensic science can arguably be considered to be the beginning of a transition from the ideals of modernity, with its insistence on apparent certainty and order[90], towards postmodernity, and its capacity to holistically embrace uncertainty[91]. This new era of uncertainty is one in which the perception of forensic science evidence as either reliable or unreliable is abandoned, and instead a new paradigm is established, one which focuses on whether the uncertainty of the evidence is 'correctly or incorrectly harnessed'[92, p.775]. A shift away from apparent certainty can be highly beneficial for the interactions between forensic science experts and the courts, as it can foster a climate of open and transparent communication between lay legal actors and expert witnesses, whereby experts are no longer expected to provide their opinions and conclusions in absolute and definitive terms. Moreover, deference to the expertise of the latter is discouraged, while education and informed decision-making of the former is placed at the forefront of trial proceedings.

Substantial progress has been achieved in dismantling fallacious notions of certainty in forensic science evidence and dualities that no longer serve – and arguably never have served – the providers or recipients of forensic science. However, there is still a long way to go in achieving a coherent understanding of what exactly is meant when the term 'uncertainty' is used in forensic science, as well as where these uncertainties can be found and how they arise. In order to achieve clarity and agreement of definitions and typologies of uncertainty, a considerable move is needed to embed ongoing conversations, and exchange of opinions, experiences and ideas among all forensic science stakeholders. This will bring us a step closer to openly acknowledging the complex and 'messy' nature of uncertainty in forensic science that transgresses disciplinary and institutional boundaries, and assist in incorporating it transparently and robustly into the scientific endeavour of crime reconstruction.

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