Uncertainty in Forensic Science: Conceptualisation, Evaluation and Communication

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I, Nicola Georgiou, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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‘Σα βγεις στον πηγαιμό για την Ιθάκη,
να εύχεσαι να 'ναι μακρύς ο δρόμος,
γεμάτος περιπέτειες, γεμάτος γνώσεις.
Τους Λαιστρυγόνας και τους Κύκλωπας,
τον θυμωμένο Ποσειδώνα μη φοβάσαι,
τέτοια στον δρόμο σου ποτέ σου δεν θα βρεις,
αν μέν' η σκέψις σου υψηλή, αν εκλεκτή
συγκίνησις το πνεύμα και το σώμα σου αγγίζει.’

‘As you set out for Ithaka
hope the voyage is a long one,
full of adventure, full of discovery.
Laistrygonians and Cyclops,
angry Poseidon—don’t be afraid of them:
you’ll never find things like that on your way
as long as you keep your thoughts raised high,
as long as a rare excitement
stirs your spirit and your body.’

– C.P. Cavafy, ‘Ithaka’, 1975

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Abstract

This thesis addresses how uncertainty in forensic science can be conceptualised, evaluated, and communicated to lay stakeholders. Traditionally uncertainty has been articulated with vague definitions, while typologies of uncertainty have not been systematically and clearly established. The evaluation of uncertainty has largely been restricted within the confines of the Bayesian theorem and the methods and means of communicating uncertainty have yet to be agreed by the academic community and the criminal justice sector. The first study of the thesis reviews the current narrative within forensic science with regards to the conceptualisation of uncertainty, through an exploration of the definitions, typologies and characteristics recognised and used by academics, policymakers and the courts. An interdisciplinary configurative review was then conducted into three allied neighbouring disciplines of medicine, environmental science and economics, to identify innovative ways to conceptualise, evaluate and communicate uncertainty to lay stakeholders in forensic science. As a result, three toolkits were developed, one each for the three facets of addressing scientific uncertainty. A third study was then carried out, to establish the sources of uncertainty that key stakeholders identified to be priorities for evaluation and communication for the application of science to the justice system. This study thereby tested that the findings from the interdisciplinary systematic review reflected the experiences of stakeholders, and in so doing provided a foundation for optimising the value of the three toolkits. The wider implications of dealing with uncertainty in forensic science in a more consistent, coherent and standardised fashion are then considered with a focus on both the discipline itself, and for different stakeholders within the criminal justice system.

There is a clear need to recognise uncertainty as a salient issue in every stage of the forensic science process, and particularly so in the presentation of forensic science evidence in court. The body of work presented here offers a starting point for the development of a more coherent and consistent understanding of scientific uncertainty in forensic science, while also encouraging fruitful conversations regarding ways through which it can be evaluated and communicated to lay stakeholders. This research identifies the key aspects of considering uncertainty as a fundamental and integrated part of forensic science by identifying the nuances, complexities and limitations of forensic science evidence in the context of the delivery and application of science in a multiple stakeholder justice system.

Impact Statement

This thesis has both practical and theoretical implications, with its findings having potential beneficial use in academia and in practice. One of the most important theoretical implications of the studies making up this thesis, is the initiation of a fruitful dialogue on the topic of scientific uncertainty in forensic science. New pathways for thinking about and discussing uncertainty in forensic science are opened up, through an exploration of practices found in 'neighbouring' disciplines with forensic science. An exchange of ideas between forensic science and its 'neighbouring' disciplines takes place in one of the primary studies of this thesis, with the purpose of achieving greater consistency and standardisation in the way uncertainty in forensic science is considered, understood, and communicated. This thesis also examines the wider theoretical implications of enhancing current awareness regarding the topic of uncertainty in forensic science. It supports that uncertainty is a vital mechanism in reversing power inequalities already in existence within the criminal justice system, as well as in redefining and reinforcing the identity of forensic science as an independent interdisciplinary discipline.

Three toolkits are also developed in one of the studies in this thesis, one each for the conceptualisation, evaluation, and communication of uncertainty in forensic science. These three toolkits are the most important practical contribution of this thesis. The toolkits can provide a wealth of resources for the selection of the most appropriate instruments to assess and communicate uncertainty in forensic science. They can also be of use to forensic science experts and juridical stakeholders with an interest in gaining a more nuanced understanding regarding the uncertainties and limitations of forensic science. Stakeholders were also engaged and encouraged to actively participate in the production of research in this thesis. The practical implications of such engagement are evident in the refinement and validation of the three toolkits. Stakeholder participation has further practical implications, by ensuring that the development of targeted frameworks for evaluation and communication of uncertainty accounts for the needs and experiences of all stakeholders, thus rendering them operable and user-friendly.

Table of Contents

List of Figures

List of Tables

1. Introduction

'An experience in matters of philosophical discovery, teaches us that, in such discovery, it is the unforeseen upon which we must calculate most largely.'

– Edgar Allan Poe, 'The Daguerréotype', 1840

'And how will you enquire, Socrates, into that which you do not know?'

– Plato, 'Meno', 429-347 B.C.

'Both the man of science and the man of action live always at the edge of mystery, surrounded by it.'

– Oppenheimer, 1955

The uncertainty that arises from the unknown and unforeseen has been the subject matter of numerous writings, philosophical discussions and debates; from Plato in Ancient Greece to Edgar Allan Poe in 19th century Baltimore. Despite the prominence of uncertainty in philosophical debates, it was not until the 20th century that the realm of science became more comfortable with the notion of uncertainty (Peat, 2002). Uncertainty was no longer considered unscientific (Klir, 1997), or contradictory to the values and aims of science.

The understanding of uncertainty in science has evolved rapidly over the past decades. Pursuits of certainty in scientific knowledge are acknowledged as illusory (Appleyard, 2007; Litre, 2014; Sheldon, 1930), while the 'man of science' is described as living at the 'edge of mystery'. In one of his essays, delivered at an international symposium, Oppenheimer (1955) recognised the 20th century as an era of growth in knowledge and skill, defined by the dispersal of authority. He noted that the man of science is surrounded by mystery, only capable of imposing partial order in the complete disorder and chaos of the universe. The power and wisdom of the 20th century man, therefore, rested in accepting the vastness of knowledge and perspectives, while recognising his personal limitations and shying away from justifying or sanctifying his ignorance. As alluded to by Oppenheimer, uncertainty was no longer to be regarded as an anathema to science, but rather an inevitability of the state of the world.

Uncertainty in science has also come to be perceived as a gateway to enhanced creativity and novelty (Rubino, 2000), combatting the narrowing of perspective that may result from convictions of certainty (Oppenheimer, 1955; Rubino, 2000). Modern philosophers welcome uncertainty as a beneficial force of change towards the dissolution of the prestige, authority and power that is often endowed to those claiming to be in possession of certainty (Rubino, 2000). Claims of scientific certainty can often lead to the reinforcement of dangerous forms of repressive power used against those who are perceived as not in possession of it – such as the hegemony of Western culture and science, over the rest of the world (Rubino, 2000).

Instead, acceptance of uncertainty and willingness to adjust and ethically operate within it, can act as a preventive force to the formation of precarious power dynamics (Rubino, 2000). Acknowledging and accepting uncertainty can further foster an environment in which public ethics of care are allowed to flourish (Rubino, 2000). In such an environment, interdependence between different actors and stakeholders is recognised and actively encouraged (Stensöta, 2015). Interdependence and co-operation between stakeholders play a significant role in meeting the aims of a number of modern, issue-driven scientific disciplines, in which the boundaries between public policy and science are blurred (Silvio Funtowicz & Ravetz, 1994). Furthermore, an environment in which uncertainty is accepted and interdependence is promoted, would constitute a significant step towards realising the hopes of Oppenheimer (1955); that the man of science and the of man of action 'can, in their work and in their lives, help themselves, help one another, and help all men.'

1.1 Forensic Science, Reliability & Uncertainty

The growing awareness of the inevitability of uncertainty in science (Silvio Funtowicz & Ravetz, 1994; Klir, 1997) arose shortly before an enhanced interest in the reliability of forensic science was expressed; a topic not too disconnected from that of uncertainty. During the end of the 20^{th} century and the beginning of the 21^{st}, a number of wrongful convictions in which forensic science evidence played a critical role came to light (Broeders, 2006). At the same time, DNA was recognised as an invaluable exoneration tool and even hailed as the gold standard of forensic identification (Saks & Koehler, 2005). As a result, academics and professional organisations started questioning the reliability of traditional types of forensic science evidence. Criticisms focused on the failure of traditional forensic identification sub-disciplines to develop sufficient empirical groundings to support their decisions and final conclusions (Murphy, 2007; Saks & Koehler, 2008; Saks & Koehler, 2005). In a seminal report, the National Academy of Sciences (NAS) (National Research Council, 2009) expressed its concerns regarding the validity of the methods used by the traditional identification sub-disciplines and concluded that, with the exception of DNA evidence, none of the other methods were in a position to make claims of individualisation. The report also recognised the absence of empirical research, published studies and peer review, as some of the most important limitations of traditional identification sub-disciplines. The report insisted on a framework which prioritises the recognition and disclosure of the strengths and weakness of each discipline, accompanied by measurements of uncertainty.

The limitations highlighted by the critics of traditional forensic subdisciplines are often linked to the perceived nature of forensic science as an ‘artistic and intuitive’ approach (Inman & Rudin, 2001, p.12). Even though a number of empirical studies have been carried out in relation to the transfer and persistence of traces and patterns (Lepot & Vanden Driessche, 2015; Morgan et al., 2018; Raymond et al., 2008) – which constitute an important evidence base to guide expert decision-making and interpretation – forensic case reconstruction, is rarely a matter of simple application of explicit codified knowledge (Gauriot et al., 2013; Inman & Rudin, 2001; Morgan, 2017a; Roux et al., 2015). This is due to the variability that exists with regards to the specific details of even seemingly similar cases, as well as due to the multitude of uncertainty sources. Uncertainty is an unavoidable feature of every scientific endeavour, yet it is particularly prominent in disciplines such as forensic science, which involve inquiries into past events, sometimes under non-laboratory conditions.

Uncertainties arise at every stage of the crime reconstruction process (Morgan et al., 2018); in the environment in which traces and patterns are identified, collected and stored, and the decision-making of experts when carrying out analyses, evaluations and interpretations. Fundamentally, uncertainties begin from the trace itself, fragmented and imperfect, generated from a usually non-reproducible and uncontrolled event (Margot, 2011; Margot, 2017). Uncertainty, also, permeates the stage of the collection of the evidence at the crime scene, primarily as a result of the evidence dynamics which may affect the state of the trace or pattern (Chisum & Turvey, 2011), as well as due to the judgment that is involved in identifying, collecting and preserving the trace or pattern. Uncertainty may also exist due to the unknown conditions in the laboratory that may result in contamination of the evidence (Kruger, 2012). Expert decision-making and interpretation are also restricted and hence uncertain, due to the limited information that is often available to the forensic science expert, regarding the context in which the particular trace or pattern was left (Taroni & Biedermann, 2015), as well as due to the reasoning process involved in the crime reconstruction process – that of abductive reasoning – involving the identification of possible causes from the observed effects (Roux et al., 2015). This form of reasoning, which differs significantly to the one that takes place in classical experimental science, is immersed in uncertainties as there are usually several competing hypotheses or retrodictive models that seek to provide an explanation for the crime scenario that resulted in the identified trace (Cleland, 2002; Margot, 2017). It is, thus, up to the forensic science expert to determine which hypothesis is superior in its explanation of the causes of the observable effects. Uncertainty regarding the decision-making of experts – the term ‘forensic science expert’ or ‘expert’ being used to denote their role as expert witnesses as determined by the Courts – is further exacerbated by the possibility of cognitive bias, which may distort the expert’s perception during the stages of analysis, evaluation and interpretation (Dror, 2018; Dror & Hampikian, 2011; van den Eeden et al., 2019).

Despite the existence of uncertainty in every stage of the crime reconstruction process, the role of forensic science experts has paradoxically been described as that of reducing the uncertainty contained within the inferential reasoning of the police, judges, lawyers and jurors (Jackson et al., 2015). Yet, for the conclusions of experts to be truly informative, they need to be of a quality that is reflective of the quality of the underlying evidence (Jackson et al., 2015). Thus, the unavoidable uncertainty found at every stage of the crime reconstruction process does not necessarily undermine the quality of the evidence or the conclusions of the experts, as long as such uncertainty is managed (Funtowicz & Ravetz, 1994), or addressed and communicated transparently to the lay stakeholders (Almazrouei et al., 2019; Smith & Stern, 2011). Providing relevant stakeholders with all the necessary information, including the uncertainties upon which their inferential decision-making and conclusions have been based, can strengthen the soundness of those conclusions (Hume, 1748; Jackson et al., 2015) and ensure the reliability of their evidence and testimonies (Koehler, 2008).

Greater transparency regarding the uncertainties that are encountered in the forensic science process, can also create an environment of heightened exchange of information and interdependence. As such, the 'man of science' – forensic science experts – and the 'man of action' – judges, jurors and lawyers – can help each other. The environment of interdependence nurtured through the recognition and communication of uncertainty can reverse the imbalance of power that may exist between expert and lay stakeholders and address many concerns that have been raised regarding the role played by judges, lawyers and jurors. These concerns have particularly been expressed with regards to the failure of judges and lawyers to act as effective gatekeepers to expert witness evidence (Edmond, 2015a; National Research Council, 2009; Roberts, 2013) and jurors deferring to the opinions of experts (Law Commission, 2011).

1.2 Unexplored Areas – Uncertainty outside the discipline of Forensic Science

Over the years, a number of definitions and typologies have been developed to capture and conceptualise uncertainty by academics, in spheres beyond that of forensic science (Lipshitz & Strauss, 1997; Morgan et al., 1990). The definitions and typologies frequently discussed in the literature of uncertainty, are hardly reflected in the discussions of uncertainty in forensic science. Uncertainty has been discussed in terms of being a corollary of the examination of past events (Jackson et al., 2006; Taroni & Biedermann, 2015) and a distinction was briefly made by Taroni & Biedermann between uncertainty and variability (2015). In the field of uncertainty and risk, Krupnick et al. (2006) distinguished between five types of uncertainty and Smithson distilled 16 different types of ignorance (1989).

In light of the absence of a definition in the context of forensic science and the need for a working definition for the purposes of this thesis, the definition introduced in the briefing of Sense about Science (2013) is adjusted to the context of forensic science. As such, in this thesis uncertainty refers to anything that falls short of determinism (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 by the forensic expert decision-maker in relation to any stage of the crime reconstruction process (Sense about Science, 2013; Walker et al., 2003).

The absence of compatible developments between forensic science and the general body of knowledge addressing uncertainty, is not only evident in the conceptualisation of the term, but also in its evaluation. In both spheres, probabilities play a dominant role. Klir (1997) noted that the evaluation of uncertainty generally took place largely within the confines of probabilities until the end of the first half of the 20th century. In forensic science, the value of probabilities was reiterated by a large number of academics who became signatories to a position statement in 2011 declaring probability theory as 'the only coherent logical foundation' for 'reasoning in the face of uncertainty' (Berger et al., 2011, p.11). From a purely philosophical standpoint, the very attempt to assign a numerical value on that which is not known is paradoxical. Plato's question in Meno as to how one goes about enquiring into that which is unknown therefore becomes highly salient. The complexity and multi-faceted nature of uncertainty cannot be reduced into a numerical formula (Flage et al., 2014), and discussions outside the discipline of forensic science eventually recognised this. Frameworks of evaluating uncertainty started embracing more qualitative elements (Spiegelhalter & Riesch, 2011; van der Sluijs, Craye, et al., 2005), while academics emphasised the need for more holistic structures that embrace all the relevant concepts, theories, and combine both qualitative and quantitative techniques for evaluating and communicating uncertainty (Flage et al., 2014)

1.3 Purpose of this thesis

The overall purpose of this thesis is to draw greater attention to the topic of scientific uncertainty in forensic science and to provide a starting point upon which fruitful conversations can take place; conversations that can inform and motivate the development of new and innovative approaches to conceptualising, evaluating and communicating uncertainty in forensic science. By addressing uncertainty holistically, capturing its nuances in a consolidated and clear manner and communicating this effectively to stakeholders, we can encourage greater transparency, more informed decision-making in legal actors and even more reflective practices in the workings of forensic science experts.

1.4 Thesis overview

This thesis consists of three primary studies (Chapters 3, 5 and 6) and two additional chapters (4 and 7), seeking to address four research questions that have been formulated in the pursuit of the overall aim of the thesis (Figure 1.1). The chapters, collectively, encourage the initiation of fruitful discussions around uncertainty in forensic science and set the foundations for identifying and developing innovative approaches to conceptualising, evaluating, and communicating it to juridical stakeholders. Figure 1.1 presents the four research questions that were formulated and demonstrates the connections between research questions and contributing chapters. The aims and objectives of each Chapter are also exhibited in this figure.

Research Questions	Contributing Chapters
What narratives are deployed by academics, policy-makers and the courts when considering uncertainty in forensic science?	Chapter 3
What instruments or tools are used to conceptualise, evaluate and communicate uncertainty in the 'neighbouring' disciplines of medicine, environmental science and economics, that can inform forensic science?	Chapters 4 and 5
What sources of uncertainty are most frequently experienced and/or are of most interest to forensic science stakeholders for the purposes of evaluation andcommunicationin court?	Chapters 5 and 6
What are the wider implications of a more precise and consistent consideration of uncertainty in forensic science?	Chapters 3, 4, 5,6 and 7

Chapter 3	Chapter 4	Chapter 5
Aim: To identify the main narrative deployed by academics, policy-makers and the courts with regards to how uncertainty in forensic science is considered.	***Aim:*** To identify those disciplines that are 'neighbouring' with forensic science, for the purposes of inclusion in the interdisciplinary configurative review.	***Aim:*** To identify the common concepts, term, patterns, instruments, methods and approaches that are used to conceptualise, evaluate and communicate uncertainty in the 'neighbouring' disciplines of medicine, environmental science and economics, that can inform forensic science.
Objectives: 1. Carry out a review of relevant academic, policy and case-law materials that concern the conceptualisation of uncertainty, specifically matters relating to definitions, sources and characteristics of uncertainty. 2. Identify patterns or narratives in how uncertainty is conceptualised. 3. Highlight any progress or shift in this narrative. 4. Highlight any gaps in the manner it is conceptualised and any progress that needs to be achieved.	***Objectives:*** 1. Identify a pool of potential disciplines for inclusion in interdisciplinary configurative review. 2. Develop discipline inclusion criteria. 3. Evaluate each discipline from the pool of disciplines against the inclusion criteria.	***Objectives:*** 1. Develop a search strategy, including identification of relevant databases, development of inclusion criteria and development of a search string. 2. Identify materials that satisfy inclusion criteria through a search of the relevant databases, followed by a title & abstract and full text screenings. 3. Identify common terms, concepts, categories – or patterns of these – that are used to conceptualise uncertainty in the disciplines of medicine, environmental science and economics. 4. Identify common instruments, frameworks, methods, approaches that are used to evaluate uncertainty in the neighbouring disciplines. 5. Identify common instruments, frameworks, methods, approaches that are used to communicate uncertainty in the neighbouring disciplines. 6. Synthesise the identified instruments for each of the facets of addressing uncertainty (conceptualisation, evaluation and communication), in a manner that can be informative and useful for forensic science.

Chapter 6	Chapter 7
Aim: To establish which of the sources of uncertainty that were identified in Chapter 5 are most frequently experienced and/or are of most interest to forensic scientists, judges and lawyers for the purposes of evaluation and communication.	***Aim:*** To synthesise the studies that were conducted as part of this thesis and discuss how a more precise and consistent consideration of uncertainty in forensic science can have a wider contribution to the discipline, as well as its interactions with stakeholders within the criminal justice system.
Objectives: 1.Develop a survey that captures in an easily understandable manner the sources of uncertainty identified in Study 1. 2.Establish network contacts which will assist with the distribution of the survey and the advertisement of the prioritisation workshop. 3.Pilot the survey prior to its distribution in order to ensure that it is understandable by the target population. 4.Distribute the survey and advertise the prioritisation workshop to as many potential participants as possible, using all available contacts and platforms. 5.Collect 24 interim priorities of the stakeholders from the results of the survey. 6.Organise a prioritisation workshop during which stakeholders can reach a consensus on their top 10 priorities in terms of sources of uncertainty in forensic science most frequently experienced/of most interest for the purposes of evaluation and communication.	***Objectives:*** 1.Highlight the most significant contributions made by the findings of the studies in this thesis. 2.Synthesise the findings and demonstrate the interconnections between the different studies. 3.Discuss the wider implications that the conceptualisation, evaluation and communication of uncertainty can have for the discipline of forensic science. 4.Discuss the wider implications that the conceptualisation, evaluation and communication of uncertainty can have for the interaction of the discipline of forensic science with other stakeholders in the criminal justice system. 5.Provide targeted recommendations for an evaluative and communicative framework for the disclosure of uncertainties associated with forensic evidence.

Figure 1.1| *Research questions and Corresponding Study Aims and Objectives*

The first study of this thesis (Chapter 3) explores the narrative deployed in forensic science in relation to the issue of uncertainty, through a review of academic, policy and case law materials. This review seeks to highlight the progressive shift away from avoidance, towards greater awareness and recognition of the prevalence, sources and characteristics of uncertainty in forensic science. Despite this shift, however, there is still significant progress to be made in order to reach the requisite level of clarity in the manner by which uncertainty is understood. Chapter 3 identifies the primary narrative and highlights the progress that remains to be achieved.

The second study (Chapter 5), recognises and engages with the fertile ground that exists outside the discipline of forensic science, in relation to issues of conceptualisation, evaluation and communication of uncertainty. Disciplines that share similar characteristics with forensic science have embraced, developed, and applied diverse and innovative approaches towards conceptualising, evaluating, and communicating scientific uncertainty. These disciplines are selected on the basis of a methodological approach developed and presented in Chapter 4. The identity and nature of forensic science as a discipline is also examined, as part of the development of the discipline inclusion criteria.

In order to explore the approaches adopted by disciplines similar to forensic science, the second study (Chapter 5) provides an interdisciplinary configurative review in the disciplines of medicine, environmental science and economics, to collect and synthesise the conceptual tools, as well as evaluative and communicative approaches and frameworks, primarily deployed in these disciplines. A collection and synthesis of these approaches, frameworks and tools provides the foundation upon which more targeted frameworks can be developed for addressing uncertainty in forensic science; frameworks that span beyond the narratives and paradigms deployed so far and which can capture the nuances of uncertainty in a more holistic manner.

The final study then builds on the results of the interdisciplinary configurative review, in order to elicit stakeholder priorities in relation to sources of uncertainty in forensic science. In order to achieve this, the third study (Chapter 6) adopted a modified Nominal Group Technique (NGT) to encourage consensus building among judges, lawyers and forensic science experts with regards to their top ten priorities in terms of sources of uncertainty they would like to see evaluated and communicated. Moreover, qualitative data were also collected throughout the different phases of the modified NGT, in order to more accurately capture and portray the experiences of stakeholders with uncertainty in forensic science.

The final chapter, Chapter 7, discusses the wider implications of this thesis, in light of the collective findings of the preceding chapters. A particular emphasis is placed on how certain power imbalances observed in the criminal justice system can be rectified, when greater attention is directed towards more holistically considering, evaluating and communicating uncertainty. This chapter also examines how an open acknowledgement of uncertainty, can have direct implications upon the identity of forensic science as a discipline, and its relationship with juridical stakeholders.

2. Literature Review

2.1 Uncertainty in Forensic Science: Pervasive yet underreported

2.1.1 Uncertainty at every stage of the crime reconstruction process

Experts from different professional spheres are frequently called to provide opinion evidence in relation to matters that are of interest to civil and criminal courts. Their reports and testimonies constitute exceptions to the opinion rule (R. v Atkins and Another, 2009) which requires witnesses to testify to facts and precludes them from presenting an opinion. Expert witnesses, including forensic science experts, are allowed to provide an opinion given that certain admissibility criteria are met. The reason for this exception is that expert witness evidence, and particularly scientific evidence, is considered to be extremely insightful on matters of guilt or innocence. The courts have expressed the value they place on scientific evidence in the case of R. v Clarke, where Lord Justice Steyn stated: 'It would be entirely wrong to deny the law of evidence the advantages to be gained from new techniques and new advances in science' (1995, pp. 429-430).

Forensic science experts are called to provide their opinion in court in relation to 'remnants of activity' – traces, patterns or marks identified at a crime scene (Roux et al., 2015, p.7). The path from crime scene evidence to opinion evidence is a complex one, also known as the chain of custody of evidence (National Research Council, 2009, p.36). It consists of multiple interlinked steps, each with their own complex processes and a number of actors involved (Morgan, 2017a). The journey of a 'remnant of activity' begins with a source leaving a trace, mark or pattern– such as a fingerprint, fibre, DNA traces, blood – in the crime scene as a result of some form of contact between the source and the item on which the trace, mark or pattern is found (Locard, 1920). Subsequently, the chain of custody begins with the trace, mark or pattern being identified, collected and preserved, if it has not been altered or its features obliterated prior to its identification (Chisum & Turvey, 2011). Depending on the 'remnants of activity' found at the crime scene, an analysis would then follow, during which the forensic science expert examines the features of the piece of the remnant found at the crime scene and attempts to discern a pattern (Stoney, 1991). The process of interpretation would then take place, whereby the examiner seeks to address hypotheses relating to the source of the material or mark, the identity, the activity and less commonly the type of offence that might have been committed (Cook et al., 1998; Graham Jackson et al., 2015).

At each of these stages, there are a number of factors that may give rise to or exacerbate uncertainty. As noted by Taroni & Biedermann (2015), uncertainty is the norm rather than the exception in the daily workload of forensic science experts, due to missing or incomplete data and information. At the analysis level, a degree of uncertainty exists as a result of the possibility of contamination in the laboratory (Chisum & Turvey, 2011), faults with the instruments used or methodological limitations whereby the detection methods utilised are not sensitive enough to the amount or types of characteristics present in the remnant (Christensen et al., 2014). Moreover, forensic science experts are vulnerable to extrinsic and intrinsic factors that affect decisions and judgements at the subconscious level (Dror, 2005; Dror & Charlton, 2006; National Research Council, 2009), thereby giving rise to further uncertainty during the stages of analysis, evaluation and interpretation with a potential to impact on the validity and accuracy of the final findings.

2.1.2 Uncertainty in reports and testimonies: underreporting and overclaiming

Despite the increasing awareness regarding the pervasive nature of uncertainty at every stage of the crime reconstruction process (Earwaker et al., 2020; Morgan et al., 2018), it is often left uncommunicated in court (Chisum & Turvey, 2011). The presentation of traditional forensic sub-disciplines, such as fingerprint analysis, hair analysis, bullet lead analysis and bitemark analysis, has been criticised over practices of 'over-claiming' by forensic science experts (Berger, 2002; Cole, 2007; Edmond, 2015b; Friedman, 2002; National Research Council, 2009; Saks et al., 2016)

Over-claiming was a term coined by Friedman (2002) to describe the phenomenon whereby forensic science experts frame their findings in stronger terms than merited by their underlying assumptions. Even though most of these criticisms have been based on the observation of U.S. cases, similar trends have been observed in trials in England and Wales. For example, in the case of R. v Smith (2011, p.19), the fingerprint expert stated: 'I have no doubt that the area of friction ridge detail indicated in the photograph was made by the appellant'. Similarly, presentations suggestive of individualisation were also evident in the case of Arbia where the forensic science expert argued: 'I have… concluded that they have been made by the same person' (R. v Arbia (Daniel James), 2010). The Court of Appeal has even allowed low template DNA evidence to be presented to jurors, using the terms 'rare' and 'somewhat unusual', despite the absence of scientific underpinnings (R. v Dlugosz, 2013).

Unlike, traditional forensic sub-disciplines, DNA analysis is an example of a sub-discipline whose experts have been communicating their uncertainties in court, and such uncertainties have generally been accepted by the courts (Kruger, 2012). Kruger (2012) argues that low-copy number (LCN) DNA, which she describes as 'visually anomalous' due to the ambiguities exhibited in the visual imagery of the sample, are communicated by experts and are generally accepted by courts in England and Wales. Yet, even with regards to DNA analysis, there are some incidents of evident underreporting of uncertainty, with Curran & Buckleton (2011) highlighting current practices by forensic science experts in the UK failing to report one of the most important sources of uncertainty, that of sampling uncertainty. Even though Curran & Buckleton (2011) highlighted such a notable gap in the reporting of uncertainty in DNA analysis nearly a decade ago, there is still no formal requirement to evaluate and report sampling uncertainty in forensic science experts' reports or testimonies (Forensic Science Regulator, 2020a, 2020b).

It has been argued that the strength of the testimonies of forensic science experts should reflect the strength of the underlying methodology and processes that were followed to reach their opinion (Mnookin, 2010). This is necessary in order to ensure that jurors attach the appropriate probative value to the evidence (Law Commission, 2011). As can be seen from the examples above, it is debatable whether the certainty of the language adopted by some forensic science experts is proportionate to the strength of the underlying evidence or reflective of the existence of uncertainties. Even in the discipline of DNA analysis, significant facets of uncertainty, such as sampling uncertainties, are not required to be disclosed in the testimonies or reports of forensic science experts.

Strong calls have been made by academics regarding the importance of openly acknowledging and disclosing uncertainty to stakeholders; an open acknowledgement that may be able to counteract practices of underreporting of uncertainty and overclaiming by forensic science experts. Examples of such calls, include Taroni & Biedermann (2015) who highlighted the need to talk of uncertainty in explicit terms, the National Academy of Science (National Research Council, 2009) which raised the issue of evaluating uncertainties in its seminal report, and the Forensic Science Regulator in England and Wales who has been showing increasingly greater interest in the topic of uncertainty (Forensic Science Regulator, 2014, 2017, 2020b). Recently, Lund & Iyer (2017) highlighted the counteracting effect that disclosure of uncertainty can have in court in preventing the overstating by experts of their underlying rationale and authority. Given the strong calls for greater transparency, this thesis seeks to identify a range of useful tools for conceptualising, evaluating, and communicating uncertainty to lay stakeholders. It is hoped that such tools can assist forensic science experts with evaluating the uncertainties they encounter throughout the crime reconstruction process and place them in a better position to report such uncertainties to lay stakeholders.

2.2 Understanding uncertainty in Forensic Science: Current contributions to conceptualisation discussions

Developing a nuanced and clear understanding of uncertainty in forensic science is critical for establishing the reliability and probative value of the evidence when presented in court (Edmond, 2015a; Koehler, 2016). Even though not in a coherent, explicit or systematic way, researchers from within forensic science and academia have contributed towards an improved understanding of the uncertainty that arises during the analysis and interpretation carried out by forensic science experts and the confidence that can be held in those.

Research is currently under development in different disciplines of forensic identification, which can increase the knowledge base on the dispersion, transfer and persistence of evidence and provide more insights into the uncertainties involved in its interpretation (Smit et al., 2018). In blood pattern analysis, research has indicated that uncertainty may arise in relation to the evaluation of source distance, as red blood cell count may alter the weight of the blood drops (Wonder, 2001). Similarly, the diameter and viscosity of blood drops may differ depending on whether the individual whose blood was found at a crime scene had taken amphetamines (Brownson & Banks, 2010). Senn & Souviron (2010) have drawn attention to the existence of uncertainty in the analysis of bite-marks, by pointing out that the reaction of a body on compression wounds is conditional on the characteristics of the teeth. In the discipline of fibre analysis, studies have increased the knowledge base on the persistence of fibres on different garments and items, as well as under different conditions, such as water immersion (Lepot et al., 2015; Lepot & Driessche, 2015). These studies do present certain limitations. Even though they seek to replicate real-life conditions, it is difficult to mimic the exact circumstances of a crime (Lepot & Driessche, 2015) and this may affect their external validity.

Research in DNA analysis has also indicated that issues of uncertainty may also arise at every step of the process (Thompson, 1995) and particularly so when visually 'anomalous' or mixtures of DNA evidence are concerned (Kruger, 2012). A number of difficulties may be encountered by examiners when analysing mixtures or visually anomalous DNA samples, such as differentiating between allelic dropouts or stutter artefacts (Balding & Steele, 2015; Bieber et al., 2016). Kruger (2012) explicitly recognised that DNA profiles exhibit significant levels of uncertainty, despite widespread beliefs regarding their infallible nature. Uncertainty may be the result of the scientific methods followed, the existence of certain unfavourable conditions in the laboratories, the statistical methods used to calculate uncertainty found in the sample (Kruger, 2012), or the validity of the population against which the sample is tested to produce the random match probability (Thompson, 2008). The latter source of uncertainty is continually mitigated with the development of increasingly reliable methods for estimating census populations (Guschanski et al., 2009; Luikart et al., 2010).

Scholarly critics have also been identifying sources of uncertainty which may impact upon the confidence that can be placed in the findings of forensic science experts. Significant consensus exists in academia over the lack of empirical research on which the opinions of experts can be based (Giannelli, 2006; Murphy, 2007; National Research Council, 2009; Saks & Koehler, 2008; Saks & Koehler, 2005). Despite the developing body of research that exists in certain disciplines, like those identified above, disciplines such as fingerprint analysis rely mostly on skill and experience rather than evidence-led methodologies (Mnookin, 2003; Zabell, 2005). This lack of research is a source of uncertainty in itself, particularly in relation to the capacity of experts to make reliable evaluations of the evidence. More specific observations include those by Saks & Koehler (2005) who pointed out the absence of data regarding the frequency of concurring characteristics. Taroni et al. (2016) also highlighted the lack of knowledge regarding the complete circumstances of a crime as an additional obstacle towards the ability of forensic science experts to paint a holistic picture in relation to the propositions in question.

Cognitive neuroscience is perhaps one of the better developed areas that has contributed to this discussion through empirical testing in order to achieve a better understanding of uncertainty (Asch, 1946; Darley & Fazio, 1980; Tversky & Kahneman, 1974). This body of knowledge was later applied and tested in the field of forensic science (Dror, Charlton & Péron, 2006; Dror, 2005). Forensic science experts are believed to be susceptible to subconscious biases when carrying out their examinations due to the subjectivity that exists in the nature of their work (Dror, 2005). This is particularly true for 'hard' cases, characterized by a significant element of ambiguity (Dror & Cole, 2010). Nevertheless, research has demonstrated that inter and intra-rater variability in the conclusions of experts, potentially attributable to cognitive biases, is not limited to 'hard cases' but has even been identified in cases that are not so difficult or ambiguous (Dror & Charlton, 2006). Cognitive biases can take many forms; expectation bias, confirmation bias, contextual bias, motivational bias, role bias, reconstructing and anchoring effects (Forensic Science Regulator, 2018) and has many sources, including personal factors and factors relating to the case in hand (Dror, 2020). Research has been carried out in relation to cognitive bias in different sub-disciplines of forensic science, such as fingerprinting (Dror & Charlton, 2006; Ulery et al., 2011; van den Eeden et al., 2019), DNA analysis (Dror & Hampikian, 2011) and forensic anthropology (Nakhaeizadeh et al., 2014).

The majority of these studies have provided support for the hypotheses that different sources of cognitive biases – whether due to subconscious influences derived from being employed by the prosecution or defence (Murrie et al., 2013) or by the order of candidates in a suspect list (Dror et al., 2012) – may psychologically contaminate forensic science experts and affect their perceptions (Kassin et al., 2013). It is worth noting that the studies mentioned were carried out in the United Kingdom and United States. Similar studies performed in the Netherlands have yielded mixed results, with some concluding that contextual information had no effect on the decision-making of experts (Kerstholt et al., 2010; Kerstholt et al., 2007), while more recent studies indicating that contextual information can have an impact on the decision-making of forensic science experts (van den Eeden et al., 2019).

Some of the most widely cited studies exhibited varying degrees of strength and any conclusions drawn from them should be done so cautiously. For example, the study carried out by Dror and Charlton (2006) demonstrated significant strengths due to the experiment taking place under routine conditions and satisfying within examiner variability testing. The study carried out in relation to cognitive bias in DNA analysis (Dror & Hampikian, 2011) was questioned for the validity of its findings, due to limitations resulting from the small number of participants and the statistical tests that were employed (Kaye, 2012). Studies into the decision-making and the potential impact of biases can be challenging to carry out effectively (Dror, 2009, 2012; Dror & Hampikian, 2011), as it is often difficult to manipulate and control all conditions. As a result, there is always the possibility that something other than cognitive biases may have been the cause of inter and intra-examiner variability (Dror, 2012). Another limitation when using real-life cases and samples of evidence for such experiments is that the ground truth is essentially unknown (Dror, 2012).

Even though the empirical studies on evidence dynamics, transfer and persistence and cognitive biases have been particularly insightful in terms of highlighting sources and characteristics of uncertainty, the identification and discussion of all the dimensions of uncertainty has not been carried out in an organized or systematic fashion. As such, unless a thorough review of the literature of forensic science is conducted, the sources and characteristics of uncertainty that are frequently observed and faced by forensic science experts, would not be readily identifiable. Even if these could be identified, the terminology to describe them concisely and clearly has not yet been developed. There is a need for standardised language to describe and communicate the sources and dimensions of uncertainty (Earwaker et al., 2020; Mastrandrea et al., 2011). Without shared terminologies across institutions, there is a risk of misunderstanding both between experts in the discipline of forensic science, as well as between forensic science experts and stakeholders. The development of a conceptual framework that can provide the semantic and linguistic tools to capture and ensure consistency in the conceptual understandings of all stakeholders constitutes one of the main aims of this thesis, addressed in Chapters 3 and 5.

2.3 Current paradigms for evaluation and communication of uncertainty

2.3.1 Probabilities, Bayes and the Likelihood Ratio

The concept of uncertainty has been the focus of extensive writing particularly in the domain of the use of probabilities in court. Following the case of R. v T (2010), a number of academics became signatories to a position statement that supported probability theory, and specifically Bayes, as the 'only coherent and logical foundation' for reasoning under uncertainty (Berger et al., 2011, p.1). The likelihood ratio has been the main instrument recommended by academics for rationalising and indexing uncertainty (Taroni & Biedermann, 2015; Taroni et al., 2016). The likelihood ratio was described as the method through which value can be added to the evidence in order to assist the jurors with updating their beliefs regarding competing propositions or hypotheses (Berger & Slooten, 2016). As such, the likelihood ratio is tightly linked to the Bayesian approach (Ligertwood & Edmond, 2012), whereby one forms a posterior belief about a set of hypotheses in light of the impact of the likelihood ratio on the prior beliefs.

Support for the use of likelihood ratios by the academic world has been noteworthy (Berger et al., 2011; Fenton, 2011; Morrison & Enzinger, 2016; Redmayne et al., 2011; Robertson & Vignaux, 1998). Endorsements have also been expressed by forensic practitioners who have been attempting to apply probabilities to the calculation of uncertainties in their respective fields. These include fingerprint evidence (Neumann et al., 2011), fibre analysis (Farah et al., 2014) and shoe marks analysis (Skerrett et al., 2011). Professional bodies have also backed up the use of likelihood ratios in the courtroom, some of these being the NAS (National Research Council, 2009), the European Network of Forensic Science Institutes (European Network of Forensic Science Institutes, 2015), and the Royal Statistical Society's Statistics and Law Working Group (Jackson et al., 2015).

The proponents of the use of the likelihood ratio in the presentation of evidence in court have presented a number of arguments to justify its beneficial value. One of the main arguments relies on the compatibility of the likelihood ratio with the adversarial and accusatorial setting of a trial, in which the competing hypotheses of the prosecution and defence have to be evaluated by the jury (Ligertwood & Edmond, 2012). It is believed that given its compatibility, it can assist jurors with achieving clarity of thought during their decision-making (Edwards, 2010) and can prevent them from engaging in prejudicial inferential reasoning (Saks & Koehler, 1991). It has also been suggested that it can be useful to all actors involved, as it would assist lawyers with explaining, jurors with evaluating the weight of the evidence, judges deciding on admissibility and experts with framing their opinions (Fenton, 2011).

Important concerns have been expressed regarding the use of a Bayesian approach and the likelihood ratio for the evaluation and presentation of forensic science evidence in court. One of these is the attachment of precise numbers on expressions of the likelihood ratio which are based on subjective evaluations (Found, 2015; Morrison & Enzinger, 2016; Tillers & Green, 1988). Presenting exact numerical probabilities to jurors when the data to calculate these are limited – which is true for many forensic disciplines (de Keijser & Elffers, 2012) – gives rise to the danger of concealing rather than exposing uncertainties in the decision-making of the experts (Allen, 2017; Risinger, 2013). This criticism reflects the legal community's wariness of attaching precise numbers on uncertain testimonies (Fenton, 2011), even if the likelihood ratio fulfils the function of capturing these uncertainties (Taroni et al., 2016). Supporters of the Bayesian approach have dismissed such argument on the basis that there will always be a subjective element in probabilities even if they are in relation to DNA evidence (Fenton, 2011; Fenton et al., 2013).

Another point of debate in relation to the use of probabilities in court, is whether they are compatible with the type of reasoning which judges and jurors engage in, and whether legal actors are actually in a position to comprehend probabilities. As mentioned previously, proponents of the likelihood ratio believe that it can enhance clarity in the decision-making of jurors (Edwards, 2010). Moreover, juror decision-making has been conceptualised in likelihood ratio terms, even if theoretically (Goldman, 1986), suggesting that juror reasoning may be akin to the workings of the likelihood ratio. There are academics however, who believe that the decision-making of jurors follows an inductive process which is non-mathematical (Ligertwood & Edmond, 2012) and which may even be considered as categorical (Redmayne, 2001). Questions have therefore been raised, as to whether the incompatibility between these two types of reasoning may lead jurors to misunderstand probabilities, and particularly the likelihood ratio, thus hindering their decision-making process (Ligertwood & Edmond, 2012).

Empirical studies have provided useful insights as to how probabilities affect the decision-making of jurors. Studies by Thompson & Schuman (1987) and Koehler (2001) have indicated that lay people are vulnerable to the prosecutor's fallacy; namely that they confuse the likelihood ratio with the likelihood of guilt, indicating that the likelihood ratio presents a challenge for jurors (Ligertwood & Edmond, 2012; Thompson, 2012). There have also been research findings to suggest that when the evidence provides weak support for one hypothesis, it is then interpreted as consistent with the alternative hypothesis (Fernbach et al., 2011; Harris et al., 2009; Martire et al., 2013).

The use of verbal scales has been strongly supported as an instrument for communicating the likelihood ratio (Berger et al., 2011). Studies have indicated, however, that judges, lawyers and even experts themselves engaged in fallacious reasoning when presented with a verbal scale on some occasions (de Keijser & Elffers, 2012). Doubts have been raised regarding the usefulness of a verbal scale, such as what is considered to be an appropriate allocation and correspondence of different ranges of likelihood ratios to different verbal expressions (Martire, et al., 2013). Furthermore, academics have pointed out that verbal scales are interpreted differently by different individuals (Brun & Teigen, 1988; Martire et al., 2014) and differently to the meaning experts intend them to convey (McQuiston-Surrett & Saks, 2007). There is also evidence to suggest that the change of belief of jurors after presented with the likelihood ratio tends to be much lower than that intended by experts, particularly when expressed through the use of a verbal scale rather than in numerical form (Martire et al., 2014; Martire et al., 2013).

Additional recommendations for communicating the Bayesian approach have been made by its proponents, who recognise the difficulties in lay people's understanding of probabilistic reasoning (Fenton et al., 2013). One of these suggestions has been the use of Bayesian networks. Bayesian networks purport to achieve a normative presentation of the relationship between different items of evidence and the hypotheses, through the use of causal nodes (Fenton et al., 2013; Lagnado et al., 2013; Pearl, 1988). The strength of this approach rests mainly in its qualitative nature and its ability to break down a case into manageable pieces of information which can easily be understood by the jurors (Lagnado et al., 2013; Fenton et al., 2013). A weakness of Bayesian Networks is that among the idioms suggested for inclusion are the alibi and motive idioms. A potential danger of including these idioms is that the expert may stray beyond the bounds of their role and into the realm of the jury. This can result in an infringement of the ultimate issues rule (Davie v Magistrates of Edinburgh, 1953), according to which it is the jury's responsibility to decide on the set of facts which are pertinent to the question at hand (Roberts & Zuckerman, 2010). Therefore, even though potentially beneficial, the introduction of

Bayesian Networks for guiding the decision-making of jurors might be responded to with scepticism and dubiousness by the judges.

Probabilities have been the dominant medium through which experts are encouraged to express their uncertainty regarding source, activity and offence propositions. However, as Flage et al. (2014) note, uncertainty is a multifaceted, complex phenomenon that cannot always be simply reduced to a numerical formula (Flage et al., 2014; Morgan et al., 2018). In addition, the arguably incompatible nature of probabilistic reasoning with the inductive, non-mathematical nature of the decision-making of lay-people may prevent its successful use in court. As such, it is worth exploring whether there are alternative frameworks that could evaluate and communicate uncertainty in a holistic manner, and which at the same time would be more in line with the decision-making models of lay decision-makers. This exploration was conducted through the interdisciplinary configurative review in Chapter 5.

2.3.2 Confidence Intervals and Error Rates

More recent debates on how to capture uncertainty in probabilistic terms have focused on whether the likelihood ratio should be accompanied by confidence intervals to indicate the uncertainty regarding the likelihood ratio itself. Opponents of the use of confidence intervals have argued that likelihood ratios are evaluations of uncertainty in light of all the information that is available in the case, so all uncertainty regarding the evidence should be encapsulated by the likelihood ratio (Berger & Slooten, 2016; Taroni et al., 2016). They also add that likelihood ratios are essentially subjective 'measures of belief in the outcome of an event or the truth of a proposition' (Taroni et al., 2016, p.6). Given that the likelihood ratio is the best expression of belief in light of all the data, then it makes little sense for that 'best expression of belief' to be accompanied by confidence intervals. There are scholars who have disagreed, arguing that not all uncertainty can be captured by the likelihood ratio (Curran, 2016; Martire et al., 2017). Martire et al. (2017) have provided as an example the fact that many forensic science experts do not possess sufficient knowledge about the influence of cognitive bias and therefore this source of uncertainty cannot be captured by their personal measurement of uncertainty. They have suggested that the uncertainty goes beyond the personal uncertainty as experienced in the quantifications of the examiner and that the current state of knowledge is lacking, preventing them from making any recommendations on how such uncertainty can be conceptualised and communicated (Martire et al., 2017).

The debate regarding the introduction of confidence intervals to signify the uncertainty surrounding the individual examiner's likelihood ratio is interlinked with the discussion around the feasibility of calculating error rates and presenting them in court. The topic of error rates in forensic science has been highly contested (Weiner & Hess, 2006). Error rates have been endorsed by a number of academics

(Koehler, 2008; Koehler, 2016; Mnookin et al., 2011; Saks & Koehler, 2005; Thompson et al., 2003) who believe that they would be a good indicator of the accuracy of an expert's conclusions (Saks, 1998). Among the arguments that have been put forward to defend the need for calculation and disclosure of error rates is the emphasis that error rates would draw on the fallibility of forensic opinions (Edmond et al., 2014). In addition, scholars argue that the greater transparency achieved through the disclosure of error rates can provide judges and jurors with critical information regarding the reliability and accuracy of the findings of forensic science experts (Koehler, 2016), without which the evidence could potentially be deemed misleading (Koehler, 1997).

A number of studies have been carried out seeking to evaluate the accuracy of the conclusions of forensic science experts, either in the form of proficiency testing carried out by the Collaborative Testing Services, or carried out by independent scholars (Ulery et al., 2011). Proficiency tests are conducted for the purposes of internally testing the competency of employees and achieving improvement (Garrett & Mitchell, 2017). Therefore, the extrapolation of the results of these tests for estimating accuracy in the conclusion of experts in specific instances may be inappropriate. Current proficiency tests and studies specifically measuring the accuracy of examiners' findings have come under severe criticism (Saks & Koehler, 2008; Saks & Koehler, 1991). These criticisms have focused on the unrealistic samples used and for their lack of blind testing (Saks & Koehler, 2005). Recommendations on how to carry out studies for the calculation of error rates have recently been made by the PCAST (2016), but as noted by academics there is a variety of methods that can be used to carry out evaluations of error rates, all of which would be a reflection of the assumptions and values of those recommending them (Hunt, 2018).

Further discussions regarding the measuring of error rates have highlighted the difficulty of achieving a consensus on the definition of error rates (Morris & Fitzsimmons, 2008) and avoiding misunderstandings of the meaning of this term by the judicial and scientific community (Christensen et al., 2014). The samples of evidence used for testing the accuracy of examiners' conclusions have also been criticised, as either lacking a ground truth when are taken from casework (Cole, 2005; Dror, 2012) or failing to achieve sufficient similarity to actual casework when based on simulations (Cole, 2005). These and other factors, such as the conditions under which the test is administered, the sample size of examiners, as well as the timing of the tests, may affect the generalizability of the results (Hunt, 2018; Marczyk et al., 2005) rendering them therefore unreliable or even irrelevant for court use in individual cases (Cole, 2005). Scholars and professional bodies have also questioned the relevance of such tests given the evolving nature of science (Hunt, 2018; National Research Council, 1996).

The discussions around error rates essentially highlight the need to achieve greater transparency in the manner in which forensic science experts present their findings. Greater transparency is essential so as to ensure that stakeholders are in an informed position to make proportional evaluations regarding the reliability of the evidence. Error rates have been recommended as suitable for enhancing transparency by the Forensic Science Regulator (2014). The Forensic Science Regulator in its 2014 guidance suggested that false positive and false negative rates can provide the means through which to report uncertainty in qualitative forensic sub-disciplines. However, the calculation of error rates is not devoid of its own uncertainties and validity concerns. Therefore, it may actually lead to greater confusion and even misleading of juridical stakeholders, while transparency is not necessarily achieved simply through a disclosure of a set of error rates.

This thesis seeks to address the aim of greater transparency and proportional stakeholder decision-making by developing conceptual, evaluative and communicative toolkits that will directly address uncertainty. These frameworks aim to capture all those factors that give rise to uncertainty and which are frequently encountered by forensic science experts. The identification of these factors (sources and characteristics of uncertainty) will allow for the development of the appropriate tools to evaluate and communicate them to judges, lawyers and jurors. The disclosure of sources and characteristics of uncertainty and their extent would potentially result in greater transparency. Greater transparency in relation to uncertainty would in turn ensure that legal lay stakeholders are provided with a more in-depth insight of the reasoning of forensic science experts and would thus be in a better position to ascertain the reliability and probative weight of the forensic science evidence presented to them. As such, the benefits that have been argued to emanate from the calculation of error rates, can potentially be achieved through the toolkits developed in this thesis (Chapter 5).

2.4 The gap in the research on uncertainty in forensic science

Uncertainty is a topic that transcends disciplinary boundaries; it arises in every aspect of life, but also in every scientific endeavour. Such widely encompassing phenomena can benefit from an exchange of ideas, approaches and tools, even between disciplines that are, prima facie, as starkly different as the sectors of economics and meteorology (Palmer & Hardaker, 2011). Yet, there is a notable dearth of information exchange between disciplines, with regards to handling scientific uncertainty (Gabriele Bammer & Smithson, 2012). Forensic science is one of the disciplines that has arguably missed a fruitful opportunity to incorporate ideas, arguments and findings that have been developed across a spectrum of other disciplines with regards to identifying and addressing uncertainty in every stage of its crime reconstruction process. This missed opportunity has perhaps contributed to the absence of theoretical and practical frameworks that provide the requisite tools for effectively conceptualising, evaluating and communicating uncertainty in forensic science.

Even though there has been significant progress in achieving a more nuanced conceptualisation and hence understanding of uncertainty in forensic science – as explored in Chapter 3 – there is still an absence of concerted and consolidated efforts to construct a framework of typologies and characteristics of uncertainty in forensic science. Such a gap can be rectified by an exploration of the large body of literature that exists beyond forensic science and by identifying potentially useful tools, frameworks and vocabularies for conceptualising uncertainty. The identification, consolidation and even assimilation of some of these tools in forensic science, can create new pathways for thinking and understanding uncertainty in forensic science.

The conceptual developments in fields beyond forensic science have been significant in identifying and constructing a multitude of definitions and typologies. Yet, it is important to note that even in light of such developments, consensus has yet to be achieved by the academic community over one definition or typology of uncertainty (Morgan et al., 1990). When it comes to the definition of uncertainty, a great number of these have been provided over the years (Lipshitz & Strauss, 1997). One of the most popular definitions can be found in the writings of Frank Knight (1921) in the sphere of economics. According to Knight's definition, uncertainty is distinguished from risk on the basis of whether a peril can be quantified or not. 'Risk' is the term used when a peril is quantifiable, whereas the word 'uncertainty' is preferred when the risk cannot be quantified. Some more modern perspectives are contradictory to the Knightian definition of uncertainty, as they support the quantifiable nature of uncertainty (National Research Council, 1996; Natke & Ben-Haim, 1997). There are still scholars who believe that uncertainties refer to issues that are 'far less clear cut' (Pidgeon et al., 2003, p.9) and are more subjective and qualitative in nature (Bammer et al., 2012). There is also the recent definition on which agreement seems to have been reached by a number of leading scholars in this field, which describes uncertainty as the part of the picture that is known or unknown to a scientist and how much confidence can be placed in their evaluation (Sense about Science, 2013).

Absence of consensus is also noticeable in the domain of uncertainty typologies. A number of typologies have been developed, a lot of which appear to be overlapping (Krupnick et al., 2006). Hacking's typology (1975) separated uncertainty into two broad categories. The first type is the result of incomplete knowledge and has been given the term 'epistemic uncertainty'. The second type is that of aleatory or stochastic uncertainty, which arises due to the inherent variability or randomness of a phenomenon. This typology has been generally accepted by academics, with some adding a third dimension – such as human reflexive uncertainties – (Dessai & Hulme, 2004), or adopting the definitions of uncertainty and variability as alternative terms for Hacking's two categories (Walker et al., 2003).

Further sub-categories were developed by a number of academics, such as Morgan and Henrion (1990) and Frey (1992), who developed a distinction between parameter and model uncertainty as sub-categories of epistemic uncertainty. Additional descriptors were also introduced for specific types of uncertainty, such as the term 'ambiguity' to describe specific types of uncertainty, particularly those relating to the reliability of risk information (Ellsberg, 1961). Krupnick et al. (2006) formulated their own typology, on the basis of an exhaustive review of the literature, which captured the five main categories identified in the literature; variability (aleatory), parameter and model (subcategories of epistemic), decision and language uncertainty. Krupnick et al.'s (2006) typology and a typology developed by Walker (2003) – consisting of conceptual, measurement, sampling, modelling and causal uncertainties – have both been discussed as relevant within the legal context (Tai, 2009). There are also taxonomies which are much more exhaustive and share few similarities with the typologies referred to here, such as Smithson, who breaks down ignorance into 16 sub-categories (Smithson, 1989).

The failure of the published forensic science literature to identify and embrace the theoretical frameworks that were developed in other domains is closely linked to its failure to formally engage with other disciplines and exchange information regarding the different methods of evaluating and communicating uncertainty. Probabilities have been the dominant tool in dealing with uncertainty historically (Klir, 1997; Zimmermann, 2010), as well as across a range of fields (Bammer & Smithson, 2012). Some of the debates found in the general literature of uncertainty can be found in the literature addressed to forensic science issues. These include, whether the Bayesian approach is the best formal method for measuring uncertainty (Bammer & Smithson, 2012; Smithson, 1997), as well as whether the use of probabilities is the best method for communicating uncertainty when working with people from multidisciplinary backgrounds (Dovers et al., 2008). The discussions that have not been captured in the forensic science literature to date are those that explore the limitations of probabilities in capturing uncertainty and alternative metrics or approaches for doing so.

A growing body of recent published literature has highlighted some of the difficulties and even dangers of quantifying scientific uncertainty probabilistically. It has also been emphasised that even in the perfect experimental conditions, one can never be too certain about the validity and reliability of the tools that are used to measure uncertainty (Spiegelhalter, 2017). Uncertainty is not only prevalent in the decision-making process and final findings of decision-makers, but even in the instruments used to assess the original uncertainty. Spiegelhalter explained elsewhere that areas with messy data (Spiegelhalter, 2014), limited data, disagreement over the values of different events, as well as the difficulty of predicting certain events (Spiegelhalter & Riesch, 2011) are all conditions that exacerbate uncertainty and present a significant challenge to statisticians.

Support for Spiegelhalter's position can be found in the writings of academics and researchers specialising in the field of climate change. For example, Hulme and Carter (1999) and Hassenzahl (2006) acknowledged that probabilities are often difficult to calculate, especially when there is incomplete or unknowable knowledge – or what could be termed as parameter uncertainty. Similarly, Kadvany (1996), described the efforts of quantifying scientific uncertainty as efforts to 'tame chance.' These sentiments were echoed by Risbey and Kandlikar (2007) who supported the premise that attaching numerical values to uncertainty should only be reserved for clear events that involve high levels of agreement among experts and substantial evidence. The National Research Council (1996) also warned that when the degree of uncertainty is high, quantitative representations of that uncertainty can cause confusion.

Alternative models of evaluating and communicating uncertainty have been developed and implemented in fields outside forensic science, such as fuzzy set theory (Klaua, 1966; Zadeh, 1965) and the precautionary principle (Farber, 2010). In addition, qualitative or partly qualitative approaches have been applied in the fields of environmental and climate change policy (Spiegelhalter & Riesch, 2011; van der Sluijs et al., 2005). These models are thought to be in a better position to avoid the limitations associated with the attachment of precise numerical probabilities on uncertainty, particularly when the data is limited and could potentially lead to further confusion and inaccuracies (Spiegelhalter & Reisch, 2011).

Communicating uncertainty – which presupposes the conceptualisation and evaluation of uncertainty (Fischhoff & Davis, 2014) – can play a significant role towards enhanced transparency (Dizon et al., 2013), accountability (Reifschneider & Tulip, 2017), and informed decision-making in lay decision-makers (Brock & Durlauf, 2015). Yet, the lack of communication between forensic science and other disciplines with regards to the phenomenon of uncertainty has been notable, as can be observed from the failure of forensic science to keep abreast with the developments in other fields. An enhanced engagement with other disciplinary perspectives can contribute significantly to the current knowledge field in relation to uncertainty, by introducing creative and innovative perspectives, skills and values (Bammer & Smithson, 2012). The introduction and incorporation of diverse viewpoints, may be pertinent to the development of a set of tools for effectively identifying all potential sources, evaluating their impact and communicating these to the relevant legal actors.

2.5 Motivation, aims and impact of this thesis

The motivation behind this thesis has been the evident gap in the published literature that addresses uncertainty in forensic science and the significant implications the rectification of this gap can have on the criminal justice system. The quality of forensic science evidence – and its interpretation – is tightly linked to the quality of the criminal justice system of a specific jurisdiction (Thompson, 2009) and its capacity to protect justice and liberty (Jonakait, 1991). By communicating uncertainties arising at all stages of the forensic science evidence process, judges, lawyers and jurors are provided with critical information regarding the reliability and probative weight of the evidence (Mnookin, 2010). Encouraging the communication of uncertainties to lay stakeholders can also be beneficial to forensic science experts, as it can foster a culture of reflexivity, humility (Damodaran, 2013) and accountability

(Reifschneider & Tulip, 2017). These implications can in turn have a positive effect on the quality of the evidence and the criminal justice system as a whole.

This thesis seeks to rectify the identified gap by encouraging a fruitful dialogue between disciplines regarding the way uncertainty can be conceptualised, evaluated and communicated to lay stakeholders. Through this interdisciplinary dialogue, it seeks to identify and collect valuable new frameworks through which uncertainty in forensic science can be understood, as well as tools which can assist with holistically evaluating and communicating it to the relevant stakeholders (Chapters 4 and 5). Furthermore, this thesis aims to set the foundations necessary for the practical application of the collected tools and developed frameworks in the criminal justice system. As such, it pursues a deeper understanding of the narratives deployed by stakeholders in making sense of uncertainty (Chapter 3), as well as establishing their priorities with regards to which specific sources of uncertainty should be prioritised when developing holistic evaluative and communicative frameworks (Chapter 6).

3. The shifting narrative of uncertainty: A case for a coherent and consistent consideration of scientific uncertainty in forensic science

3.1. 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 (Morgan et al., 2018), from the point of collection of a trace, pattern or mark in a crime scene, through to its presentation as intelligence or evidence in court. Uncertainty is therefore always present, particularly due to the nature of reconstructing past events (Morgan, 2017a) where there are often gaps in the knowledge base and evidence base due to missing data and information (Morgan, 2017a, 2017b). For this reason, a forensic science expert is not able to determine with absolute certainty the source of a non-directly individualising trace material identified at a crime scene (Martire, 2018) 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, the narrative constructed around uncertainty and the way it is understood have arguably not kept pace with the developments in other disciplines (Georgiou et al., 2020). Given the importance of forensic science evidence in a number of criminal trials (Smit et al., 2018), it is imperative that the uncertainties inherent to expert opinions are more fully understood, evaluated and communicated. Unacknowledged uncertainty can potentially lead to the overvaluation of opinion evidence (Edmond et al., 2019). However, uncertainty does not necessarily undermine the quality of the evidence or the conclusions of the expert decision-makers, as long as such uncertainty is managed (Funtowicz & Ravetz, 1994), or addressed and communicated to the lay decision-makers in a manner that is understandable (Smith & Stern, 2011) and transparent (Almazrouei et al., 2019) The degree of certainty communicated by experts when providing their findings to a jury has been found to matter significantly to jurors (Kadane & Koehler, 2018), and it has been argued that the level of certainty provided by experts can enhance the overall understanding of the evidence by jurors (Edwards, 2019).

Disclosure of uncertainty, through appropriate communicative frameworks, is beneficial in assisting jurors to evaluate and assign probative weight to specific pieces of forensic science evidence. Uncertainty has been recognised as one of the critical issues that can have an impact upon the probative value of the evidence, and it is important that this is communicated as clearly and helpfully as possible so that its bearing upon the probative value is recognised by jurors (Edmond et al., 2019). It has also been argued that the disclosure of uncertainty to jurors can also be beneficial for forensic science experts as it can improve best practice (Edmond et al., 2019) by fostering an enhanced environment of reflection, transparency and accountability. Most importantly, appropriate disclosure is fundamental to a legitimate and fair criminal trial (Attorney General's Office, 2018), by guaranteeing that the burden of proof lies with the prosecution (Edmond et al., 2019) and guilt is proved beyond reasonable doubt (Edwards, 2019).

In order to be able to communicate the uncertainty associated with forensic science evidence to lay decision-makers, it is important to articulate a clear and coherent conceptualisation of uncertainty in forensic science. This article provides an overview of the articulation and conceptualisation of scientific uncertainty by key forensic science stakeholders to date. Perspectives from academia, the courts and policymakers have been synthesised in order to identify three main facets of uncertainty: (i) definitional issues, (ii) typological concerns and (iii) characterisations of its nature. By compiling the most prevalent ways that uncertainty has been conceptualised by academics, policy-makers and the courts, this paper offers insights for developing a more coherent and consistent understanding of uncertainty in forensic science, which will allow for the selection and implementation of the most appropriate practices for effective evaluation and disclosure.

3.2. The concept of 'uncertainty' and its understanding

3.2.1 Definitions

The consistency and clarity of key terms used in forensic science is a significant concern within the academic community. Inman and Rudin (2001), highlight the lack of a single consistent definition for terms such as 'match' and 'consistent with', while Christensen et al. (2014) note the multiplicity of ways in which 'error rates' can be defined. It is becoming clear that similar concerns may be raised with regards 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' (European Network of Forensic Science Institutes, 2015; R. v Wooster (Perry), 2003; Jackson et al., 2006; Taroni& Biedermann, 2014, 2015; Thompson et al., 2018), what it is 'regarding' (Martire, 2018), uncertainty 'of' something (Earwaker et al., 2020; Tully, 2020; National Research Council, 2009) or 'as to' (R. v Arshad (Nosheen), 2012). Uncertainty is also used as an adjective to describe an event, knowledge, science or the state of science (Aitken et al., 2010; Jackson et al., 2015; Lindley, 2006; Margot, 2017; Roberts & Aitken, 2014; R. v Reed (David), 2009; R. v Arshad (Nosheen), 2012). Definitions are often required to identify the essential attributes of the concept being defined (Aristotle, 1989). In forensic science, however, the term 'uncertainty' is often introduced as an attribute, rather than introducing the term by establishing its core attributes.

Despite the principally informal understanding of the term 'uncertainty', two potentially useful definitions of this concept in forensic science have been identified. According to the first definition by Taroni & Biedermann (2014, 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 has been identified in the writings of Biedermann and Kotsoglou (2020, p.264), which is based upon a conceptualisation of the term by de Finetti (2017) 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. It may be argued 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. The definition borrowed from Sense about Science and adjusted to the context of forensic science, may provide a more nuanced alternative (see section 1.2).

Nevertheless, the explanations provided by Taroni and Biedermann (2014) and Biedermann and Kotsoglou (2020) identify some key components of the term that may contribute towards demonstrating the essence of the concept of 'uncertainty'. These components include: 'incomplete understanding', 'imperfect knowledge' and 'extent of knowledge and ignorance', as well as the personally experienced and perceived nature of uncertainty (Biedermann & Kotsoglou, 2020). 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 a narrative that does not rely as much on informal tacit understandings of the concept. They are, therefore, a valuable starting point for conceptualising, evaluating and communicating uncertainty in forensic science and has the potential to contribute to wider efforts seeking to achieve greater transparency in forensic reporting practices (Earwaker et al., 2020; Horsman, 2020; Howes, 2015; Kruse, 2013; National Research Council, 2009).

3.2.2 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 (Oberkampf et al., 2002). 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 (National Research Council, 2009). Despite numerous calls throughout the report for the development of standardized language to communicate sources of uncertainty (National Research Council, 2009), the report itself fails to use the term uncertainty in a clear and consistent manner. One section, entitled 'Uncertainties and Errors' does not explain the distinction between the two terms but rather focuses on the sources of error and measurement error, while uncertainty is merely mentioned in terms of 'intervals of uncertainty'. Intervals of uncertainty is an instrument used to provide a range of numerical values, which can qualify experts' conclusions in light of potential error sources.

Confounding of these two terms can also be observed in more recent published studies where it is suggested that uncertainties can be the result of human error (Kampourakis et al., 2019), or where uncertainty is expounded by giving the example of errors on the evidential value of DNA (Kloosterman et al., 2014). The failure to define and separate the terms 'uncertainty' and 'error' does not only obscure semantic clarity and consistency, but it also constitutes an obstacle towards gaining better insights towards the relationship of the two concepts. Too often a directional relationship between 'uncertainty' and 'errors' is assumed; a relationship in which the latter may give rise to the former. This, however, may not always be the case, particularly when the meaning behind the two terms is examined. What lies at the heart of the separation of the 'uncertainty' and 'error' is the existence or absence of knowledge. Unlike 'uncertainty', which has been described as 'imperfect knowledge' (Taroni & Biedermann, 2014; Taroni et al., 2010) or the absence of determinism (Sense about Science, 2013), 'error' is understood as inaccuracy that can be known or identified upon examination (Oberkampf et al., 2002). If such inaccuracy – error – is indeed known 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 (2014) in their definition are 'incomplete understanding' or 'imperfect knowledge'. On the basis of these definitions, the directional relationship assumed in these two published research examples (Kampourakis et al., 2019; Kloosterman et al., 2014) are arguably questionable. Moreover, in other fields it has been shown that such a directional relationship is not absolute. In the field of medicine it has been recognised that uncertainty, particularly when mismanaged, may be an important contributing factor towards the commission of errors in the decision-making or final conclusions of experts (Alam et al., 2017; Bhise, Rajan, et al., 2018).

Seeking a segregation of the two 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 (Dror & Pierce, 2020; Morgan et al., 2018). Furthermore, vague and inconsistent definitions can lead to the 'misuse and misunderstanding' of the terms (Inman & Rudin, 2002) within different institutional organisations 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.

3.3. Eliciting the concept of 'uncertainty'

3.3.1. Types or sources of uncertainty

Identifying the different facets of uncertainty is as important as maintaining a consistent definition across different institutions and organisations. The discussion of uncertainty in forensic science presented here is structured around three of the stages of the forensic science process developed by Morgan (Morgan, 2017a) and draws on the published academic literature addressing forensic science evidence that has identified different types and sources of uncertainty. 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 that of evidence dynamics or cognitive biases, have been very well documented and have implicitly highlighted sources and characteristics of uncertainty (see section 2.2), this review only includes those materials that directly or explicitly identify different types and sources of uncertainty.

The terms 'types' and 'sources' are used interchangeably here, given that to date a coherent framework that considers uncertainty and error has not yet been articulated that draws a distinction between the two terms and their respective applicability. Table 3.1 provides a summary of key published literature that addresses different sources of uncertainty as an overview of the different types of uncertainty and how these have been recognised and discussed in academia, policy and case law literature to date.

Source of Uncertainty	Academia	Policy	Case law
Evidence dynamics	Taroni & Biedermann (2014), Earwaker et al. (2020), Nakhaeizadeh et al. (2014), Chisum & Turvey (2011)	Forensic Science Regulator (2018, 2015, 2017, 2019, 2020), House of Lords Science and Technology Select Committee (2019)	
Incomplete/Imperfect/Missing data	Curran (2016), Noor et al. (2014), Margot (2017)		R. v T (2010), R. v Slade (2015)
Nature of data	Lucy & Kingdom, (2006)		
Sampling uncertainty	Kruse (2013), Hannig et al. (2019), Curran & Buckleton (2011), Wang et al. (2019)	Forensic Science Regulator (2020a)	
Knowledge uncertainties	Kruse (2013), Curran (2016), Mnookin (2010)	Law Commission (2011), Roberts & Aitken (2014)	
Analytical/Laboratory instruments	Kruse (2013)	European Network of Forensic Science Institutes (2015), United Kingdom Accreditation Service (UKAS) (2019)	
Measurement uncertainty		Forensic Science Regulator (2020a, 2020b)	
Model uncertainty	Lund & Iyer (2017), Sjerps et al. (2016), Taroni et al. (2016)		
Judgment/Inferences	Morgan et al., (2018), Taroni & Biedermann	National Academy of Sciences	

	(2014), Earwaker et al. (2020), Nakhaeizadeh et al. (2014), Morgan (2019), Martire et al. (2017)	(National Research Council, 2009), Aitken et al. (2010), Roberts & Aitken (2014)	
Contrasting views	Noor et al. (2014), Martire et al., (2017)	Puch-Solis et al. (2012)	R. v Thomas (B), (2006)
Linguistic imprecision	Noor et al. (2014)		
Inconsistent definitions			R. v Kai-Whitewind (2005)
DNA Allelic dropouts	Lohmueller & Inman (2018)	Puch-Solis et al. (2012)	
Anomalous or mixtures of DNA	Kruger (2012)	Puch-Solis et al. (2012)	
DNA Allele designation	Balding (2013)	Puch-Solis et al. (2012)	

Table 3.1| *Summary Table of the academic, policy and case-law materials identifying, recognising or discussing types/sources of uncertainty*

3.3.1.A. Crime Scene

A significant area in which uncertainty has been identified in forensic science is in relation to evidence dynamics (Earwaker et al., 2020; Nakhaeizadeh et al., 2014). Evidence dynamics refer to those conditions that exist prior to and at the crime scene that may alter the state of or obliterate forensic science materials that may be relevant to the crime reconstruction process (Chisum & Turvey, 2011). 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 (Taroni & Biedermann, 2014), as well as their final findings and conclusions (Chisum & Turvey, 2011; Nakhaeizadeh et al., 2018).

The trace, the crime scene environment and the collection of forensic science materials may give rise to what is often referred to as 'data uncertainties'. Traces found at a crime scene constitute inherently incomplete and imperfect fragments or remnants of an event (Margot, 2011b; Margot, 2017). As such, this inherently fragmented nature of traces can contribute to uncertainty (Curran, 2016; Margot, 2017; Noor et al., 2014) and can create challenges during subsequent stages of the crime reconstruction process, such as the stage of evaluation (Lucy & Kingdom, 2006), as they are the fundamental medium for the provision of data and information upon which the decision-making of forensic science experts rests. The courts have also indirectly recognised the challenges and limitations that may arise as a result of the uncertainties in the data relied upon by the expert providing opinion evidence (R. v T, 2010; R. v Slade (Dennis Patrick), 2015).

3.3.1.B. 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 recognised the importance of sampling uncertainty in explicit (Curran & Buckleton, 2011; Hannig et al., 2019) or implicit terms (Kruse, 2013). 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 (Curran & Buckleton, 2011). More specific concerns have included, the representativeness of footwear sole pattern databases (Kruse, 2013) and the impact of sampling upon the uncertainty in the computation of a likelihood ratio for forensic voice comparison (Wang et al., 2019).

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 (Curran & Buckleton, 2011). 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 (Forensic Science Regulator, 2020a). However, there is currently no mandatory requirement to carry out an evaluation of sampling uncertainty for the purposes of forensic science reports or testimonies (Forensic Science Regulator, 2020a, 2020c).

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 (Curran, 2016; Kruse, 2013; Mnookin, 2010), 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 (2013) 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 (Kruse, 2013). A perhaps broader understanding of knowledge is captured by Mnookin (2010) who raises concerns regarding valid forms of knowledge in different forensic sub-disciplines, as a result of absent formalised and standardised 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 (Morgan, 2017a) as well as in relation to 'explicit' forms of knowledge, as generated or encoded by the relevant institutions and organisations (Morgan, 2017b).

The continuum of 'tacit and explicit knowledge' as developed and applied by Morgan (2017b) 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 recognised source of uncertainties (European Network of Forensic Science Institutes, 2015; Kruse, 2013). Uncertainties may exist in the practices that involve greater elements of human decision-making and evaluative interpretation – such as fingerprint examination – in which a blend of tacit and explicit knowledge is generated (Kruse, 2013; United Kingdom Accreditation Service, 2019). Uncertainties have also been noted as relating to the precision or accuracy of techniques employed or the instruments used, such as mass spectrometry or DNA analysis (European Network of Forensic Science Institutes, 2015), which may fall on the 'explicit' form of knowledge end of the spectrum. Such uncertainties are often also referred to as measurement uncertainties.

Measurement and modelling uncertainties are a widely recognised type of uncertainty both by academics and policy makers (Forensic Science Regulator, 2020a; Lund & Iyer, 2017; Sjerps et al., 2016). Forensic science experts in the UK are required to include 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 (Forensic Science Regulator, 2020c). With regards to interpretive or evaluative sub-disciplines, the Forensic Science Regulator requires that an evaluation of measurement uncertainty is also carried out (Forensic Science Regulator, 2020a). The Code of Practice and Conduct goes on to recognise 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.

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, hence rendering it unfeasible to select with absolute certainty one model as a better fit over others in in converting the available data into probabilities (Lund & Iyer, 2017).Uncertainties have also been recognised in terms of the parameters that inform the models (Sjerps et al., 2016). 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 (Sjerps et al., 2016).

3.3.1.C. Evidence Interpretation

More recently, significant attention has been focussed on the inevitability of uncertainty in the judgment and inferences of human decision-makers. Uncertainty has been identified as being present in the decision making of forensic science experts in every step of the crime reconstruction process (Earwaker et al., 2020; Morgan, 2019; Morgan et al., 2018) with the contributing factors being well documented (Dror, 2017). One key potential factor is the gaps in the knowledge base or evidence base and the resulting necessity for abductive evidential reasoning (Earwaker et al., 2020; Taroni& Biedermann, 2014). Intrinsic and extrinsic factors influencing the decision-making of experts and giving rise to uncertainty have also been noted (Morgan, 2019). Extrinsic factors include the environmental factors which 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 (Earwaker et al., 2020; Martire et al., 2017; Nakhaeizadeh et al., 2014; National Research Council, 2009). Intrinsic factors are also significant. For example, in the judgment of the Court of Appeal in the case of R. v Thomas (B) (2006), it was emphasised 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 significant issue giving rise to uncertainty (Earwaker et al., 2020). Decision making by human actors occurs at every stage of the 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 (Morgan, 2017b) uncertainty becomes an integral part of crime reconstruction endeavours.

The uncertainty associated with the judgment and conclusions reached by forensic science experts is also manifest in the variations that can be observed in resulting scientific opinion (Martire et al., 2017; Noor et al., 2014). In the guidance provided by the Court of Appeal in R. v Thomas (B) (2006) 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 judgment may have implicitly acknowledged the range of expert views as a source of uncertainty that needs to be disclosed.

3.3.1.D. 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 (Morgan et al., 2018). 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) (i.e. gaps in the evidence base or data), 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).

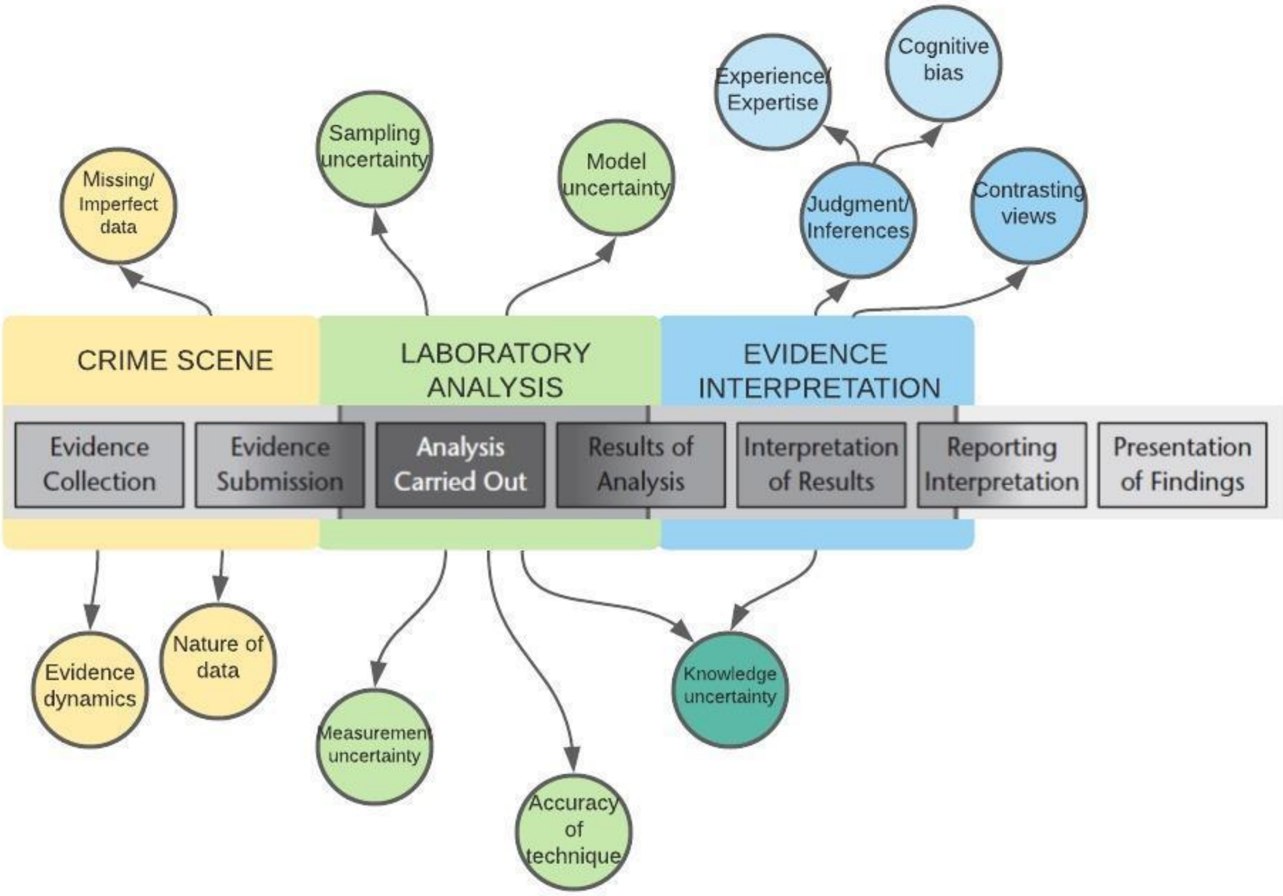

Figure 3.1| *Uncertainty types mapped on forensic science process developed by Morgan et al. (2018).*

Uncertainty is therefore present in every stage of the crime reconstruction process (Morgan et al., 2018). 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 authors. Several other sources of uncertainty also arose during the review including, uncertainties related to linguistic imprecision (Noor et al., 2014), inconsistent definitions (R. v Kai-Whitewind, 2005), and in the domain of DNA, allelic dropouts (Lohmueller & Inman, 2018), anomalous or mixed samples (Kruger, 2012), and allele designation (Balding, 2013).

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, to develop an understanding and conceptualisation of uncertainty in terms of its types and sources. Given the large number of sources and types of uncertainty that have been identified, a more coherent and systematic organisation of the nature of uncertainty is clearly necessary in order to for uncertainty to be more transparently and robustly managed in crime reconstructions.

3.3.2 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 best documented descriptions of the nature of uncertainty in forensic science is the triptych of uncertainty popularised by Donald Rumsfeld, the U.S. Defence Secretary in 2006; that of known knowns, known unknowns and unknown unknowns (Niven, 2019). According to this triptych, which has been incorporated into academic and policy reform work (Earwaker et al., 2020; Law Commission, 2011; Morgan, 2019), 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 (Spiegelhalter, 2017) and there are a wide range of taxonomies or structures of uncertainty that have been developed across a number of other disciplines, such as environmental science (Krupnick et al., 2006). There is therefore value in exploring the narratives that have been adopted by other allied disciplines (Georgiou et al., 2020) 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 (Aitken et al., 2010; Earwaker et al., 2020; Kampourakis et al., 2019; Morgan, 2019; Morgan et al., 2018;

National Research Council, 2009; Roberts & Aitken, 2014; Taroni& Biedermann, 2014) as well as whether it is reducible or irreducible (Earwaker et al., 2020; Jackson et al., 2015; Morgan, 2019; Wang et al., 2019). But perhaps the biggest shift in the narrative deployed by forensic science with regards to characterising 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 (Berger et al., 2011; National Research Council, 2009). The measurement of uncertainty was a significant topic of discussion in the National Academy of Science's seminal report (National Research Council, 2009), while reports and guidance documents of the Forensic Science Regulator have regularly highlighted it (Forensic Science Regulator, 2020a; Tully, 2020). In 2011, a number of academics became signatories to a statement which hailed probability theory as 'the only coherent logical foundation' for 'reasoning in the face of uncertainty' (Berger et al., 2011, p.11). Similar positions were expressed by the ENFSI (European Network of Forensic Science Institutes, 2015), the Royal Statistical Society (Aitken et al., 2010; Jackson et al., 2015; Puch-Solis et al., 2012; Roberts & Aitken, 2014) and more recently by Taroni & Biedermann (2014) 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 is always possible to quantify. However, this insistence on quantifying and measuring uncertainty indicates a narrative that is unable to incorporate uncertainty that is unquantifiable by nature. It is also in contradiction to some definitions of uncertainty which draw a distinction between risk (which is quantifiable) and uncertainty (which is often unquantifiable) (Knight, 1921).

There are signs that this narrative is shifting, with calls being made to address uncertainty in a more holistic manner, so as to capture those uncertainties that may not be amenable to quantification (Earwaker et al., 2020; Morgan et al., 2018). 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 (Law Commission, 2011), 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' (Law Commission, 2011, p.129). More recently, explicit acknowledgements of the need for a more holistic framework have been expressed by academics, such as Martire et al. (2017) who question whether the Bayesian subjective probabilities assigned by forensic science experts can capture uncertainty in its entirety. Similarly, Morgan et al. (2018), highlighted the need for a holistic evaluative framework of uncertainty, that goes beyond the insistence on quantification, to reflect the decision-making element of the scientific endeavour which plays a central role in crime reconstruction activities. 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.

However, details of how such evaluations could be performed have not been (to date) set out. Most recently there have been studies that suggest the value and utilisation of qualitative and semi-qualitative tools to communicate the degree of uncertainty in the evaluative interpretation of both digital materials (Horsman, 2020) and physical traces (Georgiou et al., 2020), even though criticisms have been expressed with regards to the opinions expressed by the former (Biedermann & Kotsoglou, 2020).

3.4. Conclusion:

From this review it is clear that forensic science faces challenges when it comes to communicating uncertainty and incorporating uncertainty into evaluative interpretation in crime reconstructions. These challenges stem from a contested definition of uncertainty, its typology and the characterisation of the nature of uncertainty. However, this narrative appears to be shifting, particularly with the extensive identification of sources or types of uncertainty, 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.

The gradual acceptance and open acknowledgement of uncertainty in forensic science can arguably be considered as the beginning of a transition from the ideals of modernity, with its insistence on apparent certainty and order (Williams, 2000), towards postmodernity, and its capacity to holistically embrace uncertainty (Kelso, 1997).This new era of uncertainty is one in which the perception of forensic science evidence in dual opposites is abandoned, so that there are no longer reliable or unreliable forensic science evidence, but rather 'only cases in which inherent uncertainty is correctly or incorrectly harnessed' (Pascali & Prinz, 2012, p.775).

Significant 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 significant move is needed to embed ongoing conversation, and exchange of opinions, experiences and ideas among all forensic science stakeholders. This will bring us a step closer to incorporating uncertainty transparently and robustly into the scientific endeavour of crime reconstruction.

Chapter 3 – Key Points

- There has been a principally informal understanding of the term ‘uncertainty’ in forensic science, as observed through a review of the academic literature, policy reports, and case law.
- Taroni and Biedermann (2014) and Biedermann and Kotsoglou (2020) have provided two definitions for the term ‘uncertainty’ which constitute an important shift away from an informal tacit understanding of uncertainty.
- The terms ‘uncertainty’ and ‘error’ are frequently confounded by both academics and policy-makers. A clear separation between the meaning of the two terms is important, for the purposes of consistency of understandings across stakeholders, but also for the selection and development of appropriate strategies for dealing with each of these.
- A range of ‘types’ or ‘sources’ of uncertainty have been identified in the literature of forensic science, signifying progress in the development of a more nuanced understanding of the phenomenon of uncertainty.
- There has been an increasing awareness of the existence of sources of uncertainty that are not amenable to quantification, with calls for a more holistic framework of uncertainty evaluation.
- This review has revealed a shift in the narrative through which uncertainty in forensic science is conceptualised and understood. This shift constitutes a transition from the denial of uncertainty, towards greater awareness, acceptance and open acknowledgement of its existence across all stages of the crime reconstruction progress.
- There still remains significant progress to made, in systematically and coherently organising the nature and characteristics of uncertainty, as well as in reaching an agreement by all stakeholders in relation to its definition and typologies.

4. Method Development: Forensic Science, issues of identity and ‘neighbouring’ disciplines

4.1. Introduction

Significant progress has been achieved in the last decade in developing a more nuanced and clear understanding regarding the nature and characteristics of uncertainty in forensic science. Yet, there is still a lack of coherence and standardisation in the manner by which uncertainty in forensic science is conceptualised. Furthermore, even though there is a growing awareness of the possibility of non-quantifiable types of uncertainty, the prominent paradigm in the literature of forensic science, when it comes to evaluating uncertainty, is the use of probabilities. As such, there is still a gap that needs to be addressed with regards to the conceptualisation, evaluation and subsequent communication of uncertainty to lay stakeholders.

By exploring the manner in which uncertainty is articulated, evaluated and communicated in other disciplines in a structured way, it is possible to identify new ideas, concepts and practices with potential transfer and application in the ‘home’ discipline (Miller & Mansilla, 2004, p.3). This chapter sets out the method employed to select disciplines that can be considered as ‘neighbouring’ to the ‘home’ discipline. This is a necessary prerequisite to the conducting of the interdisciplinary configurative review that can identify insights to articulate conceptual, evaluative and communicative tools for addressing scientific uncertainty in forensic science (Chapter 5). The ‘neighbourliness’ of the disciplines that are included for exploration and examination in reviews is also significant, as it can allow for a clearer and more coherent application and applicability of the identified ideas, concepts, principles and approaches – as opposed to drawing ideas from disciplines that are quite distinct from the ‘home’ discipline.

When developing the methods for the interdisciplinary configurative review, an exploration of existing methods for the selection of disciplines for inclusion was carried out. The identified reviews that engaged with multiple disciplines, failed to provide a detailed account of their methods (Greenhalgh et al., 2005; Karunananthan et al., 2009; Umoquit et al., 2011). This rendered the replication of a methodological approach for the purposes of this study infeasible. Therefore, this chapter constitutes a preliminary phase to the interdisciplinary configurative review in Chapter 5 and focuses on providing the details of the method that was developed in order to render the execution of the second study possible.

Prior to developing the requisite methods for the second study and for the selection of the disciplines to be considered for the interdisciplinary configurative review, it was necessary to evaluate whether forensic science may be regarded as a discipline, particularly in light of current discussions over its contested identity (Morgan, 2019; Morgan, 2018a; Roux et al., 2015). As such, this chapter begins with an evaluation of the nature of forensic science as a discipline, followed by a construction of an argument for the more precise conceptualisation of its identity as a type of post-normal science. Following this, the development of the inclusion criteria, as based on the conceptualisation of the identity of forensic science as a post-normal science, is reported and applied to the identified pool of disciplines.

Even though this chapter serves as a preliminary chapter, setting out the necessary foundations for the interdisciplinary configurative review in Chapter 5, it may also be considered as a valuable contribution to wider discussions around the identity of forensic science, as well as to methodological approaches in relation to the selection of disciplines for multiple-disciplinary reviews.

4.2. A case for the construction of the identity of forensic science as a post-normal scientific discipline

4.2.1 Forensic Science as a discipline:

Drawing boundaries and defining scientific disciplines has always been a challenging endeavour (Weingart & Stehr, 2000). The recognition of forensic science as a scientific discipline in its own right has been a particularly challenging and contentious undertaking (Morgan, 2017a), with its identity having historically been debated; whether it was best described as a profession, a science or an occupation (Kirk, 1963). Different contested identities for forensic science are still currently at play (Morgan, 2019). More recently, one of the terms associated with forensic science is that of 'forensics' (Roux et al., 2012). The focus of this term is on the existence of widely established disciplines, such as chemistry and biology, and how these disciplines can assist with the analysis of 'remnants of activity' retrieved at the crime scene (Roux et al., 2015). Another more modern descriptor for forensic science, has been that of 'Forensic Sciences'. There are certain connotations behind 'forensic sciences', one of which is the plurality of scientific perspectives encompassed within this 'field of study' (Morgan, 2019). According to this understanding of forensic science, the emphasis remains on the traditional disciplines, recognising however their collective application and contribution in criminal investigations and subsequently in criminal trials (Morgan, 2019).

Despite the more collective understanding achieved from the latter description of 'forensic science' – with its emphasis on traditional disciplines and their respective role in analysing each 'remnant of activity' found at the crime scene – a fragmented view of 'forensic science' still prevails. This fragmented perception of forensic science is also reflected in the existence of separate European working groups representing a specific forensic technique, rather than the discipline of forensic science as a whole (Roux et al., 2015). Such an understanding inhibits the conceptualisation of forensic science as a discipline in its own right, aimed at the holistic reconstruction of crime (Morgan, 2019). Despite calls for the acknowledgement of ‘forensic science’ as a unified discipline (Crispino et al., 2011; Margot, 2011a; Morgan, 2018a; Morgan, 2019), consensus has yet to be reached on its identity as such (Morgan, 2019). A number of perspectives and criteria that have been developed over the years are presented here for the purpose of arguing in favour of the recognition of ‘forensic science’ as an emerging coherent discipline. Three overlapping sets of criteria have been identified which represent the most dominant and frequently discussed determining factors of a discipline (Kaul, 2004; Krishnan, 2009; Liles et al., 1995). The set of features/criteria identified by Krishnan (2009) have been applied to forensic science in order to demonstrate that forensic science can, and should, be widely acknowledged as a discipline. Not all the criteria need to be satisfied for the existence of a discipline to be determined (Krishnan, 2009). However, the more criteria that are satisfied, the more likely it is that the field of research/ study/ enquiry constitutes a discipline worthy of recognition as such. Table 4.1 provides a brief overview of the application of these criteria, followed by a more detailed discussion of how well forensic science satisfies these.

Criterion	**Is it fulfilled?**	**Evidence to support decision**
1. Topic/Object of research	✓	‘Remnant of activity and/or presence’ – traces, patterns, signal. (Roux et al., 2015)
2. Body of specialist knowledge	✓	Empirical studies on evidence dynamics and subjective decision-making of forensic science experts (Chisum & Turvey, 2011; Dror, Charlton, D. & Péron, 2006; Dror, 2012; Meakin et al., 2017).
3. Theories and concepts	?	Locard’s exchange principle and Kirk’s principle of individuality (Crispino et al., 2011).
4. Terminology and language	?	OSAC lexicon (National Institute of Standards and Technology, 2018).
5. Method	✓	CAI framework (Cook et al., 1998), Numerical and Verbal Expressions (Association of Forensic Science Providers, 2009).

6. Institutionalisation	✓	Academic departments, taught degrees, professional bodies (Morgan, 2019).

Table 4.1| *Discipline Identification Criteria applied to Forensic Science*

The first defining feature of a discipline is the existence of a topic/ object of research. Forensic science satisfies this criterion, according to Roux et al. (2015), as the particular object of research that forensic science is concerned with is traces – 'the remnants of activity and/or presence' found at a crime scene (Roux et al., 2015, p.7). Forensic science experts, regardless of their subspecialisation, are concerned with the recognition, identification, analysis and evaluation of remnants, whether in the form of traces, marks or patterns, to assist with questions of activity, source, or less frequently type of offence (De Forest, 1999; Jackson, 2009).

A growing body of literature has also been developed over the years in relation to 'remnants of activity and/or presence' (Roux et al., 2015, p.7). Research has been carried out concerning evidence dynamics – the behaviour of traces or patterns under different conditions – and how these dynamics and behaviours can influence the interpretation practices of forensic science experts (Meakin et al., 2017; Chisum & Turvey, 2011). Empirical studies have also concentrated on the decision-making of forensic science experts when interpreting remnants of activity or source (Dror, 2012; Dror & Charlton, 2006). These studies can be considered as further contributions towards the existence of a body of specialist knowledge or an evidence base (Morgan, 2017a) which informs forensic science's object of research and thus fulfils the second criterion of a discipline as well.

The third criterion may not be as readily satisfied as the two preceding it, given that the existence of widely accepted and tenable theories and concepts is debatable. Two principles have been put forward as a form of support for the existence of the discipline of forensic science. Crispino et al. (2011) argue that Kirk's principle of individuality (Kirk, 1963) and Locard's exchange principle can provide the founding theoretical basis to support the existence of forensic science as a discipline in its own right. Kirk's principle of individuality suggests that all items or bodies are unique. Locard's exchange principle (Locard, 1920), according to which a trace will either be left at the scene by the perpetrator or picked up by the perpetrator (translated in English in Roux et al., 2012, p.15) , has been a foundational principle in forensic science. It was one of the first attempts at explaining the relationship between source, the activity that led to the trace or pattern, and the persistence of that trace or pattern (Crispino et al., 2011). Yet, strong criticisms have been expressed regarding both principles. The unproven nature of Kirk's claim of individuality – an admittedly largely philosophical debate – has been questioned, particularly in relation to its relevance in forensic science conclusions (Cole, 2009; Finkelstein &

Fairley, 1970). Similarly, concerns have been raised regarding Locard's exchange principle, and the dearth of relevant literature that 'supports or refutes' this axiom (Inman & Rudin, 2001, p.94). The two principles have played a significant role in organising the body of knowledge that has been developed in forensic science. However, given their highly questionable nature, it is a matter of debate whether the third criterion can be considered as satisfied.

Equally debatable may be the fulfilment of the fourth criterion for the existence of a discipline. A number of terms are frequently used by forensic science experts in their reports and testimonies, including, 'consistent with', 'cannot exclude', 'match', 'very likely came from' (Fraser & Williams, 2009), 'share a common origin' (McQuiston-Surrett & Saks, 2007). A recent codification of these has also been attempted by the Organization of Scientific Area Committees for Forensic Science (National Institute of Standards and Technology, 2018). Even though courts, have not always been quick to note or criticise the use of such terms (R. v Dlugosz), academics have raised concerns regarding the highly subjective and vague terminology used by forensic science experts in court (Champod, 2013; Evett & Pope, 2013). Terms such as the ones identified, do not provide sufficient information regarding alternative propositions (i.e. how many other sources may also be considered as 'consistent with' the retrieved trace), while their vague nature allows for diverse interpretations by jurors regarding the probative weight of the evidence (Neumann et al., 2016).

The Case Assessment and Interpretation project set up at the Forensic Science Service in the 1990s, as well as the Bayesian paradigm, contributed towards influencing the language and terminology used by forensic science experts (Cook et al., 1998). Forensic science experts are encouraged to evaluate the evidence in terms of two competing propositions that would be of interest to jurors mainly in relation to matters of source or activity (Evett, 2015). The weight of the evidence is reported quantitatively or most frequently qualitatively in relation to the two propositions (Evett, 2015). The Association of Forensic Science Providers (2009) also published a set of standards including numerical and verbal expressions to assist with the presentation of the likelihood ratio; verbal scales which have, however, been subject to criticisms by the academic community (Brun & Teigen, 1988; Martire et al., 2014; McQuiston-Surrett & Saks, 2007). Despite the existence of frequently used terms by forensic science experts, and efforts to qualitatively and consistently convey the likelihood ratio, there is a significant gap with regards to the development of a standardised vocabulary to communicate the findings of forensic science experts (National Commission on Forensic Science, 2015; National Research Council, 2009). The absence of consistent terminology by different actors and across institutions, not only inhibits the transparent communication of forensic findings, but it also constitutes an obstacle to effective collaboration between stakeholders (Earwaker et al., 2020). As such, it may also arguably be considered as an obstacle to the recognition of forensic science as a holistic, cohesive discipline.

Aside from theories, concepts and standardised language, the development of specific methods to address the aims of the field of study is also a critical requirement for the recognition of that field of study as an academic discipline. Crispino et al. (2011) suggest that the model of Case Assessment and Interpretation (CAI) (Cook et al., 1998) is a sufficiently valid method that is particular to the forensic science discipline and can be employed across sub-disciplines. The CAI framework seeks to rationally guide the decision-making of forensic science experts by insisting on a balanced, transparent and probabilistic method in dealing with the assessment and interpretation of forensic science evidence (Jackson et al., 2015). The model has not been devoid of criticisms. The CAI model has been criticised for confounding the boundaries between the roles of the forensic science expert, the police and the jury, through its development of three level propositions that are intended for consideration by the forensic science expert (Lawless, 2010). The controversial propositions are those of activity and offence, which have been argued to be matters within the remit of the police and the jury respectively (Lawless, 2010). The framework also lacked widespread acceptance, with some experts resisting its Bayesian nature (Lawless, 2010). Despite the lack of consensus regarding the application of the CAI model across institutions, it may arguably be considered as a method developed for addressing the specific purposes and research objects of the discipline of forensic science as a whole. Therefore, the fifth criterion could be deemed as satisfied.

Finally, the last criterion is perhaps the least contested of all and may even be considered as the most integral characteristic of the existence of an academic discipline; namely the existence of a discipline as a social structure. According to this criterion, a discipline must be institutionalised, either professionally or academically (De Forest, 1999; Krishnan, 2009; Stichweh, 2003). There have been significantly greater efforts in the past few decades to institutionalise forensic science and establish it as an organised, social structure, particularly within the academic world. Undergraduate and postgraduate degrees are taught at universities around the world, peer-reviewed journals with a specific focus on forensic science have gained widespread recognition, while professional bodies that oversee and represent forensic science as a coherent discipline have also been formed (Morgan, 2018a; Morgan, 2019). Some examples of the latter include, the Forensic Science Society, the Chartered Society of Forensic Sciences and the British Academy of Forensic Sciences. Arguably the title of the two latter bodies may be contradictory to the existence of a holistic forensic science discipline. Nevertheless, a forensic science community exists and has been institutionalised to a sufficient degree so as to motivate the creation of professional bodies, academic departments, university degrees and peer-reviewed journals.

As can be observed from the application of the identified relevant criteria for the recognition of forensic science as a discipline, half of these criteria may be considered as fulfilled. There is still significant room for improvement, particularly when it comes to achieving standardisation of practices and vocabulary in forensic science (National Research Council, 2009; Morgan, 2017b; Earwaker et al., 2020). However, the progress that has been achieved so far, in developing a more holistic and cohesive social organisation of forensic science as a discipline should not be overlooked. Thus, there is a strong case to be made for the wider acceptance of forensic science as a discipline in its own right.

4.2.2. Forensic & Science:

Arguing in favour of the recognition of forensic science as a discipline in its own right was not be sufficient in painting a detailed picture regarding its nature as a scientific discipline. For the selection of 'neighbouring' disciplines based on similarities with forensic science, additional characteristics/features of the 'home' disciplines were required to be elicited. The following analysis involved an examination and conceptualisation of its two key components – 'forensic' and 'science' – in such a manner so that the selection criteria of 'neighbouring' disciplines were sufficiently distinctive, yet not overly inclusive or exclusive.

4.2.2.A. Forensic:

The dictionary definition of forensic is twofold. Forensic is described as 'relating to or denoting the application of scientific methods and techniques to the investigation of crime.' It is also defined as 'relating to courts of law' (Oxford Languages, 2021). An adoption of either of these two definitions would render the inclusion criteria too restrictive. If the former was adopted, the interdisciplinary review would be restricted to those disciplines that relate to courts of law, or which are concerned with the application of science for the purpose of criminal investigation. If the latter definition was preferred, the review would be bound to only those disciplines that are concerned with expert witness testimonies in criminal or civil trials. Expert witness evidence, regardless of the area of expertise, has been the subject of criticisms not too dissimilar to those directed to forensic science (Redmayne, 2001; Roberts & Zuckerman, 2010). Reviewing areas of expertise which suffer from similar limitations as those of forensic science would defy the purpose of the interdisciplinary configurative review; the development of innovative, feasible and effectives ways to conceptualise, evaluate and communicate the complex phenomenon of uncertainty.

Even though the definitions identified may not have been suitable for the elicitation of distinctive features that could assist with the selection of 'neighbouring disciplines' – at least not in verbatim – the centrality of the role played by the court in the definition of the term 'forensic' was still recognised and preserved as significant when developing discipline selection criteria. As such, instead of viewing the court through its specific function within the criminal justice system, it was viewed as a public forum. This perspective was based on the original conceptualisation of the term 'forensic', as the study of argumentation in public forums (Kiely, 2005). Participants to a public forum, such as that of a court, frequently have little knowledge of the intricacies involved in the work of forensic science experts. The admissibility of expert witness evidence in England and Wales actually expects that the information provided by the witness should exist outside the common knowledge and experience of the jury (R. v Turner, 1975). This wider perspective that views the court as a lay audience is also reflective of the empirical studies that have been conducted so far on the communication of expert witness evidence in court, which have examined the understanding of lay participants (Martire et al., 2013) or mock jurors (Smith et al., 2011).

4.2.2.B. Science

Discussions around the second component of the discipline – 'science' – have been highly contentious. Forensic science is often referred to as an applied science (Forensic Science Regulator, 2014; Inman & Rudin, 2011), while academics such as Crispino et al. (2011) support that the defining principles upon which forensic science rests are sufficiently scientific so that forensic science merits the definition of a scientific discipline. Yet, the scientific basis of forensic science has been disputed by academics (Mnookin, 2010; Mnookin et al., 2011; Murphy, 2007) and professional bodies (National Research Council, 2009) over the years, while on a few occasions references have been made to its artistic nature. For example, Inman and Rudin (2002) have described forensic science as an 'artistic and intuitive' approach, while Stover & Joyce referred to forensic anthropology as an 'artistry along with empirical measurements' (1991, p.48).

The artistic element often observed in forensic science is the result of the significant role played by human, subjective expertise in the processes of the analysis and interpretation of forensic science evidence (Dror & Hampikian, 2011; Thompson, 1995), especially when faced with a substantial degree of uncertainty. Even though it is recognised that uncertainty is inherent in all scientific undertakings, uncertainty in forensic science is particularly prevalent, often considered the norm rather than the exception (Taroni & Biedermann, 2015). Not only do forensic science experts deal with the uncertainty arising due to the unknown nature of past events, the remnants of which they have to examine, they frequently have to work with scarce data and facts (Dror, 2018). Every crime reconstruction case is different, therefore even when empirical studies are available, the applicability of these to the specific case in hand is not always straightforward. Furthermore, the generalisability of existing empirical researches is somewhat suspect, as they are carried out under more sanitised conditions, rather than exactly replicating the messy real-life conditions in which traces, marks, patterns or signals are found (Lepot & Driessche, 2015).

Therefore, experience, skill and the previous training of forensic science experts contribute towards the forming of inferences and assumptions that are necessary to fill in the gaps (Inman & Rudin, 2001). These elements constitute the basis of the forensic science expert's expertise, an expertise considered valuable (Morgan, 2017b; Mnookin et al., 2011), particularly when it comes to filling in the gaps that arise due to uncertainty. Yet, it is a form of expertise described by the confounding of the boundaries between art and science (Inman & Rudin, 2001).

4.3. 'Neighbouring' Disciplines:

Inquiring into the terms that make up the title of 'forensic science' as a discipline, led to the identification of certain distinctive identifying features. These distinctive features included, interactions with a lay audience, the existence of significant uncertainty, variation between cases, human subjective decision-making and expertise, and the blurred lines between art and science.

These characteristics, as well as the social context in which forensic science operates, are captured to a great extent by the theory of post-normal science (Ravetz, 1999). This theory recognises and embraces the uncertainty, value-loading and plurality of perspectives that are inherent in any application of science to a social, issue-driven context, as well as the high stakes involved in the conclusions of issue-driven science experts (Funtowicz & Ravetz, 2003). Textbook knowledge is acknowledged as important, yet insufficient at addressing the issues at hand (Ravetz, 1999), while a number of techniques which would have been dismissed as invalid under the traditional criteria of the philosophy of science, are viewed as necessary and valuable (Funtowicz & Ravetz, 2003).

The intricacies of forensic science are reflected well in the theory of post-normal science, as a result of the permeating uncertainty encountered in every step of the crime reconstruction process, the plurality of perspectives that may exist due to divergence of expert opinions, as well as the high stakes at play if an error were to be committed (Kirk, 1963). Given how well-placed forensic science is within the theoretical framework of post-normal science, the 'neighbouring' disciplines were selected on the basis of their compatibility with this theory and the respective features associated with professional consultancies or post-normal science disciplines. The conceptualisation of the three categories of issue-driven science – applied science, professional consultancy, post-normal science – was used to guide the selection process. Issue-driven science is described by Ravetz as the science applied in a social context, and which is often called to assist on policy matters (1999). This thesis uses the term-issue driven science to refer to those disciplines the expertise of which is required by lay-individuals in a social context in order to make decisions. Such interpretation is consistent with the first term found in the title of 'forensic science' – that of forum, as has been extrapolated and conceptualised in section 4.2.2.A.

Two criteria determine where on the spectrum an issue-driven science falls; the gravity of the decision-stakes of the lay stakeholder and the extent of the uncertainty found in the issue-driven science.

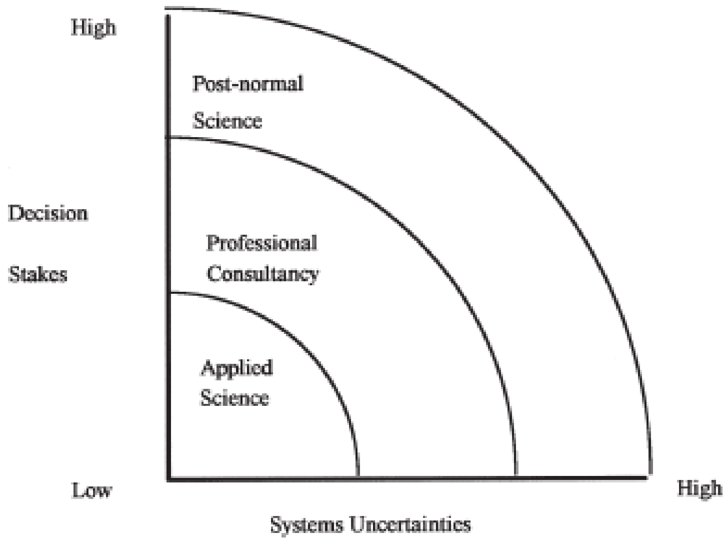

Figure 4.1| *Spectrum of Issue-Driven Sciences (Ravetz, 1999)*

As can be seen from Figure 4.1, when both of these criteria are low, the issue-driven science is considered an applied science. When at least one of these is salient, it is a professional consultancy, while if at least one is severe it is deemed a post-normal science (Ravetz, 1999; Funtowicz & Ravetz, 2003). Only those disciplines that fall under the latter two categories of issue-driven sciences were included in the review, as the levels of uncertainty found in forensic science and the decision-stakes of its lay stakeholders – judges and jurors – could best be described as greater than low. Figure 4.2 provides a number of additional features identified by Ravetz (1999) and Funtowicz & Ravetz (2003) which assisted in determining where on the spectrum an issue-driven science may fall. Section 4.4 utilised these features to examine the pool of potential disciplines and determine their inclusion in the interdisciplinary configurative review.

Figure 4.2| *Guiding features for determining whether a discipline can be described as post-normal science or professional consultancy*

4.4. Selection of Disciplines:

4.4.1. Development of Discipline Selection Criteria

Given the conceptualisation of forensic science as fitting within the theory of post-normal science and as exhibiting strong interactions and communications with a public forum (lay audience), two main selection criteria arose for the inclusion of 'neighbouring disciplines':

1. The experts within the discipline are required to interact strongly with a lay audience, and
2. The discipline may be described as a professional consultancy or post-normal science.

Prior to applying these selection criteria, a pool of potentially suitable disciplines had to be identified. The pool of disciplines was drawn from 'Scopus'; the largest peer-reviewed database (Scopus, 2021). The breadth and consistency of the disciplines encompassed within 'Scopus', were decisive factors in its selection as the pool of disciplines. Scopus has a set of 26 academic disciplinary category labels that remain consistent regardless of the search terms used. A preliminary search using the term 'uncertain*' yielded results in 28 categories.

- Twenty-six of these were recognised academic disciplinary categories (see Figure 4.3). The term 'categories' is used, as some of these labels encompassed more than one academic disciplines (i.e. Physics & Astronomy; Agricultural and Biological Sciences).
- Two categories were defined as 'multidisciplinary' and 'undefined'.

The wide search term 'uncertain*' was chosen in order to prevent a restrictive initial exploration.

4.4.2 Evaluation of 'neighbourliness' of disciplines:

The evaluation of the identified disciplines began with an examination of their nature as a professional consultancy/ post-normal science and then proceeded to assess the extent of its interaction with a lay audience. One those disciplines that met at least one of the criteria are discussed in this chapter. Figure 4.3 captures the process of inclusion and exclusion of disciplines from the selected pool, following the application of each of the selection criteria.

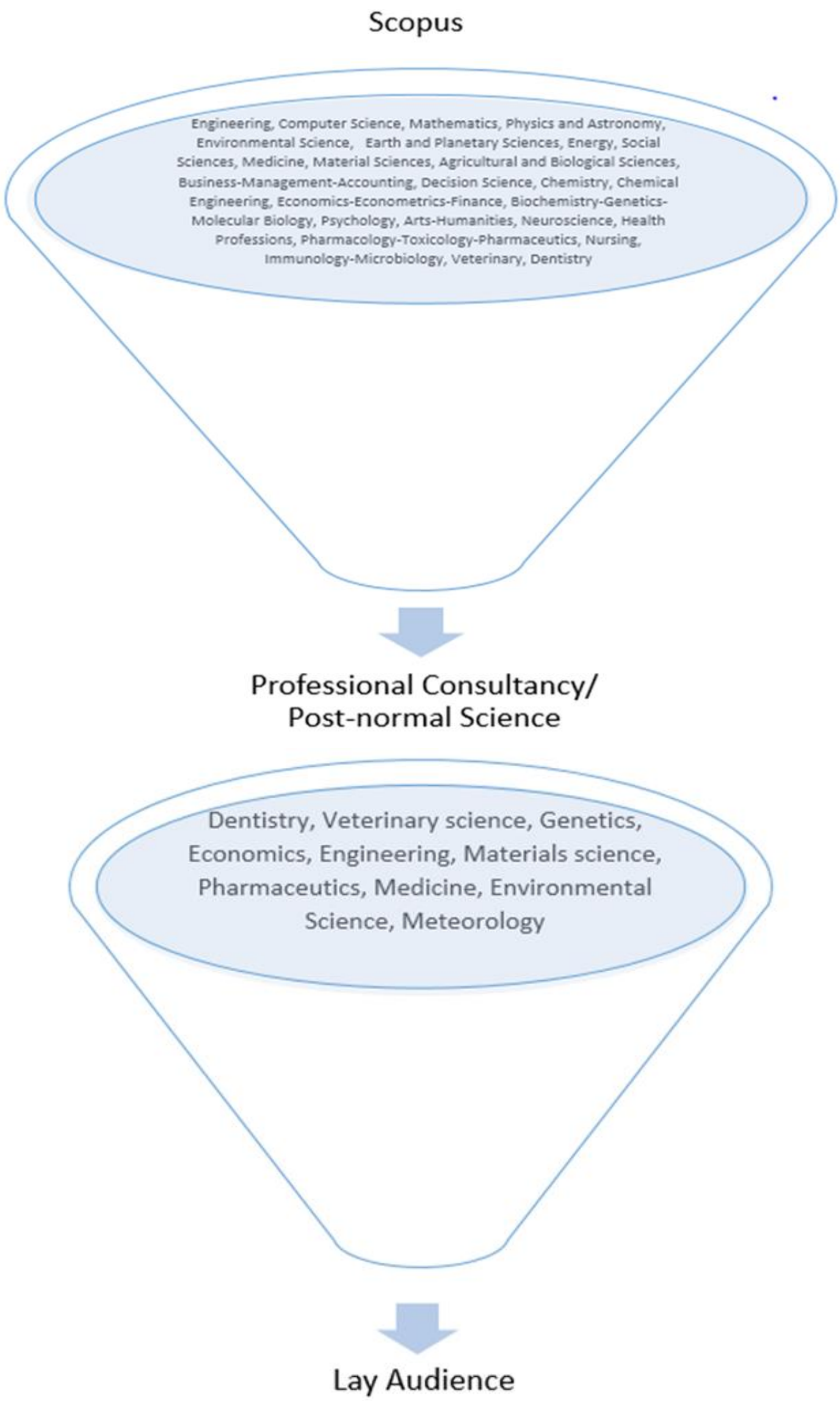

Figure 4.3| *Application of the first criterion (post-normal science or professional consultancy) for the selection of disciplines*

The application of the first criterion to each of the 26 disciplines found on 'Scopus', resulted in ten of those disciplines being considered as a good fit with the theory of post-normal science (Figure 4.3). The identified features of a professional consultancy or post-normal science (Figure 4.2) were used to assist with this evaluation. The ten disciplines that satisfied this first inclusion criterion were:

1. Dentistry
2. Veterinary science
3. Genetics
4. Economics
5. Engineering
6. Materials science
7. Pharmaceutics
8. Medicine
9. Environmental science
10. Meteorology

Sections 4.4.2.A and 4.4.2.B present the arguments supporting the identification of these ten disciplines as professional consultancies or post-normal sciences. The ten disciplines are then examined against the second criterion; namely, whether they exhibit a strong interaction with a lay audience in section 4.4.2.C.

4.4.2.A Professional Consultancy

Eight disciplines were found to share the characteristics of a professional consultancy: dentistry, veterinary science, economics, engineering, materials science, pharmaceutics and medicine.

The first two disciplines assessed were those of dentistry and veterinary science. Both disciplines share a common focus on health care provision. Health care provision involves a strong element of decision-making (McCreery & Truelove, 1991); an element accepted to be intrinsically tied to uncertainty. Yet, the decision stakes in both disciplines may generally be considered as low, given their subject of study, inquiry or practice. Therefore, the satisfaction of the first criterion rests on whether the overall uncertainty found in their decision-making and conclusions can be considered as salient or severe, as either uncertainty or the decision stakes have to be salient for the discipline to be eligible for consideration as a professional consultancy.

In veterinary science, the diagnostic decisions involved could potentially be considered as more difficult and uncertain than those of doctors. The reason for this is that human patients can express the symptoms they are experiencing, whereas when it comes to animals the expression of symptoms comes from an observer. It can therefore be argued that this is a major obstacle towards gathering crucial information and knowledge for the decision-making of veterinary experts, and due to this obstacle the uncertainty is greater than low. Uncertainty in dentists' decision-making could also be deemed salient, given that there is often absence of evidence regarding the success and survivability of certain treatment procedures, such as primary root canal (Mohamed & Steier, 2017). The sources of uncertainty in dentistry are also manifold, thus contributing to the growing uncertainty which dentists face (McCreery & Truelove, 1991). As a result, it was deemed that the levels of uncertainty in both of these disciplines were greater than low, thus satisfying the first criterion.

The level of uncertainty in the decision-making and opinions of geneticists was also debatable. Geneticists must deal with various sources of uncertainty, despite the primarily quantitative nature of their work. Epistemic uncertainty in relation to DNA sequencing, for example, may be the result of a dearth of sequencing or poor base detection (O'Rawe et al., 2015). The decisive factor in this discussion, however, is the existence of 'skill, judgment and sometimes even courage' (Funtowicz & Ravetz, 2003, p.4), as well as the 'exercise in design for the discovery of facts' (Funtowicz & Ravetz, 2003, p.4), which are indicators of professional consultancy. Often geneticists are required to exercise judgment and even courage when it comes to deciding whether a fragment with low intensity should be marked as present or not (Bonin et al., 2004). Interpretation is also evident in the decision-making of geneticists, as Pyeritz (2017) highlights that the phenotype has to be interpreted in light of the setting in which it arises. Due to the presence of these characteristics, genetics could be described as falling under the category of professional consultancy, thus satisfying the first criterion of inclusion.

Similarly, the disciplines of economics, engineering and materials science will also be included under the category of professional consultancy. Experts in these three fields operate in an environment where human decision-making and the exercise of judgment play a vital role in carrying out their responsibilities. Economists are required to explain various economic phenomena, whether in the form of forecasts or postcasts, which are often based on a number of unpredictable policy and non-policy variables (Ouliaris, 2011). Interpretation and judgment are prominent in economists' work, as they often purposefully include their real-life experience in their predictive models (Ouliaris, 2011); a strong sign of interpretation, judgment and design in a context of salient uncertainty.

Similarly, engineering was considered as an amalgamation of elements of science, engineering science and design, while some have argued that the role of the engineer revolves mainly around design (Layton et al., 2015). Uncertainty was also prevalent in this discipline, as Beer et al. (2016) emphasise how widespread epistemic uncertainty is in the sub-discipline of civil engineering. Given the prevalence of design in the field of engineering, the existence of salient epistemic uncertainty is likely not only found in civil engineering, but in engineering as a whole.

Epistemic uncertainty is also regularly faced by experts in the field of materials science, particularly so in the early stages of design during which a lot of crucial data regarding the properties of the materials are lacking (Shahinur et al., 2017). Uncertainty is therefore more salient than that experienced by applied scientists. Further support for the inclusion of materials science under the category of professional consultancy is the integral role played by design in the decision-making process of material scientists (Savage, 2006).

Design also plays a fundamental part in pharmaceutics, indicating a degree of significant uncertainty. According to one definition, pharmaceutics is considered as the science of medicine design (UCL, 2021). In addition to the significant level of uncertainty that may result from the element of design involved in pharmaceutics, the decision stakes could also be considered greater than low. The decision stakes of the stakeholders that rely on the judgments of experts are salient, due to the extensive impact they bear on human health. The salience of the decision stakes, in combination with the strong element of design, as alluded by the definition of this discipline, indicated that pharmaceutics were of a similar nature to that of a professional consultancy.

The last discipline that satisfied the first criterion was medicine. Medicine is a prime example of a professional consultancy. The uncertainty relating to the decision-making of experts, as well as the decision stakes involved could best be described as salient. Researchers and practitioners support that uncertainty is pervasive in all facets and processes of medicine, including in relation to diagnoses (Hatch, 2017) and treatment (Gorovitz & MacIntyre, 1975). Equally salient are the stakes involved in the decision-making of doctors and their lay stakeholders, as the well-being, health and often the life of patients depend on. Further support for the classification of medicine as a professional consultancy can be found in Ravetz's portrayal of the closely related field of surgery as a professional consultancy (1999, p.650).

4.4.2.B Post-normal science

Two disciplines were recognised as falling clearly under the category of post-normal science: environmental science and meteorology. The latter was identified as a sub-discipline under the wider category of 'Earth and Planetary Science' on Scopus. Strong support for the classification of these categories as post-normal science can be found in two seminal articles regarding post-normal science (Ravetz, 1999; Funtowicz and Ravetz, 2003). The authors regularly referred to science directed at environmental issues as examples to support and justify the conceptualisation of post-normal science. Uncertainty is significant in both environmental science and meteorology due to the 'chaotic dynamics' of climate (Palmer, 1999, p.2), which render its study extremely difficult. Research bodies, such as the Lowell Centre for Sustainable Production, have expressed their concerns regarding the way environmental science has been dealing with the high degree of uncertainty found in the study of the environment (Tickner, 2003). It is thus evident that the unpredictability inherent in these disciplines would render the quantification of risks extremely difficult, while policy decisions particularly in the field of environmental science are so severe that perhaps a wrong judgment would lead to irreversible long term damage to the environment. Therefore, these disciplines were classified as post-normal sciences.

4.4.2.C. Lay audience

The ten disciplines that fulfilled the first inclusion criterion, were then assessed for how well they satisfied the second inclusion criterion; whether they exhibited strong interactions with a lay audience.

The role of a lay audience was particularly prominent in the fields of medicine and genetics, environmental science and meteorology, where there is a direct communication between the expert and the lay audience. Moreover, the expert's opinion is critical towards the decisions taken by the lay stakeholders. Following the decision of the Supreme Court in Montgomery v Lanarkshire Health Board (2015), an informed consent from a patient regarding treatment is only valid if the patient has been informed about the risks involved and any alternative treatments available. Given the importance of informed consent, the communication of uncertainty both by doctors and geneticists to patients is vital for the effective fulfilment of their duties.

Environmental science and public environmental policy are highly interconnected. Scientists in this field play a critical role in policy making decisions (Houck, 2003). The communication of uncertainty by experts to policy makers is thus a very significant aspect of their responsibilities. Similarly, the relationship between meteorologists and lay people is equally significant. The decision-making of meteorologists is not only of interest to the average individual taking an interest in the weather, but also to practitioners who have vested interests in weather forecasts for scientific or business purposes.

Moreover, the extent to which experts in the disciplines of veterinary science, engineering, economics and pharmaceutics communicate with a lay audience is noticeable. Experts in the disciplines of economics (Zografos & Howarth, 2010), engineering (Beck et al., 2006; Beck et al., 2016) and pharmaceutics (Meijer et al., 2013), are being encouraged to actively interact with lay stakeholders and discuss their interests and needs. The final consumer of the products of pharmaceutical experts are essentially patients, who have a vested interest in understanding the uncertainties involved (Pathak & Bhola, 2015). Similarly, economists and engineers are often required to present their findings and opinions to lay stakeholders, including public bodies and policy makers. Veterinary experts deal with agricultural professionals who may possess sufficient knowledge, yet they also deal with owners of pets who would not normally possess any expert knowledge at all. Thus, there was sufficient evidence to support that in the disciplines of veterinary science, engineering, economics and pharmaceutics, the presence of a lay audience is not negligible. For the experts to successfully dismiss their duties, they would need to effectively communicate the uncertainties involved in their decision-making and opinions.

There was not as strong or evident interaction identified between experts in the discipline of dentistry with a lay audience. The satisfaction of the second criterion was, thus, debatable. The decision-making of dentists involves two types of decisions; ‘effective’ and ‘preference sensitive’ (Johnson et al., 2006). ‘Preference sensitive’ decisions, unlike ‘effective’ decisions’ (Johnson et al., 2006, p.138) require consultation with patients, and thus engagement with a lay audience. Despite the presence of ‘preference sensitive’ decisions in the decision-making of dentistry experts, research has indicated that patients are not regularly involved in the decision-making process regarding their dental health (Chapple et al., 2003). As such, the expectations for exchange of information between dentist and patient are not as prominent as in medicine. In principle, however, dentists are required to communicate with their patients when it comes to ‘preference sensitive’ decisions (Johnson et al., 2006, p.138). On this basis, dentistry could arguably be considered a professional consultancy.

The only discipline that failed to satisfy the second criterion, was that of materials science. According to Hill et al. (2016), a wide range of stakeholders may interact with material scientists, including the producers of research, funding agencies, the producers of the product which request the material in question, and publishing bodies of relevant research. These stakeholders would require at least some level of basic knowledge of the subject matter, in order to be able to effectively cooperate with material scientists. Thus, material scientists would not be required to convey information to an audience that possesses minimal knowledge (lay audience) in relation to the subject matter of their expertise. Given that there was not a strong evidence base to support the existence of a public forum in material sciences – in the manner that has been conceptualised and defined for the purposes of the inclusion criteria – this discipline was excluded from the interdisciplinary configurative review.

4.4.3 Results of discipline selection:

Out of the 26 disciplinary categories identified on Scopus, nine disciplines satisfied both inclusion criteria. Ten disciplinary categories satisfied the criterion of being a professional consultancy or post-normal science, while nine of these also satisfied the criterion of exhibiting strong interactions with a lay audience. These nine disciplines were, therefore, deemed to be sufficiently ‘neighbouring’ with forensic science and were thus selected for inclusion in the interdisciplinary configurative review. A breakdown of the process can be seen in Table 4.2.

Name	**Criterion 1**		**Criterion 2**	**Inclusion**
	Professional Consultancy	***Post-normal Science***	***Lay audience***	

Engineering	V	X	V	V
Computer science	V	X		X
Mathematics	X	X		X
Physics and Astronomy	X	X		X
Environmental Science	X	V	V	V
Earth & Planetary Science:				
Geology	X	X		X
Oceanography	X	X		X
Meteorology	X	V	V	V
Astronomy	X	X		X
Energy	X	X		X
Social Sciences	X	X		X
Medicine	V	X	V	V
Materials Science	V	X	X	X
Agricultural & Biological Sciences	X	X		X
Business, Management & Accounting	X	X		X
Decision Sciences	V	X		X
Chemistry	X	X		X
Chemical Engineering (considered under wider engineering category)				
Economics, econometrics, Finance	V	X	V	V
Biochemistry, genetics, molecular biology:				
Biochemistry	X	X		X
Genetics	V	X	V	V
Molecular Biology	X	X		X
Psychology	X	X		X
Arts & Humanities	X	X		X
Neuroscience	X	X		X
Health Professions	X	X		X

Pharmacology, Toxicology, Pharmaceutics:				
Pharmacology	X	X		X
Toxicology	X	X		X
Pharmaceutics	V	X	V	V
Nursing	X	X		X
Immunology and Microbiology	X	X		X
Veterinary Science	V	X	V	V
Dentistry	V	X	V	V

Table 4.2| *Discipline selection process results*

Chapter 4 – Key points

- The terms 'forensic' and 'science' were closely examined to reveal distinctive characteristics that could guide the selection of disciplines for inclusion in the interdisciplinary configurative review.
- The term 'forensic' was interpreted in such a way, so as to denote the interaction of experts within a public forum.
- The term 'science' was interpreted through the application of the theory of post-normal science.
- Two criteria for the inclusion of disciplines in the review were developed:

1. The discipline can be described as a professional consultancy or post-normal science, and
2. The experts of the discipline exhibit strong interactions with a lay audience.

- The two criteria were applied to 26 disciplinary categories retrieved from 'Scopus'. Ten of these disciplines satisfied the criterion of potentially being regarded as a professional consultancy or post-normal science, while 9 of these also satisfied the requirement of exhibiting strong interactions with a lay audience.
- The disciplines of Dentistry, Veterinary Science, Medicine, Pharmaceutics, Environmental Science, Meteorology, Economics, Engineering and Genetics, were initially selected for inclusion in the in the interdisciplinary configurative review (Chapter 5).

5. Conceptualising, evaluating and communicating uncertainty in forensic science: Identifying commonly used tools through an interdisciplinary configurative review

This chapter builds on the methodological groundwork that was laid out in Chapter 4, through its exploration of three of the disciplines that were deemed to be 'neighbouring' with forensic science (Medicine, Environmental Science and Economics). It begins with an examination of the current state of knowledge with regards to uncertainty in forensic science, seeking to demonstrate the incompatible developments between the discipline of forensic science and other disciplines, thus highlighting the motivation behind this study. This chapter also includes a presentation of the methods that were deployed for conducting the review, as well as the three toolkits that were developed, one each for conceptualisation, evaluation and communication.

5.1 Introduction

Every stage of the crime reconstruction process in forensic science, from the crime scene to the presentation of forensic science evidence in court, must address uncertainty (Morgan et al., 2018). Uncertainty is an inherent attribute of science and therefore, of forensic science (Taroni & Biedermann, 2015). The scientific method is predicated on the testing of hypotheses and falsification (Popper, 1961), to draw inferences in a manner that must accommodate missing or incomplete information. In forensic science, due to the complexity of the forensic process as it operates at the nexus of science, the law, policy and government (Morgan, 2017a; Roux et al., 2012) it is very rare to be able to establish a 'ground truth' (Morgan et al., 2018) to test derived inferences which can stand in contrast to the scientific 'laws' that can be established through laboratory based experimental studies or population level studies.

Uncertainties are present when identifying, recovering, preserving and analysing traces and patterns, and also in the decision-making of experts as they interpret what those materials mean in the context of a crime reconstruction (Kruger, 2012; Morgan, 2017a; van Oorschot et al., 2019; Wonder, 2001). Uncertainty needs to be considered during the collection of traces or patterns at the crime scene, particularly given their dynamics which may affect the state of those traces or patterns (Chisum & Turvey, 2011). The impact of these dynamic events in turn influences the judgements and decisions made in terms of what is searched for, where or if a clue is recovered, how it is recovered and preserved, and how it may be analysed within the context of the specific case (Kruger, 2012). Expert decision-making and interpretation must take place under conditions of uncertainty which can be influenced by the contextual information that is or is not made available (Almazrouei et al., 2019; Taroni & Biedermann, 2015) often considered extrinsic factors, in addition to the well documented intrinsic factors of human cognition (Dror & Hampikian, 2011, Dror, 2018, Dror et al., 2006, Nakhaizadeh et al., 2014, Nakhaeizadeh et al., 2019). Academics and professional organisations have been increasingly calling for more acknowledgement, disclosure and articulation of uncertainty. Taroni & Biedermann (2015) highlighted the need to explicitly and clearly articulate uncertainties, the National Academy of Science (National Research Council, 2009) raised the issue of evaluating uncertainties in its seminal report, while the Forensic Science Regulator in England and Wales has been showing significantly greater interest in the topic of uncertainty and evaluative interpretation (Forensic Science Regulator, 2014) in laboratory based sub-disciplines as well as in the evaluation and communication of uncertainty in more qualitative based sub-disciplines. Whilst the issue is highlighted the report fell short of providing any detailed or specific directions for addressing uncertainty revealing the complexity of the issue. The Government Chief Scientific Adviser in his annual report (Walport, 2015) also addressed the topic of evaluating and communicating uncertainties in forensic science, however, evaluation was solely discussed in terms of measurement associated with analytical tests and results. In a more recent report the UK Forensic Science Regulator (Forensic Science Regulator, 2017) stated her intention and ongoing plans to develop a calibrated interpretative framework which would also include the tackling of uncertainty issues. However, it is not clear what type of evidence base can be utilised to establish such a framework. The communication of uncertainty to stakeholders (investigators, legal professionals, policy makers and scientists) is consistently being highlighted as a prerequisite for ensuring that jurors are appropriately informed about the evidence presented to them (Edmond et al., 2019) and are in a position to evaluate whether the prosecution has dismissed the burden of proof beyond reasonable doubt (Edwards, 2019). At the very least, it is clear that a transparent dialogue addressing the uncertainties that are inherent in science and in the forensic science process is needed and has the potential to enhance expert performance (Edmond et al., 2019, Earwaker et al., 2020).

Sources of uncertainty which may impact the confidence that can be placed in science findings and inferences in a forensic science context have also been identified. Significant consensus exists in the published literature that there is a lack of empirical research addressing expert analysis and interpretation of materials found at the crime scene (Giannelli, 2006; Murphy, 2007; Saks & Koehler, 2005; Saks & Koehler, 2008; National Research Council, 2009, House of Lords, 2019). Despite the developing body of research that exists in certain disciplines, fields such as fingerprint analysis are generally considered to be based on skill and experience of examiners rather than primarily methodologies based on the scientific method (Mnookin, 2003; Zabell, 2005). There are of course many reasons for this, and ongoing debate about the most appropriate way to consider fields within forensic science that rely on both explicit and tacit knowledge (Morgan 2017b, 2018b), while ensuring that there is transparency in how a conclusion has been reached that is communicable to appropriate audiences (Found & Edmond, 2012). This lack of consensus to date is an additional source of uncertainty, particularly in relation to the capacity of experts to make transparent evaluations of the science evidence that can assist investigators and the courts.

Despite these contributions, a common framework with a consistent language and structure capturing, evaluating and conveying uncertainty has yet to be developed (Earwaker et al., 2020). Uncertainty in forensic science has traditionally been discussed in terms of being a corollary of the examination of past events (Taroni & Biedermann, 2015; Jackson et al., 2006) and the unknowability of a 'ground truth' (Dror, 2012; Morgan et al., 2018). More recently, efforts have been made to think of forensic science as a system made up of individual, interrelated components (Morgan 2017, Morgan et al., 2018; Thompson, 2009; Roux et al., 2015). There have also been calls to move focus away from the calculation of error rates (Saks & Koehler, 2005; Koehler, 2008), which have been fraught with contention in terms of definitions (Morris & Fitzsimmons, 2008; Christensen et al., 2014), the methods by which these should be calculated (Cole, 2005; Dror, 2012; Marczyk et al., 2005; Hunt et al., 2018) if at all, and considerations of whether a framework of risk assessment and management could be a more valuable pathway forward (Forensic Science Regulator, 2014; Earwaker et al., 2019; McCartney, 2008; Wilson et al., 2018). This has led to recent considerations of how uncertainty can and should be articulated within forensic science with the use of terms, such as 'known unknowns' and 'unknown unknowns' reflecting conceptualisation trends originating in other disciplines (Morgan, 2018; Earwaker et al., 2019).

The broad body of knowledge established in a wide range of disciplines has only been applied very sparsely to forensic science to date. An extensive range of definitions and typologies have been developed over the years (Lipshitz & Strauss, 1997); ranging from the Knightian uncertainty indicative of unquantifiable peril, to a more modern understanding of uncertainty associated with issues that are 'far less clear cut' (Pidgeon et al., 2003, p.9) and of more subjective or qualitative in nature (Bammer et al., 2012). The typologies seeking to characterise uncertainty have also been as diverse, with different approaches ranging from Krupnick et al. (2006) who distinguished between five types of uncertainty and Smithson (1989) who identified a synthesis of 16 different types of ignorance (1989). Therefore while there is a broad and extensive diversity of definitions and typologies of uncertainty, and a general lack of consensus due to the diversity and complexity of disparate fields, this body of knowledge offers the potential to gain insights that offer a pathway forward in forensic science for considering uncertainty and developing a conceptual construct of uncertainty that moves the discipline forward.

The absence of compatible developments between forensic science and the general body of knowledge addressing uncertainty is not only evident in the conceptualisation of the term, but also in the evaluation and communication of uncertainty. Evaluation and communication have generally been considered within the framework of probability theory (Klir, 1997), and in forensic science, the value of probabilities has been strongly advanced with declarations that probability theory, and specifically Bayesian approaches, represent 'the only coherent logical foundation' for 'reasoning in the face of uncertainty' (Berger et al., 2011, p.11). However, the complexity and multi-faceted nature of uncertainty cannot always be reduced into a numerical formula and is not always easily quantifiable

(Flage et al., 2014). This is especially true when data are not available to help establish priors or conditional probabilities, as is often the case in forensic science. Indeed, discussions outside the discipline of forensic science have recognised this with frameworks of evaluating uncertainty embracing more qualitative elements (van der Sluijs et al., 2005, Spiegelhalter et al., 2011). At the same time there is a growing emphasis on the need for more holistic structures that embrace all the relevant concepts and theories, and combine both qualitative and quantitative techniques for evaluating and communicating uncertainty (Flage et al., 2014; Morgan, 2017b; Morgan, 2018b). Such holistic structures could potentially also allow for innovative ways of evaluating and communicating uncertainty to exist alongside, and to complement the established Bayesian paradigm.

Forensic science necessarily brings together explicit and tacit forms of knowledge and therefore frameworks for evaluating probabilities in some fields where the predominant forms of knowledge are more explicit may not always be appropriate for, or easy to directly apply into, forensic science. This is particularly the case when considering how to evaluate the uncertainties associated with human, decision-making, which may not be amenable to quantification (Morgan et al., 2018) due to the blend of both tacit and explicit forms of knowledge (Morgan, 2017a, 2017b). One clear issue with regards to the use of probabilities in the communication of uncertainties in court has been identified in terms of the degree to which it can introduce a form of reasoning that is incompatible with the non-mathematical, inductive and even categorical reasoning of jurors (Ligertwood et al., 2012; Redmayne, 2001). Empirical studies have also indicated that the use of probabilities in court may lead to fallacious juror reasoning (Thompson, 1987, Koehler, 2001).

There is therefore, a need to consider whether it is possible to identify and articulate a consideration of uncertainty within the forensic science process in a holistic manner that considers the entire system (Earwaker et al., 2020; Morgan, 2017a; Morgan et al., 2018). Therefore, this study considered three frameworks for uncertainty to elicit potentially valuable concepts, instruments and approaches to set the foundations for more systematically conceptualising uncertainty and more holistically evaluating and communicating it within a forensic science context. This study recognised the fruitful ground of inquiry that exists in other disciplines and sought to draw together the knowledge that has been developed in other disciplines in an organised and systematic manner to offer insights for forensic science. A configurative interdisciplinary review of the disciplines of medicine, environmental science and economics was therefore carried out, in order to assess how scientific uncertainty is conceptualised, evaluated and communicated in these disciplines (as disciplines that can be considered to be distinct from but related to forensic science in terms of interdisciplinarity and the consideration of complex systems) and whether these can be developed into an appropriate format for considering, understanding and communicating uncertainty in forensic science.

5.2 Method

5.2.1. Design

iven the lack of established methods to address uncertainty within forensic science, this study sought to establish how other disciplines with similar characteristics to forensic science deal with uncertainty by undertaking a configurative review. The principal format of the configurative review was a critical interpretive synthesis (CIS), for the analysis and synthesis of the data. CIS was selected as it is aligned with the aim of concept and theory development (Dixon-Woods et al., 2006), it endorses work across multiple disciplines, and allows for the inclusion and synthesis of different forms of materials (Dixon-Woods et al., 2006). The flexible and non-reproducible nature of CIS (Dixon-Woods et al., 2006, Heaton et al., 2012) also permits the use of elements from alternative methodological approaches in order to complement CIS (Heaton et al., 2012, Perski et al., 2017, Morrison et al., 2012). Therefore, this study combined elements from other approaches, such as that of traditional systematic review and thematic analysis, throughout its various stages (see Figure 5.1) as enabled by the CIS approach.

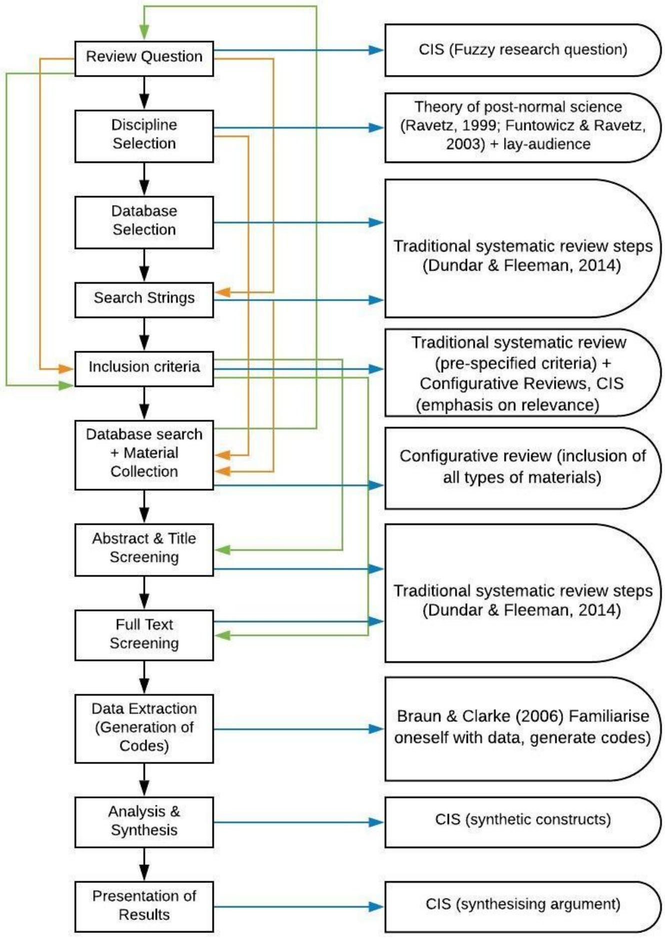

Figure 5.1| *Study Design Process. Orange arrows indicate influences, green arrows indicate revisions, and blue arrows indicate foundations.*

5.2.2 Selection of Disciplines

The 'neighbourliness' of a discipline with forensic science constituted the primary guiding factor in selecting the disciplines that were included in the review, as 'neighbouring domains' often prove to be valuable sources of ideas for the resolution of problems that transgress disciplinary boundaries (Chapter 4)

Of the 26 disciplines, nine disciplines satisfied the criteria for neighbourliness: engineering, environmental science, meteorology, medicine, economics, genetics, pharmaceutics, veterinary science and dentistry. The disciplines of medicine and environmental science were reviewed first, as they had returned the greatest number of articles; with the exception of engineering, which encompassed an extremely large volume of articles which was beyond the capacity of this study.

By the time the materials of environmental science had been coded and analysed, thematic saturation was reached. The discipline of economics was also reviewed in order to ensure that the saturation was based on as wide a dataset as possible (Glaser & Strauss, 1967). The rest of the disciplines were not reviewed after saturation was reached.

5.2.3 Search Strategy

The key-words found in the original research question were entered into a table, along with their synonyms. This table formed the basis for the development of the search terms (see Appendix B). Boolean-operators and wildcard characters were used to combine these into search strings. A pilot was carried out on Scopus to ensure that the search string that was created (see Appendix B) returned enough relevant results. The search string that was tested in the pilot had to be adjusted in some of the databases, due to the intricacies and limitations of each of their search engines – such as failure to recognise Boolean operators (Moat et al., 2013).

Additional electronic databases were also searched for academic and grey literature in the three disciplines forming part of this review. The databases that were searched were: Scopus, UK government, Nuffield Trust Publication, MEDLINE, EMBASE, Intergovernmental Panel on Climate Change (IPCC), Georef, Greenfile, EconLit, Institute of Economic Studies, Office for Budget Responsibility, International Monetary Fund, and the National Institute of Economic and Social Research. Despite efforts to carry out a full search, the possibility that certain relevant materials were not identified as a result of database selection is acknowledged.

5.2.4 Material Selection

Relevance, rather than exhaustiveness, is at the heart of most configurative, interpretive reviews (Dixon-Woods et al., 2006; Gough et al., 2012). As such, there is often no restriction on the types of materials that are included (Greenhalgh et al., 2005; Dixon-Woods et al., 2006). This study followed this approach and included a wide range of materials, such as empirical studies, editorials, opinion articles and policy reports.

Allowing for a large range of included materials can often result in unmanageable load, so the CIS uses sampling instead of the development of pre-specified inclusion criteria (as per traditional reviews) to ensure the manageability of the contributions load and the relevance of the included materials (Dixon-Woods et al., 2006). However, this study did not follow this step of the CIS process. Instead, the development of pre-defined inclusion criteria was carried out to ensure the manageability of the contributions load, and also to minimise the potential for bias as much as possible, given that the review was undertaken by a single-reviewer.

The construction of the inclusion criteria was guided by the principle of relevance – given its prominence in configurative reviews – and the research question. Inclusion was limited to materials published in the past ten years and those that were concerned with uncertainties associated with human/subjective decision-making. These criteria were developed in order to ensure that the concepts and instruments identified would be as relevant and potentially applicable to forensic science as possible. Inclusion was also limited to materials in English for practical purposes (Greenhalgh et al., 2005; Sidebottom et al., 2017).

The following inclusion criteria were thereby developed:

1. Provides substantive information on the evaluation of uncertainty in relation to any stage of the decision-making or conclusions reached by scientific experts.
2. Provides substantive information on the communication of uncertainty in relation to any stage of the decision-making or conclusions reached by scientific experts, to a lay audience.
3. Provides substantive information on the sources and/or types of uncertainty in relation to any stage of the decision-making or conclusions reached by scientific experts.
4. The uncertainty has to be related to at least some form of subjective/human decision-making process, rather than a purely laboratory or mechanical process.
5. The material has to be in English.
6. The material must have been published in the ten years up to the commencement of the database search. The majority of the database search was carried out in the end of 2018, with some searches also conducted in early 2019 – thus resulting in the inclusion of certain materials published in early 2019.

5.2.5 Material Collection

Once the database search was completed and all the resulting materials retrieved, EndNote was used to store the materials and delete duplicates. A title and abstract screening was carried out (Dundar & Fleeman, 2014), where each article was marked as either irrelevant or potentially relevant on the basis of the inclusion criteria. Following this, the full text documents of those marked as potentially relevant were downloaded and scanned, in order to more thoroughly examine whether they satisfied the inclusion criteria. Short reasons for exclusion were noted for each of the materials on EndNote. Those articles for which the full-text could not be retrieved were excluded from the review (McGovern & Harmon, 2017).

5.2.6 Material selection results

The database search yielded 14,428 materials in total. Once the materials were exported to EndNote, duplicates were removed, resulting in 5,445 records for medicine, 4,177 for environmental science and 1,793 for economics. Following the screening processes (see Figure 5.2), 91 articles from medicine, 60 articles from environmental science and 70 articles from economics were deemed to have fulfilled the inclusion criteria and were thus included in the review (See Appendix A for the full list of included contributions).

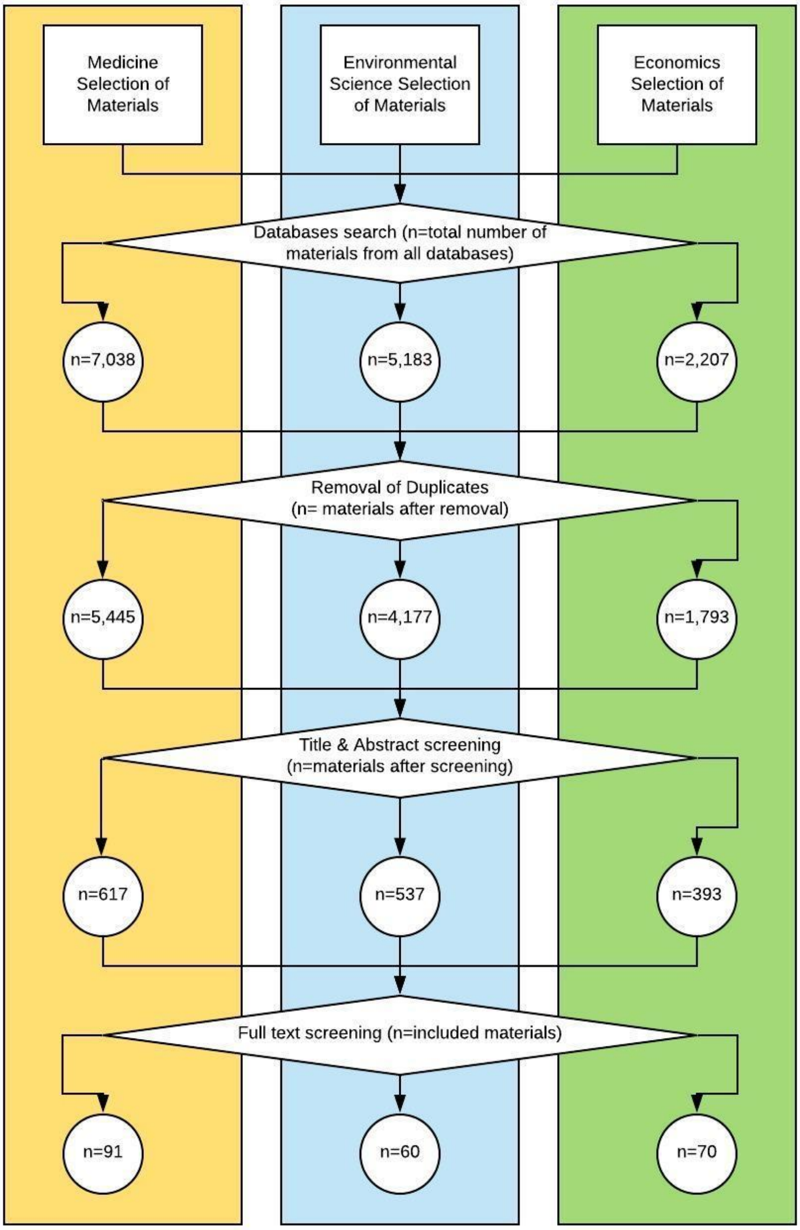

Figure 5.2| *Material Selection process for the disciplines of medicine, environmental science and economics*

5.2.7 Quality Appraisal

A quality appraisal was not carried out, given their contentious nature in configurative reviews (Campbell et al., 2014; Dixon-Woods et al., 2006; Flemming, 2010; Perski et al., 2017). A number of configurative reviews do not carry out quality appraisals, but instead focus on ensuring relevance of materials (Ginis et al., 2016; Heaton et al., 2012; Moat et al., 2013; Morrison et al., 2011; Perski et al., 2017). The design of the inclusion criteria was, therefore, driven primarily by the need to ensure relevance of materials.

5.2.8 Data analysis and synthesis

A framework for data extraction and thematic analysis developed by Braun & Clarke (2006) was followed; involving six steps (familiarise oneself with data, code generation, search, review, definition of themes, and write up).

The NVivo software was used to assist with the data extraction and analysis phases (Campbell et al., 2014). Open-coding was used to code anything of interest or relevance to the research question (Maguire & Delahunt, 2017). Free-coding was used to code words, phrases and sentences that were of interest. Once a number of initial free codes were generated, wider codes were then produced which encompassed a number of the initial free codes that had an identical or very similar meaning/topic.

The coding process yielded 876 codes (Table 5.2), which were organised into parent and children nodes during the analysis stage. These codes were then transcribed manually to assist with their organisation, the identification of patterns and the development of synthetic constructs and synthesising arguments. From the 876 codes, 342 codes were retained following a data cleaning process and the merging of codes that carried the same meaning.

After the generation of codes, sub-synthetic and synthetic constructs were developed and revised (Dixon-Woods et al., 2006; Braun & Clarke, 2006). The conceptual patterns identified through the codes were captured by the sub-synthetic constructs (i.e. knowledge uncertainties), while the purpose of the synthetic constructs was to represent the patterns identified among the sub-synthetic constructs (i.e. sources of uncertainty) (See Figure 5.3). The codes informed the development of six overarching synthetic constructs and 29 sub-synthetic constructs (see Table 5.2). Synthetic constructs, instead of themes, were developed as per the CIS process, given their emphasis on interpretation of the available evidence and codes in a more unified and explanatory manner (Dixon-Woods et al., 2006).

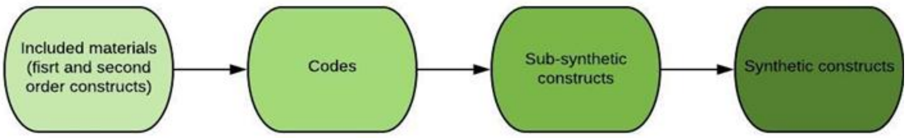

Figure 5.3| *Process from included materials to synthetic constructs*

A number of the sub-synthetic and synthetic constructs were named after some of the existing codes, such as the sub-synthetic constructs of level, location and nature borrowed from Walker et al. (2003). Other sub-synthetic and synthetic constructs were provided with original names that better represented the underlying codes and evidence (Flemming, 2010). For example, the sub-synthetic construct of evaluative structures was not directly taken from one of the codes but was instead prescribed to describe a certain pattern recognised among the evaluative instruments that were collected. The final step was that of synthesising the synthetic constructs into a synthesising argument. The ‘synthesising argument’ represents the network of relationships between the synthetic constructs and seeks to explain their connection (Dixon-Woods et al., 2006).

5.3 Results

5.3.1 Description of Included Contributions

The majority of the included contributions were non-empirical in nature (n=177), consisting of review and opinion articles, letters to editors, editorials, essays and commentaries. Among the non-empirical materials were three systematic reviews from the discipline of medicine (Ahmadi et al., 2018; Alam et al., 2017; Bhise et al., 2018) and 37 grey literature materials. The majority of these (n=33) were retrieved from the discipline of economics and included reports by the Office for Budget Responsibility (OBR), the Bank of England, the International Monetary Fund, the Deutsche Bundesbank Eurosystem and the European Central Bank. Four further grey literature contributions were identified in the materials of environmental science, all relating to the Intergovernmental Panel on Climate Change. The empirical articles only made up a small proportion of the 221 included materials (n=44), 21 of which were retrieved from the discipline of medicine, 20 from the discipline of environmental science and three from economics.

Table 5.1 summarises the characteristics of the included contributions, including year of publication, discipline, whether it was an empirical study or not, as well as its primary topic in relation to the three main themes. The majority of the included contributions had as their primary focus only one of the three main themes (n=151), while the rest engaged with two of the themes (n=44) or all three of them (n=26).

Characteristics of Included Materials			
Characteristics		Number	Percentage of total
Year Published	2009	16	7.2%

	2010	11	5%
	2011	22	10%
	2012	28	12.7%
	2013	24	11%
	2014	16	7.2%
	2015	21	9.5%
	2016	25	11.3%
	2017	35	15.8%
	2018	18	8.1%
	2019	5	2.3%
Discipline	Medicine	91	41.2%
	Environmental Science	60	27.1%
	Economics	70	31.7%
Empirical/ Other	Empirical	44	19.9%
	Other	177	80.1%
Primary Topic	Conceptualisation	29	13.1%
	Evaluation	59	26.7%
			%

Table 5.1| Characteristics of included contributions

5.3.2 Analysis & Synthesis results – background information

Of the 342 codes, only 36 codes were commonly identified in the materials of all three disciplines. The distribution of the codes according to discipline, including any overlaps, is captured in Figure 5.4.

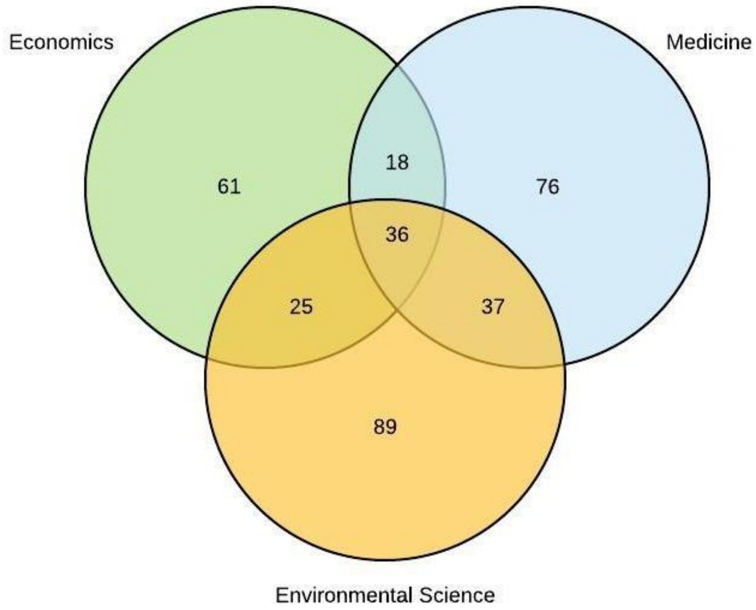

Figure 5.4| *Codes produced by the materials of each discipline*

The codes informed the development of six overarching synthetic constructs and 29 sub-synthetic constructs. The sub-synthetic and synthetic constructs, as well as the number of codes encompassed under each of these can be seen in Table 5.2.

Topic	***Synthetic & Sub-synthetic Constructs***	***No Codes***
Conceptualisation		342
	Sources of Uncertainty	Total = 84
	Knowledge Uncertainties	6
	Data Uncertainties	25

	Methodological Uncertainties	18 (10 of which are broadly captured under the term model uncertainty in Figure 7)
	Probability Uncertainties	5
	Expert (decision maker)-centred uncertainties	11
	Semantic Uncertainties	3
	Innate Uncertainties	16
	Characterisation of uncertainty	Total =20
	Level	6
	Location	9
	Nature	5
Evaluation		
	Instruments	Total = 68
	Mathematical or Statistical	48
	Graphical representations	3
	Qualitative instruments	5
	Structures	12
Communication		
	Elements & Approaches	Total = 117
	Format of communication	7
	Instruments & terms	42
	Forms of language	4
	Framing	12
	Mediums of communication	8
	Content	24
	Desirable characteristics	20
Effective Evaluation & Communication		

	Obstacles	Total =28
	Affective responses of lay stakeholders	9
	Cognitive responses of lay stakeholders	3
	Affective responses of expert decision makers	3
	Cognitive responses of expert decision makers	3
	Empirical	10
	Benefits	Total=25
	Lay audience decision makers	8
	Expert decision makers	9
	Both	9

Table 5.2| *Codes organised in synthetic and sub-synthetic constructs*

5.3.3 Analysis and synthesis results – the three toolkits:

5.3.3.A. Conceptualisation

The analysis and synthesis of the codes revealed that uncertainty was conceptualised either in terms of the sources that give rise to it, or through certain descriptions of its features (i.e. its magnitude, location or reducible or irreducible nature). Two synthetic constructs were created to reflect this distinction: 'sources of uncertainty' and 'characteristics of uncertainty'.

A model was also developed in the form of an 'Uncertainty Map' (see Figure 5.5) that portrays the synthetic and sub-synthetic constructs relating to the sources of uncertainty, as well as the individual codes that come under these. The individual codes are placed on the circumference of the circle. Each of these codes is connected to the centre of the circle. The different coloured connections represent the sub-synthetic constructs developed under the synthetic construct of 'Sources', which capture the patterns of the codes in terms of their main source area. Seven source areas were identified: data, knowledge, methodological, probability, semantic, innate and expert-centred.

Data constitutes one source area, as limitations in relation to the data that is available to the expert decision maker (Alby et al., 2017; Cubasch et al., 2013; Damodaran, 2013) can give rise to uncertainty. In addition, limitations can exist with regards to the knowledge base that will form the foundation of decision-making by an individual (Cristancho et al., 2013; Falkinger, 2016; Thomsen et al., 2016), as well as due to the methods employed (Eiseman et al., 2014; Hansen, 2014; Maxim & van der Sluijs, 2011), such as the precision of analytical instruments, or how the data is stored and used. Uncertainties may also arise due to probabilities, either due to the difficulty of assigning probabilities to the occurrence of events in question (Chiffi & Zanotti, 2017; Dizon et al., 2013) or simply because probabilities are unknown or unknowable (Dizon et al., 2013). Probabilities may also arise as a source of uncertainty relating to the precision of the probabilistic evaluations of decision makers (Han et al., 2009; Rossi et al., 2016). Three further source areas were identified, as those relating to the decision maker (e.g. quality of the individual, heuristics or judgment), to the semantics (e.g. conceptualisation of uncertainty) or to inherent uncertainties (e.g. back-casting, bounded expert knowledge).

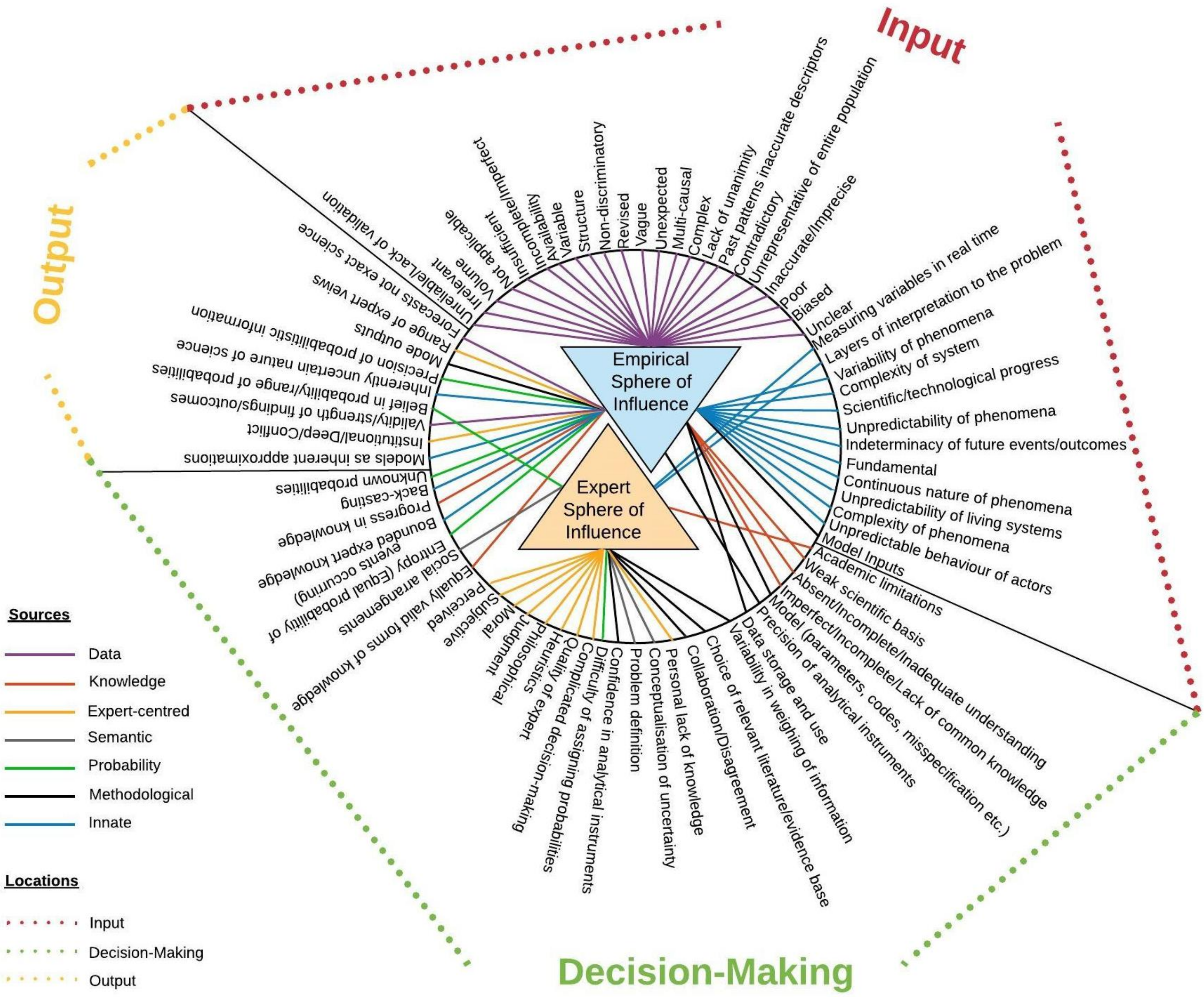

Figure 5.5| *Uncertainty map*

The model also captures two further elements of the characterisation of uncertainty: location and nature of uncertainty (expert and empirical spheres of influence) (See Table 5.3).

There are three sub-synthetic constructs in total within the synthetic construct of 'characterisation of uncertainty': location, level and nature. The terms for these sub-synthetic constructs were taken from Walker et al. (2003), whilst not an included paper in the review, it was referred to on numerous occasions by some of the included contributions (such as Baillon et al., 2012; Ekström et al., 2013; Grutters et al., 2015; Janssen et al., 2010). It is important to note that the original meaning of these three terms have not been maintained throughout because certain patterns of concepts identified in the review fitted well under the sub-headings produced by Walker et al. (2003), yet did not comply with the original meaning intended by Walker et al. (2003).

The locations identified shared significant similarities with the sources of uncertainty. For example, there were codes relating to uncertainty located in the findings (Ekström et al., 2013; Kundzewicz et al., 2018), in probabilities (Al-Najjar & Shmaya, 2015; Dannenberg, 2011) and the methodologies and techniques used (Office for Budget Responsibility, 2016; Maxim & van der Sluijs, 2011). As such, these codes were analysed in conjunction with the sources of uncertainty in developing the sub-synthetic construct of location, which would more efficiently organise the patterns of related concepts.

The forensic science process model developed by Morgan (Morgan, 2017a) was used as the basis for organising the concepts relating to the point in the process that the uncertainty is introduced. Part of the model is the recognition of the different steps of the forensic science process; crime scene, analysis, interpretation, intelligence and evidence. In order to better capture the more general nature of expertise studied through this review, three locations were developed. The 'crime scene' step is embodied in the first location, that of 'input'. Analysis and interpretation correspond to the location of 'decision-making', while intelligence and evidence to that of 'output'. The three locations that were developed were effective at representing the locations of the specific sources of uncertainty that were coded from the data of the included contributions, as can be seen from the 'Uncertainty Map (Figure 5.5).

The second sub-synthetic construct was that of the level (magnitude) of uncertainty. The meaning of level of uncertainty remained largely unchanged from that initially intended by Walker et al. (2003), with the addition of three further levels of uncertainty. These additions were made so as to represent the entirety of the evidence collected and analysed from the review. As a result, a spectrum of uncertainty was produced in this study ranging from deterministic knowledge to total ignorance (Figure 5.6). Within that range, statistical uncertainty is the closest level to deterministic knowledge, as it refers to uncertainty that can be quantified (Walker et al., 2003). Scenario uncertainty follows, indicating unquantifiable uncertainty which is nevertheless known and recognised (Walker et al., 2003). Qualitative uncertainty is the uncertainty that can be expressed in qualitative terms and is as such subject to greater evaluation than total ignorance (Grutters et al., 2015), upon which a value cannot be added (Walker et al., 2003). Total ignorance marks the end of the spectrum, implying uncertainty that is so grave that 'we do not even know that we do not know' (Curry, 2011, p.726).

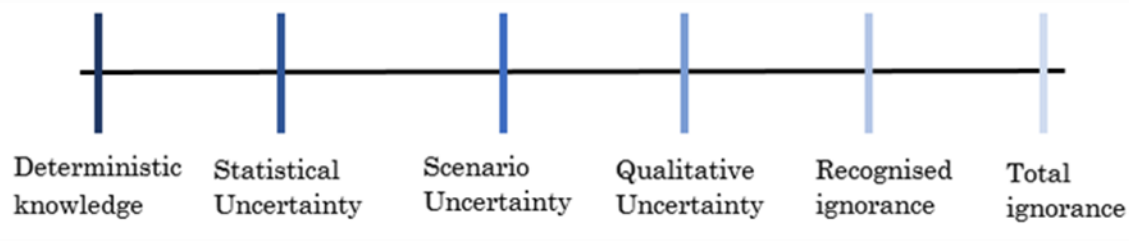

Figure 5.6| *Level of uncertainty spectrum*

The last sub-synthetic construct represents those codes taken from some of the included contributions, which refer to the nature of uncertainty. Six features of the nature of uncertainty were identified. As can be seen in Table 5.3, each of these features consists of two sets of opposites. Similarities are shared by the opposite features on the same column. Aleatory uncertainty refers to variability in data, behaviour, phenomena etc. Aleatory uncertainty is also irreducible and can also be described as inherent. Of these features, only 'sphere of influences' was captured by the 'Uncertainty Map' (Figure 5.5).

Nature of Uncertainty - Features	
Irreducible (Cannot be reduced through further research)	Reducible (Can be reduced through further research)
Aleatory (inherent variability in phenomena)	Epistemic (Related to limitations of knowledge)
Empirical sphere of influence (uncertainties lying outside the decision-making of expert)	Sphere of influence of expert (uncertainties related to experts' decision making)
Unknown Unknowns - Black swans (unforeseeable or unforecastable rare events)	Known unknowns
Inherent	Non-inherent

Table 5.3| *Nature of Uncertainty*

5.3.3.B. Evaluation

Four main types of evaluative approaches were identified in the included materials: mathematical or statistical, graphical representations, qualitative instruments and evaluation structures (Figure 5.7).

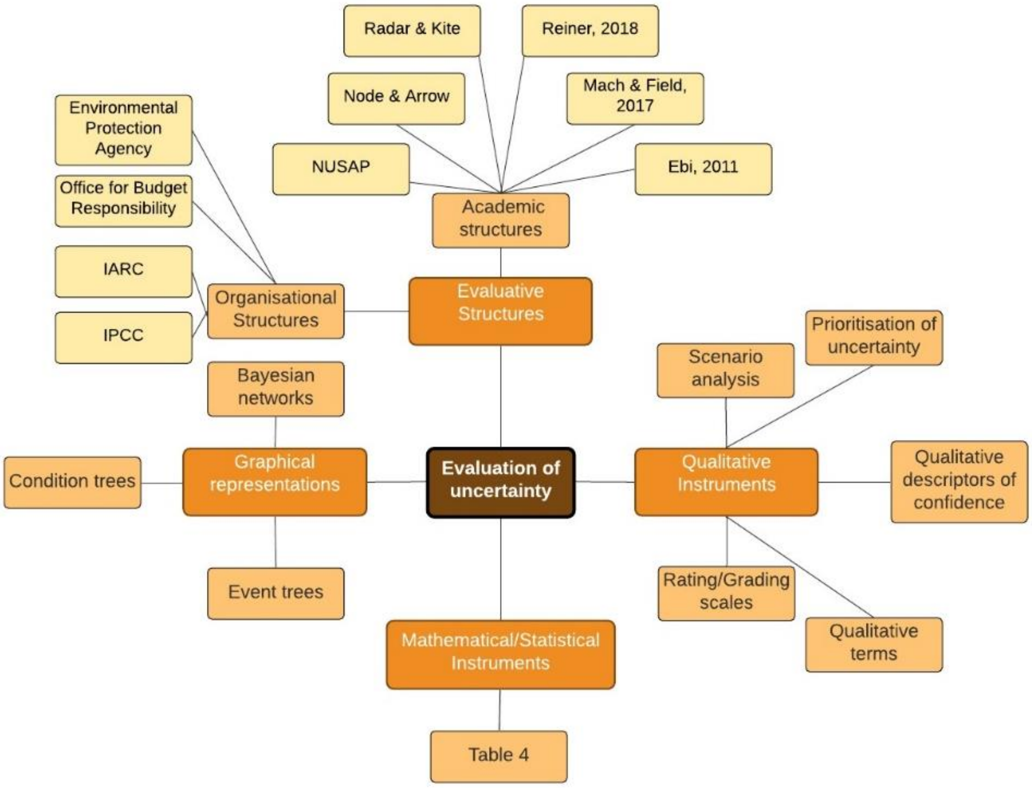

Figure 5.7| *Evaluation Instruments*

Mathematical/Statistical Instruments

Table 5.4 presents the mathematical and statistical instruments collected from the included contributions. Despite their quantitative nature, each of these have disparate applications; some respond better to specific sources of uncertainties, while others are designed for particular purposes. Possibility theory, for example, focuses on the uncertainties that arise due to the imprecision of language and natural systems, while 'fuzzy sets' are capable of dealing with uncertainties that arise due to vagueness of the data. Information theory is particularly fitting in contexts where a significant element of probabilistic inferencing is involved as part of the decision-making of experts, while info-gap decision analysis is more suited to situations characterised by severe uncertainty and parameters that lack clear definition. Moreover, there are also those instruments that are directly applicable to models, such as compositional fuzzy models; rough sets which use machine learning to generate models that evaluate scenarios; Monte Carlo simulations that produce probability distributions for outputs; and the contribution index which quantifies each element that contributes to the overall model output uncertainty.

The identified instruments are not necessarily autonomous or independent, but are instead used as tools to execute other approaches encompassed under the synthetic construct of mathematical or statistical approaches. For example, Monte Carlo simulations are used for the purposes of a contribution index, while the likelihood ratio also forms part of the Bayesian analysis.

Sensitivity analysis and Bayesian theorem are two mathematical instruments that were discussed in the included materials in all three disciplines. Both of these seek to address specific uncertainty related needs. Sensitivity analysis is used to quantify those sources of uncertainty that have the greatest impact on the results, while Bayesian theorem is used to update a set of prior beliefs in light of new data or evidence.

Mathematical & Statistical Evaluation Instruments			
Aggregate density forecasts	Distance between individual forecast and perfect forecast	Interval probability three valued logic	Probability distributions for model parameters
ANOVA	Shannon Entropy	Likelihood Ratio	Root Mean Squared Forecast Errors
Asymptomatic reliability analysis	Evidence theory	Markov Chain Monte Carlo	Robust optimization
Average of squared differences	Fuzzy probability	Mean and standard deviation of past errors	Rough sets
Bayes	Fuzzy set	Measure of disagreement of different forecasts	Sensitivity analysis
BKLS	Fuzzy stochastic	Model averaging	Standard Deviation

Bootstrap analysis	Identifiability Analysis	Monte Carlo simulation	Stochastic optimization
Composite indicators with uncertainty analysis	Information Gap decision analysis	Multimodel Analysis	Stochastic simulation
Compositional Fuzzy Model	Information theory	Parameter Estimation	Uncertainty Analysis
Contribution Index	Interquartile range calculation	Past forecast errors	Uncertainty propagation
Data analysis	Interval Fuzzy Robust Dynamic Programming (IFRDP)	Point forecast and density forecast	Variance of Mean Forecast Errors (using General Autoregressive Conditional Hederoskedasticity)
Dispersion	Interval mathematics	Possibility theory	Volatility estimation

Table 5.4| *Mathematical or statistical evaluative instruments in alphabetical order*

Graphical representations

The second sub-synthetic construct of graphical representations is the most closely connected to the sub-synthetic construct of mathematical or statistical instruments. The graphical representations may be subject to probabilistic analysis, while the Bayesian theorem found in the first sub-synthetic construct appears as the basis or a component of some of these graphical representations. One of the graphical representations under this construct are Bayesian networks. These are underpinned by Bayes rule and are recognised as useful tools for their ability to provide clear representations of different causal relationships, whether quantitatively or qualitatively. Further graphical representations under this sub-synthetic construct, include event trees and condition trees. Event trees present a sequence of events so as to provide a clear understanding of the uncertainties involved, while they also often appear to be subject to Bayesian analysis (Fearnley, 2013). The last form of graphical representation is that of the condition tree, which is considered to be a valuable tool in identifying all sources of uncertainty and avoiding oversights (Beven et al., 2015)

Qualitative Instruments

The instruments discussed so far had a significant statistical or mathematical element involved. The sub-synthetic construct of qualitative instruments captures those instruments that had a purely qualitative character. These instruments appear to be more valuable when the uncertainties are not subject to quantification (Ekwurzel et al., 2011). Grading/rating scale was the only qualitative instrument recognised by authors of the included contributions in all three disciplines. These scales require the use of qualitative ratings with regards to different issues relating to uncertainty; such as confidence in risk estimates (Han, 2013), the quality of the underlying evidence or the strength of the experts' recommendations. Qualitative descriptors of confidence, such as likely, very likely and so forth go hand in hand with rating scales (Ekwurzel et al., 2011; Han, 2013).

Qualitative terms in contrast, are more ad hoc in nature, and have been found mostly in the included contributions of medicine (Bruno et al., 2017; Engelhardt et al., 2015). Examples of these include terms such as 'suggestive of' and 'possibly'. Scenario analysis and prioritisation of uncertainty are not as conventional in evaluating uncertainty per se. Scenario analysis is a process through which different scenarios of outcomes are predicted. These scenarios can then be used as model inputs which can lead to a more tangible evaluation of uncertainty (Ekström et al., 2013). Similarly, prioritisation of uncertainty may not evaluate uncertainty in a traditional sense, but it does so by identifying and prioritising uncertainties according to the values and interests of stakeholders.

Evaluation Structures

The evaluation structures that were identified were either developed by academics or organisations. These structures exhibit significant similarities in the manner in which they evaluate uncertainty. The majority of these combine quantitative and qualitative metrics to evaluate uncertainty. They also use proxies of uncertainty, for some or even all of their metrics. Their common characteristics can be seen in Table 5.5, along with an outline of the individual properties of each structure.

Structure	Quantitative/ Qualitative	Metrics	Use of proxies	Instruments
Ebi, 2011	Qualitative	1. Agreement 2. Evidence 3. Theory	Yes: all metrics are proxies of uncertainty	Qualitative descriptors/scale

IARC (as discussed by Ebi, 2011)	Qualitative	1. Agreement 2. Confidence 3. Evidence 4. Theory	Yes: all metrics are proxies of uncertainty	Qualitative descriptors
Impact Matrix (Environmental Protection Agency, as discussed by Makinson et al., 2012)	Qualitative	1. Level of uncertainty 2. Level of impact	No	3x3 matrix with qualitative descriptors. Vectors = 2 metrics
IPCC TAR Guidance Note (Schneider & Moss, 1999, as discussed by Ebi, 2011)	Both	1. Identify most important factors and uncertainties 2. Document ranges and distributions in the literature 3. Determination of level of precision 4. Distribution of values of outcome/event 5. Rate and describe state of scientific knowledge informing values in step 4 6. Prepare traceable account of how estimates were constructed	Yes for step 5: type/amount of evidence and level of peer acceptance/consensus	Quantitative or qualitative evaluations for value and range; qualitative descriptors for state of knowledge

IPCC AR4 (as discussed by Mastrandrea et al. 2011; Ekwurzel et al. 2011)	Both	1. Qualitative levels of understanding 2. Levels of confidence 3. Likelihood (probabilities)	Yes for qualitative levels of understanding: Amount of evidence and agreement between expert decision makers	Qualitative descriptors/scale & probabilities
IPCC AR5 (as discussed by Ebi, 2011; Helgeson et al., 2018; Jones, 2011; Mach et al., 2017; Mastrandrea et al., 2011)	Both	1. Confidence scale 2. Likelihood scale	Yes for confidence scale: Underpinned by evidence strength (amount, type, consistency and quality) and agreement of lines of evidence	Qualitative descriptors/scale & probabilities
Mach & Field, 2016	Both	1. Underlying evidence and agreement 2. Scientific Knowledge 3. Likelihood of the outcomes of interest	Yes: All metrics are proxies of uncertainty	Model to capture overall structure; qualitative descriptors for second metric; subjective probabilistic evaluations for third metric with corresponding verbal scale
Node & Arrow (Chen et al., 2007, as cited in Makinson et al., 2012)	Both	1. Identification of causes of uncertainty 2. Confidence of expert in each of the causes (nodes)	No	Confidence intervals; visual node and arrow diagram

Radar & Kite Diagram (van der Sluijs et al., 2005)	Both	1. Theory 2. Method 3. Validation 4. Value laden 5. Proxy 6. Empirical	Yes: all metrics are proxies of uncertainty	Numerical evaluations; confidence in evaluations; visual diagram representing confidence in numerical evaluation of each metric.
NUSAP (Funtowicz & Ravetz, 1990 as discussed by Curry, 2011)	Both	1. Numerical 2. Unit 3. Spread 4. Assessment 5. Pedigree (qualitative)	Yes for pedigree: quality and pedigree of underlying data and methods.	Confidence intervals, error rate, variance for third metric; qualitative grading scale for fifth metric.
OBR EFO, (March, 2016)	Qualitative	Total uncertainty rating	Yes: 1. Data uncertainty 2. Modelling Uncertainty 3. Behavioural Uncertainty	Qualitative descriptors/scale
Reiner, 2018	Both	Characterise source of uncertainty in medical reporting and create end-user specific uncertainty profiles	Yes: 24 variables impacting the user-specific uncertainty profile	6 questions and 24 provider (physician) profile variables

Table 5.5| *Evaluation structures*

5.3.3.C. Communication

Seven dimensions to the communication of uncertainty were identified. These seven dimensions were captured through the sub-synthetic constructs of format, instruments and terms, form of language, framing, medium of communication, content and desirable characteristics (Figure 5.8).

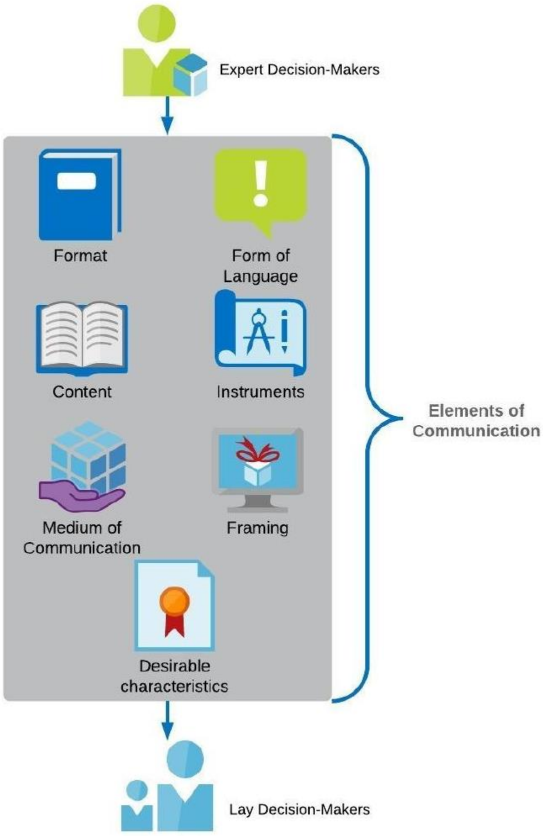

Figure 5.8| *Communication of Uncertainty dimensions*

A complete breakdown of the elements that are encompassed under each of these sub-synthetic constructs are presented in Table 6. With regards to the format of communication, the empirical evidence has indicated that even though numerical representations are preferred by participants (Bostrom et al., 2015; Budescu et al., 2012), the communication of uncertainty in numerical and verbal forms has been found to be more effective (Budescu et al., 2012). The combination of the two formats increases the level of differentiation between the different verbal descriptors and enhances the consistency in the interpretation of the terms among the audience and the consistency in the understanding of the audience and how those terms were intended to be understood. Budescu et al. (2012) argue that a strength of the combination format is that it tends to the preferences and understandings of different audiences. Despite this, concerns have been expressed that the combination of verbal and numerical terms may confound the process of communication (Budescu et al., 2012).

A visual framework was supported by a number of the included contributions. Beck et al. (2016) has suggested that it can improve communication as it is more easily understood and the information is better retained by the audience. Bostrom et al. (2015) supports this position, by arguing that visual representations of uncertainty information are more interpretable by the audience, while an empirical study carried out by Han et al. (2011) indicates that visual communication has a reductive effect on ambiguity aversion.

Among the four forms of language that were identified, natural language was the least recommended by academics, due to its vague and imprecise nature (Beder & Mayrhofer, 2017). The use of narrative language or 'the power to tell stories' (Litre, 2014, p.317) has been argued to be particularly useful in conveying uncertainty due to its ability to bridge the gaps between expertise and non-expertise (Hughes, 2017). Using a translatory discourse has also been recommended as a method for balancing the inequality of arms between expert and lay stakeholder decision makers, and ensuring that the assumptions on how the results should be interpreted and applied are consistent between the experts and lay stakeholders (Beven, 2016). The manner in which the uncertainty information is framed has been suggested to be equally important as the form and format of language (Isendahl et al., 2010). Different framing techniques and approaches were identified in the review. Uncertainty can be explicitly or implicitly acknowledged, it can be framed as positive or negative, or it can be framed as being in line with the goals of the stakeholders. Moreover, it has been suggested that emphasis should be placed on the robust aspects of the experts' decision-making process, so that the importance of the message to be conveyed is not reduced. In order for the perceived uncertainty not to be magnified by the lay audience, it is important to frame the relevant actors as trustworthy. The manner in which uncertainty will be received by the audience also depends on whether it is presented as urgent, where the responsibility for that uncertainty lies and whether the information is framed in line with the goals of the stakeholders. Hedging and contrasting the information with other similar pieces of information may have an impact on how the uncertainty is understood. It has also been suggested that the understanding of uncertainty by the lay audience may be enhanced when uncertainty information is translated within the context in which it arises, and when it is aligned with the mental processes of the lay audience. The full list of framing techniques discussed by the included contributions are presented in Table 5.6.

Among the instruments and terms used to convey uncertainty, two of these were identified in the materials of all three disciplines: confidence intervals and sensitivity analysis. Confidence intervals have been noted as more suitable to audiences that are numerate (Milne et al., 2015), while sensitivity analysis is considered best when there is a need to show that the variation in the input can cause output uncertainty (Makinson et al., 2012). Empirical research casting light on the effectiveness of communication instruments and terms, include those by Budescu et al. (2012), Milne et al. (2015), Gibson et al. (2013) and Han et al. (2011). According to these empirical studies, verbal presentation of frequencies was found to achieve greater consistency of understandings among participants, rather than verbal representations of probabilities (Budescu et al., 2012). Box-plots and shaded arrays are preferred by participants who work in the government and policy, while histograms were found to be the most confusing graphical representation (Milne et al., 2015). Histograms were also found to decrease the odds of correctly reporting probability of harm, similarly to summaries, while stacked bar graphs doubled the odds of doing so (Gibson et al., 2013). Colour coding of tables was found not be of assistance in enhancing the understanding of a lay audience (Milne et al., 2015). In addition, the use of blurred/solid edges confidence interval bar graphs alongside texts did not have any impact on worry, perception of risk or perceived credibility of the information, in comparison to the perceptions of the participants who were exposed to the textual information only (Han et al., 2011).

A range of content features to be disclosed when communicating uncertainty, as well as additional desirable characteristics for the overall communication were also elicited from the included contributions. With regards to content, authors advised that experts should make reference to the depth of the analysis undertaken when reaching the conclusion, the level of belief in the conclusion, the maturity of the findings, the relatability of the findings, the scope of the claim, the literature on which decision-making was based. Furthermore, contributing authors advise that the knowns and unknowns are stated, any research gaps that exist, as well as the confirmed and dependable knowledge which guided the experts' decisions.

The full range and sources of uncertainty of the key findings, their impact and the inevitable nature of some types of uncertainties should also be presented. Experts are also encouraged to share their rationale and underlying expert judgment when reaching a finding, any hidden assumptions and inadequacies in their knowledge and whether they deferred to other sources when reaching their conclusion. Reference should also be made to contextual factors that may have influenced their decision-making, the research process that was undertaken, the theory and the evidence upon which the conclusion was made. In addition, the included contributions suggested the disclosure of the range of uncertainties as well as of expert opinions on a given topic. The full list of the content features and desirable characteristics can be found in Table 5.6.

Instruments & Terms				
Ad hoc drawings	Contribution index	Icon arrays	Percentile Range	Sensitivity analysis
Blurry-Solid edges confidence interval bar graphs	Credibility interval	Likelihood and confidence scales	Pictographs	Shade around median
Box plots	Diagnostic Diagram	Likelihood ratio	Probabilities	Shaded arrays
Box Whiskers	Dot diagrams	Loops	PDF, MPDF, CDF, CCDF, GLF	Stacked bar graphs
Certainty terms	Error bands	Mean Absolute Error Table	Probability Distribution	Summaries
Colour coding	Evidence base	Natural frequencies	Range of baseline forecasts and their error rates	Tables
Confidence interval	Fan chart	Numerical Ranges	Robustness function	Uncertainty interval
Confidence terms	Histograms	Opportunity function	Scatter plot	Verbal representation of frequencies
Verbal representations of probabilities	Visual Timelines			

Desirable Characteristics				
Accessible	Avoid recipe based approach	Consistency of terms	Exhume expert competence	Succinct
Accurate	Avoid superfluous information	Depth of language	Honest	Use of parenthesis
Avoid mid-range category use	Careful consideration of order	Economy of words	Readable manner	Vocabulary that is understood by lay-audience
Avoid poor structure	Clear	Engaging	Simple statements	Well organised

Content of communication				
Address common misinterpretations and misperceptions	Depth of analysis	Knowledge gaps	Rationale	Scope
Baseline forecast + error rates	Full range of uncertainties	Knowns and Unknowns	Relatability	Source and impact of uncertainty
Belief in conclusion	Hidden assumptions	Literature	Relevant contextual factors	Underlying expert judgment
Confirmed and dependable knowledge	Inadequacies in knowledge	Maturity of findings	Research gaps	Underlying theory
Deference to other sources	Inevitability of uncertainty	Range of expert views	Research process	

Mediums of Communication
Briefing notes
Interactive media
Leaflets
Presentation
Short orienting overviews
Videos
Written material
Online tools

Format of Communication
Numerical
Numerical and Verbal
Verbal
Verbal & Visual
Visual
Visual & Textual
Written

Form of Language
Narrative
Natural
Technical
Translatory

Framing of Uncertainty Information	
Aligning with mental models of audience	Responsibility
Contrasting	Subjectification
Emphasis on robust elements	Trustworthiness
Explicit	Urgency
Goal framing	
Hedging	
Implicit	
Positive~Negative context	

Table 5.6| *(Set of tables) The seven dimensions of communicating uncertainty with their underlying codes*

5.3.3.D. Efficacy of Conceptualisation, Evaluation and Communication of uncertainty

A number of obstacles to conceptualising, evaluating and communicating uncertainty and the benefits that could result, were identified through this review (Figure 5.9). The obstacles were subdivided into 5 sub-synthetic constructs, broadly capturing three different types of obstacles: affective responses, (e.g. denial, decision paralysis, worry and concern), cognitive responses (e.g. lack of understanding of statistics, confusion and misunderstanding), as well as empirical issues. The first two types of obstacle to the effective conceptualisation, and particularly evaluation and communication of uncertainty, related to the experience of both expert and lay decision-makers, even though the specific obstacles that each set of actors would have to overcome differed. The third type of obstacles are more empirical in nature and often more innate and perhaps harder to overcome. These include: questions that are unanswerable, the diversity of audiences, as well as inherent uncertainties associated with the nature of language and the effect of heuristics.

However, if obstacles can be overcome or at least mitigated, a great number of potential benefits can arise from conceptualising, evaluating and communicating uncertainty, both for the expert and lay decision-makers. Some of the benefits that were identified were directly related to the expert decision-maker, others were linked to the lay decision-makers, while a third sub-synthetic construct captured those benefits experienced by both. Some of the benefits include: strengthening the respect and trust between expert and lay audiences, the empowerment of lay decision-makers and their encouragement to engage in public debates, as well as enhanced humility and avoidance of errors. The details of the obstacles and benefits are captured in Figure 5.9.

Figure 5.9| *Obstacles and Benefits of Uncertainty Conceptualisation, Evaluation & Communication*

5.4. Discussion

5.4.1. Summary of findings

The aim of this study was to identify the conceptual, evaluative and communicative tools that are utilised in the disciplines of medicine, environmental science and economics for addressing uncertainty. Three hundred and fourty-five codes were produced which constituted bit-size information addressing some aspect of the research question. Sub-synthetic and synthetic constructs captured common patterns in these codes. The majority of these constructs were further organised under the three main themes to which they contributed – conceptualisation, evaluation, communication.

Conceptualisation of uncertainty revolved around two main synthetic constructs – sources and characterisation, while the evaluative instruments identified were organised in the sub-synthetic constructs of qualitative approaches, evaluation structures, graphical representations and mathematical or statistical instruments. The sub-synthetic constructs that were developed to organise the body of knowledge on the communication of uncertainty included, the format of communication (e.g. verbal, visual, etc.), the instruments and terms used (e.g. confidence terms), the form of language (e.g. narrative), the manner in which the information is framed (e.g. hedging, contrasting), the medium of communication (e.g. videos, interactive media), the content of communication (e.g. research gaps, rationale) and lastly a set of desirable characteristics (e.g. clear and succinct communication). An additional theme was identified, underpinning all three main themes, concerned with the efficacy of the conceptualisation, evaluation and communication of uncertainty. This theme encompassed as its synthetic constructs the obstacles that would need to be overcome, as well as the benefits that can be gained from evaluating and communicating uncertainty.

5.4.2. Disciplines and their uncertainty

Each discipline provided a different perspective on how uncertainty arises, how it is experienced by its expert decision makers, as well as the approaches that are utilised to evaluate and communicate it to its stakeholders. Uncertainty was reported to exist at every aspect of the decision-making process of doctors (Kennedy, 2017; Martinez, 2012; Bhise et al., 2018), whether that is relating to diagnosis (Bhise et al., 2018), end of life care (Fisher & Ridley, 2012) or treatment selection (Shelton et al., 2019). Authors in medicine have highlighted the difficulties of conceptualising and defining uncertainty, as well as the absence of a coherent framework for its measurement (Bhise et al., 2018; Ahmed et al., 2012). Hence, the majority of the evaluative instruments identified from the materials relating to medicine belong predominantly to the synthetic construct of qualitative instruments. Challenges regarding the communication of uncertainty are also highlighted in medicine, due to the diversity of values and characteristics among the plethora of physicians and patients that interact on a daily basis. The legal principle of informed consent was seen to underpin a lot of the discussions in medicine regarding the communication of uncertainty. A legal and ethical responsibility is placed on physicians to step away from a paternalistic approach and enhance the agency of their patient and the ability of the patient to reach an informed decision regarding their health (Rossi et al., 2016; Bansback et al., 2016).

Uncertainties are also inherent and pervasive in environmental science (Budescu et al., 2012; Litre, 2014), as is evident from a consideration of the IPCC assessment reports. The uncertainty frameworks developed and revised as part of the IPCC's annual reports indicate that scientific uncertainty associated with climate change projections and assessments is worthy of international attention. The greater attention that has been drawn to the issue of scientific uncertainty in environmental science may be the reason behind the apparent less severe struggles within environmental science to evaluate uncertainty, in comparison to medicine. A greater variety of approaches were identified in the included contributions in this study from environmental science, spanning across the four evaluative synthetic constructs. A significant amount of information was also drawn from the included contributions of environmental science with regards to the seven dimensions of communicating uncertainty. Communication of uncertainty in environmental science does not serve the purpose of informed consent per se, as in medicine, but it rather intends to assist its lay stakeholders with reaching informed decisions (Beck et al., 2016) and engaging in public debates (Haila et al., 2014).

The included materials from the discipline of economics exhibited a predominant concern with the evaluation of uncertainty, and more specifically its quantification. This does not come as a surprise, given that the strategy to manage uncertainty in economics has been one of 'tam[ing] and domesticat[ing]' it (Quiggin, 2009, p. 195). The central role played by quantification in the discipline of economics may be considered at odds with the fact that one of the leading definitions for uncertainty originates in the discipline of economics, where uncertainty is distinct from risk on the basis of its non-quantifiable nature (Knight, 1921), with this definition being observed in the included contributions of all three disciplines considered in this study. Nevertheless, evaluations of uncertainty featured heavily in the included contributions, particularly model-based ones. The role of expert decision making heuristics in the constructions of these models and thus in the existence of uncertainty was also highlighted by a number of published research papers, as well as domestic and international financial organisations (Beißner & Khan, 2019; Crawford et al., 2014; Pflug et al., 2017; Responsibility, 2015).

Uncertainty is a phenomenon that is inherently polytopical. It transgresses disciplinary boundaries and a multitude of perspectives have been voiced over the years with regards to its conceptualisation, evaluation and communication. Despite the diversity in the experiences of uncertainty between disciplines and even within disciplines, two transcendent themes that capture the essence of uncertainty were identified. First, the innate and inescapable existence of uncertainty in nearly all scientific endeavours. Uncertainty was often conceptualised as a form of deficiency or incompleteness. Fisher & Ridley (2012) highlight the impossibility of achieving complete certainty, Domen (2016) notes the incompleteness of scientific knowledge, while Martinez (2012) makes references to philosophers who argued against the existence of deterministic knowledge and objective truth. Second, the open acknowledgment and recognition of uncertainty. Openly recognising uncertainty was advocated by a number of authors (Baillon et al., 2012; Bostrom et al., 2015; Cooke & Lemay, 2017; Cristancho et al., 2013; Dannenberg, 2011; Fisher & Ridley, 2012; Frenkel & Cohen, 2014; Haila et al., 2014; Johnson & Gustin, 2013; Kennedy, 2017; Lazaridis, 2019; Politi et al., 2013) as a prerequisite for the effective treatment and management of uncertainty (Mach & Field, 2016, Kennedy, 2017). This concept of openness seems to be in line with the current trends which have seen scientific uncertainty acknowledgement being on the rise (Wildson & Willis, 2004), as well as with the open science movement, encouraging greater participation by the public in scientific matters (Brody et al., 2014).

5.4.3 This study and forensic science: Three toolkits

The objective of this interdisciplinary configurative review was to identify and synthesise the approaches and evidence that are currently in place when conceptualising, evaluating and communicating uncertainty in the neighbouring disciplines of medicine, environmental science and economics. The result was the development of three toolkits to assist and guide with each of these three aspects of uncertainty management.

<u>Conceptualisation toolkit:</u>

The benefit of speaking of uncertainty in explicit terms (Taroni & Biedermann, 2015) and presenting it to the decision-makers (Wardekker et al., 2012) has been highlighted on several occasions. This, however, cannot be achieved unless a coherent, organised framework is in place that will provide the requisite vocabulary that will enable open communication and discussion of uncertainty.

The conceptual framework developed as part of this study has provided the requisite vocabulary to transpose some of the existing concepts to the discipline of forensic science. For example, even though Taroni & Biedermann (2015) and Jackson et al. (2006) refer to the uncertainty tied to the examination of past events, in the discipline of environmental science, the term 'back-casting' was identified (Haila et al., 2014), which can provide a more precise and solid term to the phenomenon described by the authors in forensic science. The lack of empirical research to support the findings and conclusions reached by expert decision makers was also discussed as a potential source of uncertainty by scholars in forensic science (Giannelli, 2006; Murphy, 2007; National Research Council, 2009; Saks & Koehler, 2008; Saks & Koehler, 2005) (see section 2.2). The conceptual framework identified the appropriate term to describe this source; namely weak scientific basis as part of the sub-synthetic construct of knowledge uncertainties. The sub-synthetic construct of data uncertainties can also encompass – once applied to forensic science – the uncertainties that have as their source the incomplete and fragmented nature of the trace (Margot, 2011b; Margot, 2017), constituting an imperfect source of data pervasive in forensic science (Taroni & Biedermann, 2015), as well as the absence of data in relation to the frequency of concurring features experienced in some forensic sub-disciplines (Murphy, 2007).

The Uncertainty Map (Figure 5.5) is not only helpful in highlighting and mapping those sources of uncertainty that have already been discussed explicitly or implicitly in forensic science, but it may also draw further attention to sources of uncertainty that have not been identified or discussed yet by academics or practitioners in the field. Semantic sources of uncertainty are significant examples of these. The manner in which uncertainty is conceptualised and understood both personally by the forensic science expert, and collectively through the social institutions that develop and reinforce the disciplinary structural understandings of the concept have not been part of the discussions of uncertainty in forensic science. Yet, the absence of the plurality of perspectives that may exist with regards to the understanding of what is meant by uncertainty is in itself a source of uncertainty that should not be overlooked.

Evaluation toolkit:

Perhaps the greatest benefit of the evaluation toolkit for forensic science has been its departure from placing the Bayesian theory at the core of the uncertainty evaluation discussion. The identification of a plethora of instruments ranging from fully quantitative to purely qualitative, demonstrated the complexity and multifaceted nature of uncertainty, which is not amenable to evaluation through a singular 'one-size fits all' approach. Equally important has been the recognition of the highly interwoven elements of conceptualisation and evaluation. Gaining an understanding of the uncertainties involved in the decision-making and final conclusions of expert decision makers is a necessary precondition to the initiation of a process of evaluating these uncertainties and communicating them to the relevant stakeholders (Wardekker et al., 2012; Lazaridis, 2019).

When it comes to forensic science, it will be necessary to identify the predominant sources and characteristics of uncertainty that are of most interest to expert decision makers and stakeholders, before being able to determine which uncertainties are subject to quantification, which should be evaluated on a purely qualitative basis (when they are not subject to quantification) and which would benefit from a structure of instruments to capture their complexities. Factors such as the ability of expert decision makers to carry out statistical or mathematical uncertainty analyses, as well as the feasibility of cooperating with experts in the fields of statistics and mathematics will have to be taken into account prior to deciding on the best approach. The evaluation and communication of uncertainty are also resource and commitment intensive (Fischoff & Davis, 2014), therefore developing a simple and standardized framework is crucial.

Given the multiplicity of fields encompassed under the discipline of forensic science, as well as the diversity of sources and characteristics of uncertainty that exist, an evaluative framework which combines quantitative and qualitative elements may be the best approach towards achieving a more holistic evaluation of uncertainty in forensic science (Flage et al., 2014). The evaluation toolkit comes as particularly valuable in the pursuit of a holistic and nuanced evaluation of uncertainty in forensic science, due to the large number of approaches that have been identified. The identified evaluative approaches are not only plentiful, but are also diverse in terms of their forms and applications; some are mathematical or statistical, while others use qualitative scales to assess factors such as the underlying evidence or the agreement of expert decision makers, as proxies to assessing uncertainty when uncertainty is not subject to quantification (Curry, 2011; Makinson et al., 2012).

Communication toolkit:

The benefits of the communication toolkit for forensic science are similar to the benefits identified above in relation to the evaluation of uncertainty. A number of the synthetic and sub-synthetic constructs that were developed to organise and represent the patterns regarding the communication of uncertainty have not yet been discussed in the forensic science literature. The forensic science literature emphasises heavily on the use of probabilities to convey the findings of expert decision makers (Thompson, 1987; Koehler, 2001), the use of the likelihood ratio (Ligertwood et al., 2012; Thompson, 2012), as well as conveying uncertainty through verbal scales (Berger et al., 2011; Martire et al., 2013).

The literature on the communication of uncertainty as discerned from the disciplines of medicine, environmental science and economics constituted a much more fertile ground from which insights and ideas were drawn. Seven dimensions to be considered when communicating uncertainty where identified, while a wide range of instruments to convey such information were identified; spanning from pictographs and fan charts, to scatter plots and blurry edge confidence interval bar graphs. A number of empirical studies testing various dimensions of the communication of uncertainty and their efficacy were also discovered, which could provide inspiration for similar experiments to take place in the context of forensic science and the legal system. Examples include the study by Budescu et al. (2012) which examined the influence of different presentation methods on the motivated interpretation of participants.

5.4.4. Limitations

5.4.4.A. Single Reviewer

The absence of a team of reviewers is one of the limitations of this report (Greenhalgh & Brown, 2014). Even though there is little evidence on how the quality of a review may be affected by the number or characteristics of reviewers (Uttley & Montgomery, 2017), it is typical practice that a team of reviewers share the workload (Sidebottom et al., 2015; Greenhalgh et al., 2005; Dixon-Woods et al., 2006). The primary reason for this is to eliminate bias at the different stages of the review. Bias resulting from the researcher's views, knowledge and outlook on the study is not limited to the field of systematic reviews, but can be found in all types of research, and particularly so in qualitative research (Patnaik, 2013). In order to limit any biases, significant efforts were made to remain as reflexive and transparent as possible throughout the review (Uttley & Montgomery, 2017). Practices to assist with this included reflexive note taking, where the reviewer assessed her own subjectivities and biases, and regular discussions regarding these as well as the progress of the review were carried out with the reviewer's supervisors.

It is important to note, that in light of the configurative nature of the review and the open-ended and flexible research question which guided the review, it is less likely that bias would influence the decision-making process. The reason for this is that there was no hypothesis that needed to be tested, therefore, there were no motives behind the selection of materials to be included.

Another potential limitation of having a single reviewer is the possibility of errors. When there is a team of reviewers, the application of the inclusion criteria during the title, abstract and full text screenings is more accurate and effective. The impact of such limitation may not be as severe for a review of this nature, given the non-exhaustive goal of configurative reviews (Gough et al., 2012).

5.4.4.B. Search Restrictions:

<u>Language:</u>

The restriction of language to those articles that were in English was added for practical purposes and for ensuring accuracy of reading and subsequent representation of the information in the results. There exists a possibility of bias as a result of this restriction, even though the effects of excluding non-English studies from a review have been found to be modest (Jüni et al., 2002).

<u>Timeframe:</u>

The limitation of adding a publication timeframe for inclusion of materials may have introduced an additional source of bias. Methods, principles, values and trends guiding the evaluation and communication of uncertainty may change over time. This change does not necessarily indicate that earlier contributions are of little value. However, the cumulative nature of science, mitigates the negative implications of such a restriction as it supports that new research is unavoidably built on prior knowledge and findings (Zeigler, 2012). To further mitigate the possibility of bias, references made by the authors of materials that were included within the review to previous research, were not excluded, but were rather taken into account during the data extraction and analysis phases.

5.5. Conclusion

'Generalizable and holistic approaches' to addressing uncertainty have yet to be developed in the discipline of forensic science (Morgan et al., 2018). Yet, a myriad of approaches to conceptualise, evaluate and communicate scientific uncertainty exist in the total body of knowledge on the topic of uncertainty. This study has identified and mapped out the most prominent conceptualisation, evaluation and communication tools in disciplines neighbouring with forensic science, which can be used as a guide by all stakeholders involved in criminal trials. The three toolkits may be a useful starting point for forensic science experts who are interested in developing approaches for increasing the transparency of their testimonies or reducing the uncertainties in their decision-making. The conceptualisation toolkit more specifically may also be important to judges and lawyers, as it explicitly highlights the existence of uncertainties, and may assist them in identifying areas in the decision-making of experts that could be subject to greater scrutiny during trial.

Characterising, evaluating and communicating uncertainty are challenging tasks (Bhise et al., 2018; Ahmed et al., 2012). However, even when the acknowledgement of uncertainty does not consist of a formal identification and evaluation of its nuanced features, the toolkits are still an important first step towards enhancing transparency in the reporting and presentation of forensic science evidence in a way that is clear about what is known, can be known and what is not known or cannot be known. The toolkits produced by this study can raise stakeholder awareness around the limitations of forensic science (Domen, 2016) and offer a starting point for developing the common language necessary for more creative discussions on how uncertainty can best be communicated to take place.

Chapter 5 – Key points:

- Three toolkits were developed, one each for conceptualisation, evaluation, and communication of uncertainty.
- Conceptualising uncertainty focused on the examination and identification of its sources and characteristics.
- Four types of evaluative instruments were synthesised and developed: quantitative, qualitative, evaluation structures and graphical representations.
- Eight facets of communication were noted as significant in developing a strategy to disclose uncertainties to lay stakeholders: the format of communication, the instruments and terms used, the form of language, the manner in which the information is framed, the medium of communication, the content of communication, and lastly a set of desirable characteristics.
- Obstacles to effective communication, as well as benefits gained from disclosing uncertainties to lay stakeholders, were identified.

6. Sources of uncertainty in forensic science and stakeholder priorities: Modified nominal group technique and thematic analysis

6.1. Introduction

The results of the interdisciplinary configurative review (Chapter 5) were valuable in terms of identifying new pathways for conceptualising, evaluating and communicating uncertainty in forensic science. Uncertainty is a highly complex phenomenon, not suited to a recipe-based (Jones, 2011) or a one-size-fits-all approach (Martinez, 2012). As such, incorporating insights from relevant stakeholders was necessary in order to optimise the value of the three toolkits developed in Chapter 5 and ensure that they are applicable in real world contexts (Horsman, 2020).

6.1.1. Forensic Science & Stakeholder engagement:

Forensic science is often considered as being situated at the intersection of scientific research, practice, policy and the law (Morgan, 2017a). Diverse parties and stakeholders have regular interactions with forensic science experts, and such interactions can have an important impact upon the scientific knowledge produced, as well as on the decision-making of experts (Morgan, 2017b; Almazrouei et al., 2019; Earwaker et al., 2020). As a result of this intricate network, the production of evidence by forensic science experts can also have an impact upon the decision-making of the actors and stakeholders with which they are interlinked. A strong example of this is how evidence is disclosed in the reports and/or testimonies of forensic science experts in court and the influence such presentation can have upon the decision-making of judges, lawyers and jurors (Earwaker et al., 2020).

It is, therefore, significant that the complex network of relationships in which forensic science operates is accounted for when research in the domain of forensic science is conducted. There has been increasing encouragement by the wider scientific and research community to engage stakeholders in the production of research (Hart et al., 2017; Klenk et al., 2015). One of the drivers behind this change has been the inability of the traditional single-directional, top-down collaboration between scientists and stakeholders to reflect, and eventually meet, the wishes and expectations of relevant stakeholders (Burger, 2011). As such, greater attention to the expectations and priorities of those who are at the receiving end of scientific research has been advocated (Yoshida et al., 2016). Such an approach, when applied to the field of forensic science, can encourage a research culture which nurtures the identity of forensic science as a discipline in its own right, with the ability to holistically capture the crime reconstruction process and encourage effective collaboration between its different actors, parties and stakeholders (Morgan, 2019; Earwaker et al., 2020; Roux et al. 2015).

6.1.2. This study

Domestic and international policy-making institutions have drawn significant attention to the need to evaluate and report uncertainty in forensic science (National Research Council, 2009; Forensic Science Regulator, 2018, 2020a). Despite these discussions, the interests of the actors and parties making up the complex network of relationships in which forensic science is situated, have been overlooked. However, it is necessary that the wishes of those who will be making use of information regarding uncertainty, and whose decision-making might be influenced by the provision of such information, are identified.

This study sought to bring to the forefront the experiences and priorities of relevant stakeholders to incorporate into the findings from studies 1 and 2 (Chapters 3 and 5).The specific end-users relevant for the purposes of this study were the recipients of forensic science evidence in court, particularly judges and lawyers. The experiences of forensic science experts whose reports and testimonies will be affected were also consulted, as it is necessary to ensure that any resulting frameworks of evaluation and communication of uncertainty are accessible and easy to use for the purposes of their reports and testimonies (Earwaker et al., 2020).

Stakeholder engagement was also necessary in order to assess and potentially add weight to the findings of the interdisciplinary configurative review by functioning as a ‘test of recognizability’ (Jasanoff, 1996, p.69), whereby the toolkits developed through the review of the materials within ‘neighbouring disciplines’ are tested for their correspondence with the actual experiences of said stakeholders. This form of consultation also made it possible to refine the sources of uncertainty that were identified in the second study, to allow for the development of a more targeted and operative framework of uncertainty evaluation and communication (Flage et al., 2014).

Therefore, the aim of this study was to identify the sources of uncertainty that are most frequently experienced and/or are of most interest to forensic science experts, judges and lawyers for the purposes of evaluation and communication.

6.2. Methods

6.2.1. Research Design

6.2.1.1. Available Consensus Methods

Consensus methods constitute a suitable approach for assisting stakeholders/study participants in reaching a consensus with regards to aspects of the study that are of interest to them (McMillan et al., 2016). They also have the benefit of ensuring correspondence between research findings and practical operations (Pastrana et al., 2010) and bridging the gap between researchers and practitioners (Harvey & Holmes, 2012; Søndergaard et al., 2018). Consensus methods are widely used in medical and health research (Hattingh, 2019; James Lind Alliance, 2013) for the purposes of establishing priorities in terms of future research (Smith et al., 2017), uncertainties to be addressed (Elwyn et al., 2010), and treatment (Eubank et al., 2016). Notwithstanding the prominence of these methods in the field of clinical research, there have also been applications of these beyond clinical and medical research (Feyers et al., 2020).

There are three principal formal consensus methods: the Delphi method, the Nominal Group Technique (NGT) and the Consensus development conference (Murphy et al., 1998). The RAND/UCLA method is often considered a variation of the Delphi and Nominal Group Technique (Murphy et al., 1998; Humphrey-Murto et al., 2017). Its official purpose, however, is not to achieve a consensus, but rather to identify points of agreement between experts (Fitch et al., 2001). As such, it was not considered a suitable method for this study. The Consensus development conference requires the commitment of participants, usually over the course of a few days, while interest groups are also invited to present evidence (Murphy et al., 1998). The time and resource intensive nature of this method rendered it unfeasible for the purposes of this study.

One of the main benefits of the two consensus methods most suitable for application to this study – Delphi and NGT – was their flexibility, particularly when it came to their use in combination with other methods (McMillan et al., 2016). The NGT method was preferred over the Delphi method because it was developed for the purposes of market research (Van de Ven & Delbecq, 1971), and encourages a dialogue between participants for the purposes of exchange and generation of new ideas (Humphrey-Murto et al, 2017; Hattingh, 2019). In addition, given the complex nature of the research topic (Hattingh, 2019; Søndergaard et al., 2018), and the use of the novel vocabulary that emanated from the conceptual framework of the interdisciplinary configurative review – not currently in widespread use – it was deemed best to have a significant conversational element incorporated into the method, so as to ensure clarity of concepts and terms (Waggoner et al., 2016). A disadvantage of the NGT method is the limited generalisability of its results (Søndergaard et al., 2016), as typically only a small group of participants – usually between 2 and 14 – are invited to reach a consensus (McMillan et al., 2016).

6.2.1.2 Selection and application of the Modified Nominal Group Technique

In order to take advantage of the focus-group-oriented nature of the NGT, while minimising its primary limitation of small numbers of participants, a modified NGT method was adopted. Modifications to the NGT method are considered a common and beneficial feature of the method for the purposes of adapting to the objectives and restraints of each individual research (Lennon et al., 2012). The process for a modified NGT technique, fostered by James Lind Alliance Working Partnership (JLA) was selected. The JLA has developed and adapted the NGT method (Nygaard et al., 2019; Vella-Baldacchino et al., 2019), in order to allow stakeholders to express their opinions, so that research can be more targeted and thus beneficial to all relevant stakeholders (Hall et al., 2013). A number of research projects seeking to achieve consensus, particularly in the health research field, have been making use of the modified NGT version developed by JLA (Healy et al., 2018; Smith et al., 2017; Vella-Baldacchino et al., 2019).

The JLA process consists of six main steps (James Lind Alliance, 2020b), which have been adjusted and applied in such a way so as to respond to the parameters of this present study. The six main steps as traditionally followed, and their application to the current study are presented in Figure 6.1.

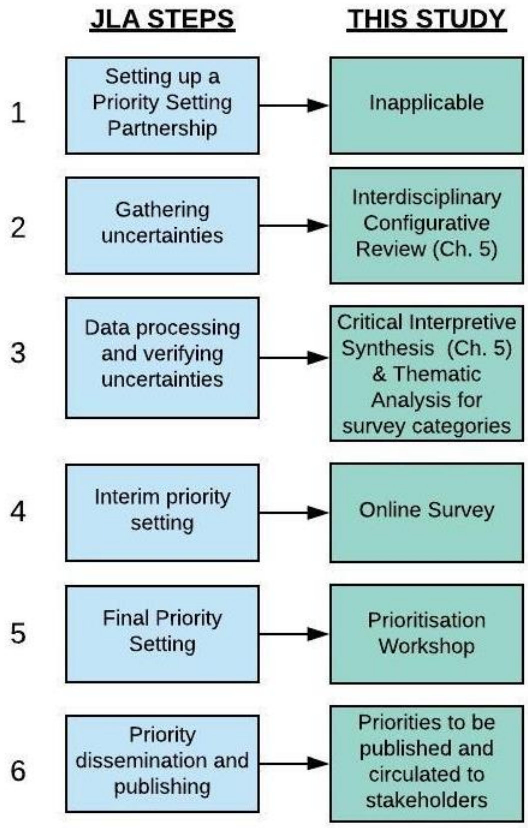

Figure 6.1| *JLA process and its application to the study*

The first step in establishing a priority setting partnership was inapplicable, given that an actual partnership can only be established with JLA if the research concerns clinical priorities. The following two steps were completed to the greatest extent through the interdisciplinary configurative review (Chapter 5). The most common method used under the JLA process for the purposes of gathering uncertainties is through a survey. Nevertheless, a systematic/literature review is also recommended as an alternative (James Lind Alliance, 2013; Hiligsmann et al., 2013; James Lind Alliance, 2020b). As such, the interdisciplinary configurative review (presented in Chapter 5), served the purpose of fulfilling this second step and gathering the uncertainties to be prioritised through the following steps. The third step, requiring the processing and verification of uncertainties, was also largely completed through the review and the critical interpretive synthesis that was used to combine the findings of the review. To complement the processing of the data collected for the purposes of the survey, a consolidation and simplification of the sources of uncertainty that resulted from the configurative review was carried out, before being presented to the participants in the interim priority setting survey (Section 6.2.3.1) (Nygaard et al., 2019).

For the final priority setting exercise (step 5), the JLA supports the use of the Nominal Group Technique, specifically the use of a prioritisation workshop (James Lind Alliance, 2013). Even though a face-to-face workshop is preferred, this study endorsed an electronic prioritisation workshop in order to establish the top ten stakeholder priorities. The workshop was carried out online due to the unforeseen circumstances surrounding the COVID-19 pandemic, in particular the 'lockdown' that was in place in the UK at the time. Aside from the unforeseen circumstances, there were significant advantages in carrying out the prioritisation workshop online. Some of these advantages included the ease of access to the prioritisation workshop, which would have prevented a number of interested experts from attending had their physical presence been required. Similarly, it allowed forensic science experts from outside the UK to also take part in these discussions.

The final step of the JLA guidance requires that the findings are published and circulated among stakeholders so that they can inform funding applications. In keeping with the requirements of this approach, the findings were circulated to all participants who expressed an interest in the research. A manuscript with the findings of this study was also written for the purposes of publication in an academic journal.

6.2.2. Data Collection

6.2.2.1. Participants & Recruitment

6.2.2.1.A. Target Population

The target population for this study were the stakeholders that have an interest in how forensic science is being used in criminal trials; namely forensic science experts, lawyers and judges. In addition, an 'other' category was provided in the survey, in which participants were requested to specify their occupation. The purpose of this was to allow for additional professions that may not have initially fallen within the target population, but whose professional expertise and experience could contribute an interesting perspective on this topic (such as policy makers and quality assurance experts, see section 6.2.3.1.).

Initially, stakeholders based in the UK were considered as the target population. However, the use of social media as a platform for promoting the survey (Figure 6.2), resulted in the participation of individuals outside the UK, that had not been originally anticipated. Moreover, given the COVID-19 pandemic and the ensuing feasibility of including stakeholders outside the UK in online discussions for the final priority setting exercise, stakeholders based outside the UK were thus allowed to participate. Such an approach was also deemed compatible with the aims and objectives of this study, as its primary focus was on the uncertainties that lie within the scientific domain. Regardless of jurisdiction, the science informing the practices of forensic science experts remains largely the same. As such, it was considered valuable to allow for diverse and international perspectives to inform considerations of the application of science to law generally, and then more specifically in the UK criminal justice system.

6.2.2.1.B. Recruitment

A combination of convenience and snowball sampling was used as the recruitment strategy, both for the interim priority setting stage (survey) and the final prioritisation exercise (online prioritisation workshop). Convenience and snowball sampling were considered the most suitable approaches, given that the target population was hard to reach, with often limited availability (TenHouten, 2017; Valerio et al., 2016). The recruitment strategy can be seen in Figure 6.2:

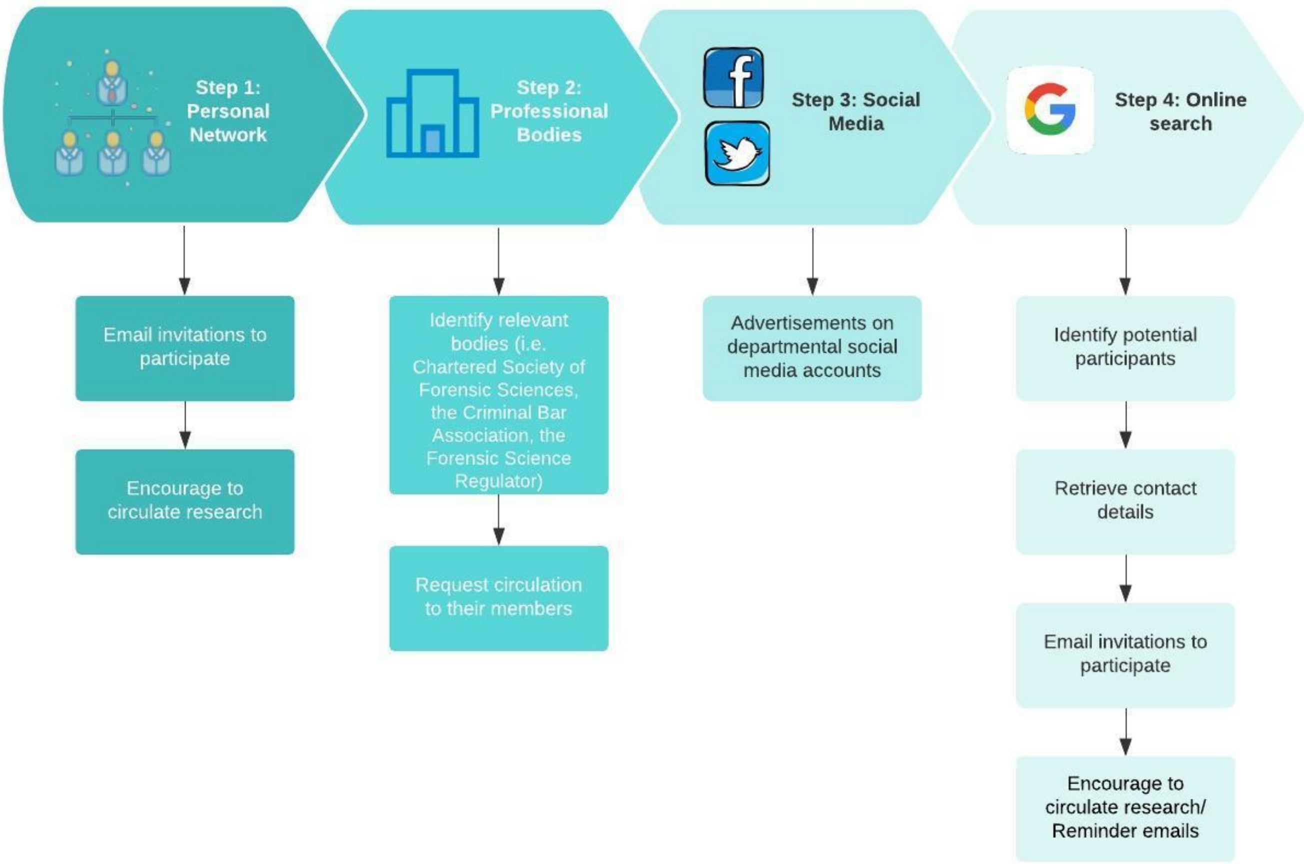

Figure 6.2| *Participant recruitment process*

The recruitment of participants for the prioritisation workshop was based on the interest expressed by participants in the survey for further involvement in the project. The individuals who had expressed such interest were contacted, and a date and time that was convenient for the majority of them was arranged. Most of the workshop participants were forensic science experts, with varied expertise in sub-fields of specialisation. The only participant to the workshop who was not a forensic science expert was a criminal barrister.

6.2.3 Materials & Processes

6.2.3.1 Survey

The survey for this study was built upon the basic survey format used by organisations in collaboration with the JLA. At the time of the survey design, a printed version of an interim survey found on the JLA's website was consulted (James Lind Alliance, 2020a). The survey structure was largely adhered to, resulting in a brief introduction explaining the research aim and purpose of the survey, followed by a clarification of the core terms and the use of the collected data, concluding with the main body consisting of the interim prioritisation questions (See Appendix C). Even though most interim surveys required participants to select up to 10 of the available questions or uncertainties as their priorities for further research, this study allowed for the selection of up to 14. It was important that each of the source categories were represented in the final prioritisation workshop. Therefore, given that there were seven source categories, it was deemed best to allow for the selection of up to 2 from each category.

A key concern throughout the development of this survey was the readability and understandability of the survey (Atalay et al., 2019). In addition, it was necessary to process and verify the sources of uncertainty that had been collected through the interdisciplinary configurative review (Chapter 5). As such, similar sources of uncertainty were grouped together under broader categories (Hart et al., 2017), so as to process the sources of uncertainty from the review and simplify the survey in order to ensure its comprehensibility (See Table 6.1).

Unlike the interim surveys of the JLA partnerships which comprised of closed-ended questions from which participants were required to select their top ten priority, this survey combined closed-ended and open-ended questions for each source category. In order to prevent respondents from engaging in satisficing behaviour – whereby they arbitrarily select an answer, or select the first acceptable answer (Krosnick & Presser, 2010) – an open-ended question followed the closed-ended question in each source category part, requiring participants to provide examples for their selected priorities. The open-ended questions would also allow for the collection of qualitative data that could potential prove useful in painting a more detailed picture of the experiences of stakeholders with uncertainty in forensic science. The final survey question was completely open-ended and gave participants the opportunity to express their opinions with regards to sources of uncertainty that might not have been identified in the survey (see Appendix C).

After the survey was developed, it was piloted within a group of eight individuals with a legal or forensic science background (doctoral and post-doctoral candidates, as well as one lawyer with a previous academic experience in forensic science). The pilot assisted in the identification of terms that were ambiguous or not easily understandable. Changes were made based on the feedback from the pilot respondents (Taylor et al., 2020).

6.2.3.2 Prioritisation Workshop: Overview and Materials

The prioritisation workshop served as the final priority setting exercise (step 5) (JLA, 2013). The purpose of the prioritisation workshop was to allow participants to exchange their opinions and reach a consensus on their top ten priorities with regards to sources of uncertainty in forensic science they would like to see evaluated and communicated (James Lind Association, 2013; Healy et al., 2018; Vella-Baldacchino et al., 2019).

The JLA guidebook allows for an electronic version of the prioritisation workshop (JLA, 2013), and a few asynchronous NGT techniques have been carried out so far. However, an asynchronous NGT method was not preferred, due to its time-consuming nature requiring extensive commitment from the participants who volunteered. The online conferencing platform 'Zoom' was instead used in order to reproduce as closely as possible the face-to-face final prioritisation exercise recommended by the JLA. The steps for carrying out the final priority setting exercise according to the JLA process, were followed (James Lind Alliance, 2020b). Figure 6.3 presents the approach taken for preparing for the prioritisation workshop and the phases that took place during the workshop.

Figure 6.3| *Timeline of the preparatory steps and phases of the prioritisation workshop*

A list of uncertainty sources for pre-workshop ranking (see Table 6.3), participant biographical information, and discussion cards, were used to prepare the participants prior to the workshop, as well as to guide their discussions during the workshop (see Figure 6.4 and Appendix D) as suggested by the JLA guidebook (James Lind Alliance, 2013, 2020b).

Figure 6.4| *Materials for preparation and use during the prioritisation workshop*

6.2.3.4 Prioritisation Workshop Phases:

First Phase:

During the first phase participants were divided into two smaller groups (see Figure 6.3). In the two smaller groups, participants were presented with a set of discussion cards and encouraged to express their views with regards to those sources they felt the strongest or least strong about (see Figure 6.5). The facilitator ensured that there was an ongoing discussion and debate, and that all individuals expressed their opinions.

Following the discussion, the first group reached a consensus regarding their rankings of the 24 sources of uncertainty. The second group could not reach a consensus and thus a private voting process took place. A score of 24 was given to the highest priority and a score of one to the lowest priority. One of the participants expressed their difficulty in providing a ranking for those priorities that fell outside their top ten, and as a result a median rank of 12 was given to all the other priorities for which they had not voted.

Following the calculation of the final scores for the second group, their aggregate ranking as a group was produced. The rankings of both groups were then transposed into scores, in order to produce an aggregate ranking for both.

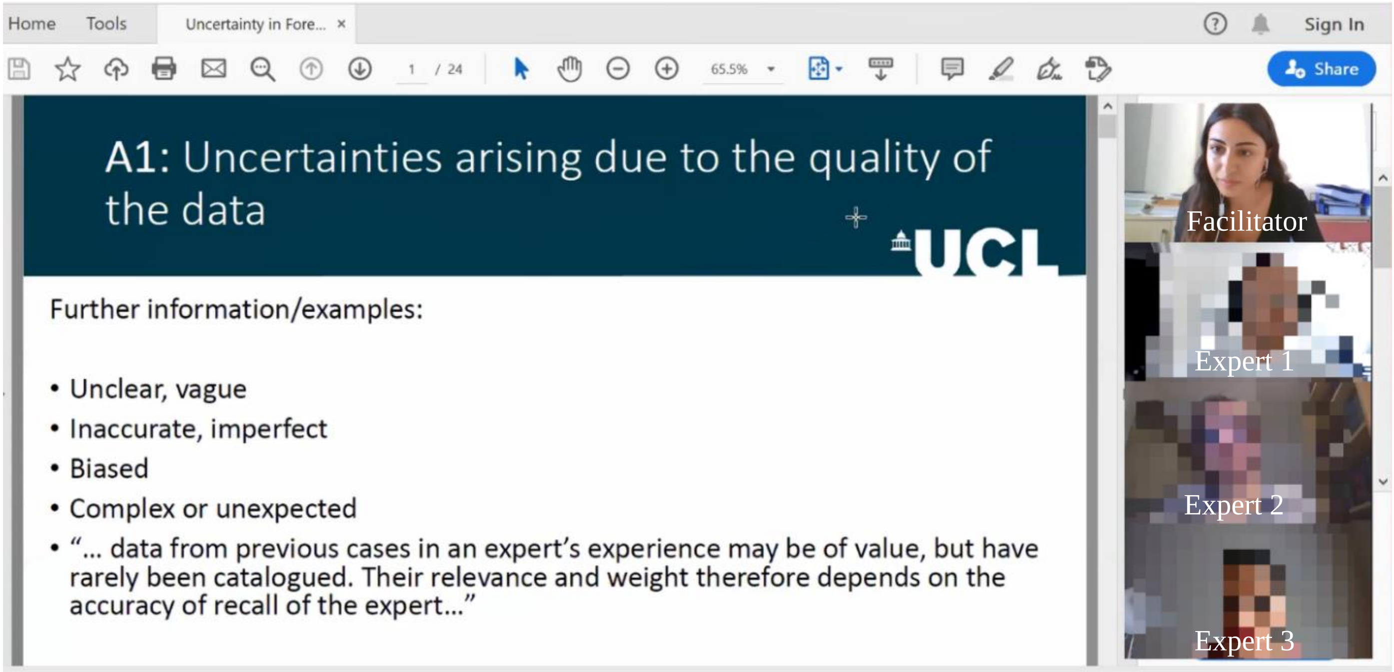

Figure 6.5| *Prioritisation Workshop - Facilitator & three Experts*

Second Phase:

Even though the JLA process recommends the use of 3 phases, the two final phases were merged into one for the purposes of this study, given that a consensus was reached during the discussions of the second phase (See Figure 6.3). According to the traditional NGT methods, additional discussions and voting beyond the initial round are not considered mandatory, and 'may take place' if it is deemed necessary to reach a consensus (Foth et al., 2016, p.114). Despite differences between the traditional NGT and modified NGT, this recommendation was followed and achieving consensus in an earlier phase was allowed. Following the presentation of the voting results from Phase 1, a discussion commenced between the four participants, who by the end of it came into agreement with regards to their top 16 priorities, as well as the top ten. In order to reach such a consensus, they agreed that a few of the sources of uncertainty could be merged into broader categories (JLA, 2013), thus capturing the variations in their views and priorities.

Third Phase:

Following the completion of the workshop, and the absence of a final round of discussion and voting, it was considered appropriate to get in touch with participants electronically to present the top 16 priorities that had emanated as a result of their merging of categories of sources of uncertainty, as well as the top ten that they had reached during the workshop. Such presentation was also accompanied by a request for a final validation and approval of the top 16 and top ten, which was provided by all participants.

6.2.4 Data Analysis

The analysis of the data collected through a modified NGT is often considered a synthesis of both quantitative and qualitative approaches (De Villiers et al., 2005; Stewart, 2001). The analysis consisted of a numerical ranking exercise, both for the survey and final prioritisation workshop, and a thematic analysis for the qualitative data that had been collected (See Section 6.3). Contemporaneous notes were taken throughout the processes, so as to ensure that the researcher remained reflexive while rearranging participants' responses, and when thematically analysing the qualitative data (Cruz, 2015).

6.3 Analysis & Results

This section provides an outline of the analysis that was carried out throughout each stage of the modified NGT, the interim and final results of the prioritisation exercise. It also provides a presentation of the thematic categories that arose from the participant responses to the open-ended survey questions and the discussions in the prioritisation workshop. Sections 1-3 and 5 focus on each stage of the modified NGT, respectively, while section 4 provides a more detailed and holistic picture of the experiences of stakeholders as reported in the available text data collected from the survey and the prioritisation workshop recording transcripts.

6.3.1. Gathering Uncertainties, Data Processing & Verifying

6.3.1.1 Analysis:

For the purposes of data processing, verification of the sources of uncertainty that had been collected through the review (JLA, 2013), and ensuring the comprehensibility of the survey (Hart et al., 2017), a regrouping exercise was carried out. Those sources that were deemed to be overlapping were grouped together under more general sub-categories with simpler terms. Some specific sources of uncertainty were then used as examples in brackets for the more general sub-categories that were developed. Other sources of uncertainty were simply rephrased (see 'uncertainty conceptualisation' in Table 6.1). The original categories of the seven source areas were retained. The pilot study was helpful in identifying those sources or sub-categories of uncertainty that were not comprehensible enough, and these were amended accordingly to ensure ease of understanding. Examples of how sources of uncertainty were grouped together or rephrased can be found in Table 6.1.

Data Sources from Review	**Category as presented in the survey**
Incomplete/ imperfect	Uncertainties arising due to the quality of the data (such as inaccurate data, unclear, vague, complex etc.)
Structure of data	
Vague	
Unexpected	
Complex	
Inaccurate/imprecise	
Poor	
Biased	
Unclear	
Uncertainty conceptualisation	Uncertainty about how the issue of uncertainty is understood/defined.
Subjective (inability to apply moral rules)	Moral uncertainties (i.e. lack of moral rules, inability to apply moral rules, etc.)
Moral (facing moral uncertainty due to lack of moral rules)	

Table 6.1| *Example of regrouping and rephrasing categories of sources of uncertainty for survey presentation*

6.3.1.2. Results

The interdisciplinary configurative review (Chapter 5) served as the first step of the JLA process. The configurative review resulted in the identification of 84 sources of uncertainty located in seven different source areas: data, knowledge, methodological, probabilistic, semantic, innate and examiner-centred. These seven different source areas served as the main categories around which the survey questions were formed. The seven main questions of the survey asked participants to select two of the sources of uncertainty under each main source area, which they considered to be their own priorities for the purposes of evaluation and communication to stakeholders. The grouping together and rephrasing of the original sources of uncertainty identified in the review resulted in five sub-categories for the general area of data uncertainties, three for knowledge uncertainties, four in methodological sources, five for innate, four for semantic, three under probabilistic sources, and five for examiner-centred sources (See Table 6.2).

Table 6.2 constitutes a condensed version of the survey questions and the sources that participants were required to prioritise for each source area. For the full survey, including the open-ended questions, introduction and conclusion see Appendix C.

Question Select up to two of the following *[data/methodological/etc.]* sources of uncertainty that you encounter most frequently and/or you would like to see evaluated and communicated to all stakeholders (judges, lawyers, jurors).	**Priorities options (other than 'other' or 'none of the above')**
<u>Data Sources</u>	1. Uncertainty arising from volume of data (i.e. data unavailable, very little or too much data, etc.). 2. Uncertainty arising due to the quality of the data (such as inaccurate data, unclear, vague, complex etc.). 3. Uncertainty arising from non-discriminatory nature of data (i.e. data that cannot assist in discriminating between features, hypotheses, etc.). 4. Uncertainty arising from inapplicable data (i.e. irrelevant, unrepresentative of entire population, unreliable etc.). 5. Uncertainty arising from changing nature of data (i.e. data that is revised, variability of data etc.).

Knowledge Sources	1. Progress in knowledge (i.e. knowledge in the field constantly progressing, being updated, etc.). 2. Lack of theoretical understanding. 3. Limited underpinning science.
Methodological Sources	1. Uncertainty arising due to concerns regarding analytical instruments (i.e. precision of analytical instruments/methods; model uncertainties, such as algorithms used for automated fingerprint comparisons; etc.). 2. Uncertainty arising due to different methods used by different forensic science experts. 3. Uncertainty arising due to concerns regarding methods employed for data management and storage (i.e. tools/databases selected to store and manage data; methods selected to enhance photographs of trace evidence taken at the crime scene, etc.). 4. Uncertainty arising from the choice or use of relevant academic/scientific literature in the case in hand.
Innate Sources	1. Unpredictability or variability/changeability (i.e. degradation or cross-contamination of physical evidence; unpredictable behaviour of first responders to crime scene, etc.). 2. Complexity (i.e. complex case, layers of interpretation to the problem, complex behaviour of trace evidence, etc.). 3. Inherent limitations of quantification (such as unquantifiability of events/propositions, model results inherent approximations, etc.). 4. Indeterminate elements (aspects in the case study that are not exactly known, established or defined). 5. Inherently uncertain nature of science (i.e. science can never be separated from its social context; provisional nature of knowledge; scientific knowledge cannot entirely correspond to objective truth, etc.).
	1. Uncertainty about how the issue of uncertainty is understood/defined/perceived. 2. Uncertainty arising due to descriptions or definitions (i.e. vagueness of language, ambiguity of language etc.). 3. Uncertainty as a result of the influence your institution or interpersonal relations have on the understanding/definition/perception of elements that form part of your work. 4. Uncertainty arising due to differing understandings/perceptions of the problem (i.e. different

Semantic Sources	stakeholder perceptions about which exhibits are critical to the case and should thus be analysed/prioritised for analysis, etc.).
Probabilistic Sources	1. Uncertainty around the precision/validity of probabilities (i.e. precision/validity of probability/range of probabilities of a DNA match if the prosecution proposition were true). 2. Uncertainty arising due to unknown probabilities (i.e. unknown probative value of comparison between two patterns). 3. Uncertainty arising due to difficulties of assigning probabilities (i.e. to events, propositions, hypotheses, etc.).
Examiner-Centred Sources	1. Uncertainty arising from range of expert views (i.e. disagreement between experts, conflicting findings/views, equally valid but differing frames of knowledge, etc.). 2. Quality of expert (i.e. experience, training, lack of knowledge, etc.). 3. Uncertainty arising from expert judgment/decision-making (i.e. mental shortcuts, assumptions, etc.). 4. Moral uncertainties (i.e. lack of moral rules, inability to apply moral rules, etc.). 5. Personally perceived uncertainties (existing in the mind of the forensic science expert).

Table 6.2| *Closed-ended survey questions and multiple-choice options*

6.3.2. Interim Priority Setting Exercise

6.3.2.1. Demographics

There were 66 participants in the interim priority setting exercise (survey). Out of the 66 participants, 45 completed the survey fully, while the rest only provided partial responses. Participants that had completed at least one of the questions from the main body of the survey were considered as partial-responses and their records were retained. The final question invited participants to suggest additional sources of uncertainty. Those responses which consisted of remarks along the lines of ‘none of the above’, ‘does not apply’ or ‘no’ were excluded.

Figure 6.6 provides a breakdown of how many participants responded to each of the source area questions.

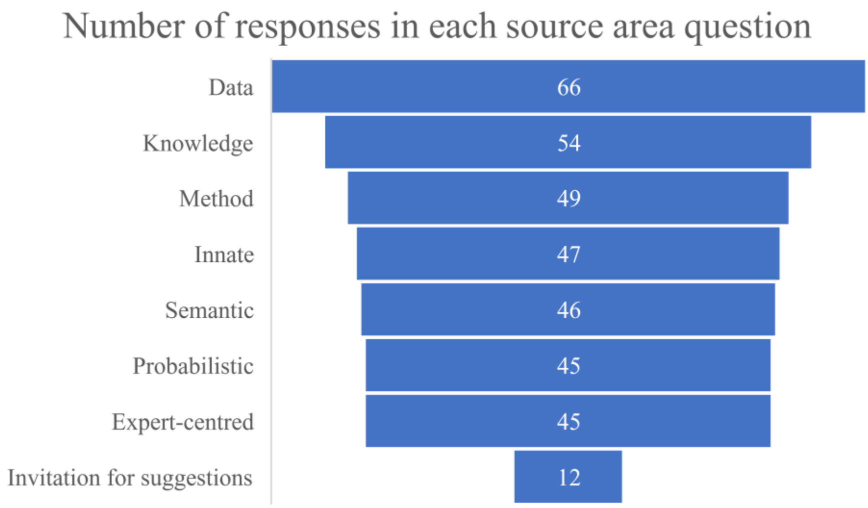

Figure 6.6| Number of responses for each of the survey source areas

Most of the respondents identified as forensic scientists. Even though originally only forensic scientists, lawyers and judges were targeted, the survey allowed for the selection of 'other' in the question regarding their profession. As such, certain 'other' professions were considered as valid points of view and the data of these were retained. Among the 'other' fields were 'forensic science research', 'quality assurance', 'policy-making' and 'analytical toxicology'.

Figure 6.7 indicates the corresponding number of participants for each professional field.

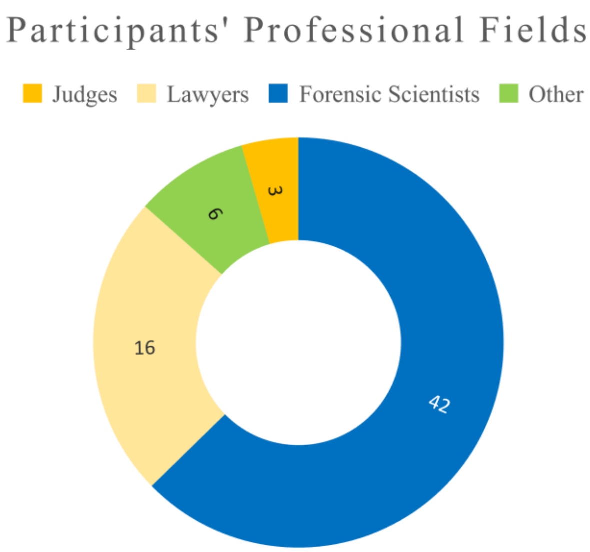

Figure 6.7| *Participant's Professional Fields*

6.3.2.2. Analysis

Participants were required to select up to two of their top priorities from each source area. Three additional sub-categories of sources of uncertainty, that had not been previously identified in the survey, were developed as a result of the open-ended responses of participants.

To ensure that each source area was equally represented, the three priorities from each source area with the highest number of votes were selected for presentation in the prioritisation workshop. Votes were counted after the selections of participants were validated against their response to the follow up open-ended question and rearranged accordingly where necessary.

The survey responses to the open-ended questions were analysed concurrently with the transcripts from the prioritisation workshop using thematic analysis. Any responses provided in the open-ended follow up question subsequently to the selection of the 'other' option were either rearranged in one of the available options and counted towards the final frequency count accordingly, or they formed part of the qualitative analysis or additional sources that were grouped together as miscellaneous (Figure 6.15). The results of the thematic analysis will be presented in Section 6.3.4.

6.3.2.3 Results

Following the validation of participants' selected priorities, the votes for each source area were counted. Two of the uncertainty source areas – knowledge and probabilistic sources – only had three available options for prioritisation. As such, all of the options for each of these source areas were included for discussion and prioritisation in the workshop. Nevertheless, there was a significant disparity in the interest expressed by participants in relation to which specific source they were most interested in being evaluated and communicated to lay stakeholders. In relation to knowledge uncertainties, limited underpinning knowledge/science was the option that collected the most votes, while the precision/validity of probabilities collected the highest number of votes with regards to probabilistic sources of uncertainty. Figures 6.8 and 6.9 indicate the number of votes for each of the specific sources of uncertainty with regards to these two source areas.

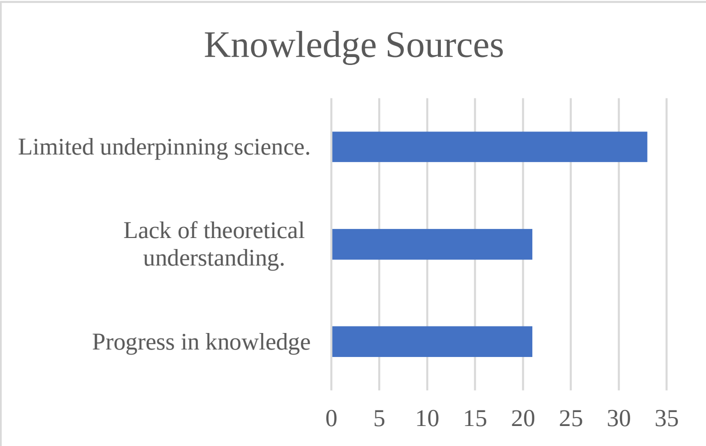

Figure 6.8| *Knowledge sources number of votes*

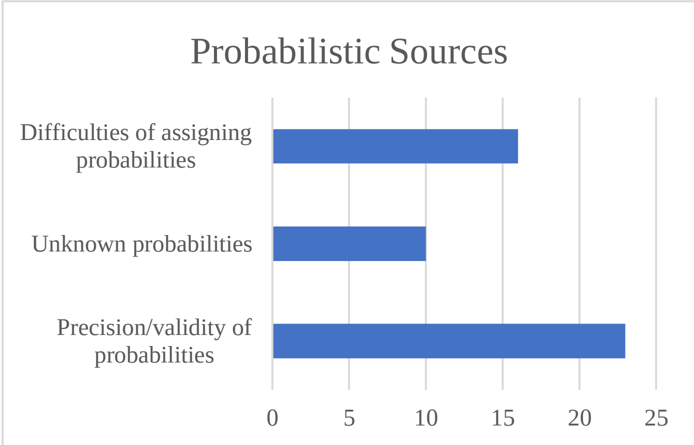

Figure 6.9| *Probabilistic sources number of votes*

There was also a clear discrepancy in the number of votes between the available options for the remaining source areas. As a result, the selection of the three sources of uncertainty for inclusion in the prioritisation workshop was straightforward. The specific sources that were of most interest to the survey participants, in relation to evaluation and communication purposes, were uncertainties arising due to the volume of the data (data sources), the different methods used by different forensic science experts (methodological), unpredictability or variability/changeability (innate), how the issue of uncertainty is understood/defined/perceived (semantic), as well as the quality of the expert (expert-centred).

Figures 6.10-6.14 provide a detailed breakdown of the number of votes accrued by each of the available options for the area sources of data, methodological, innate, semantic and expert-centred. The total number of votes for each of these source areas does not include those votes that had selected the ‘other’ or ‘none of the above’ options.

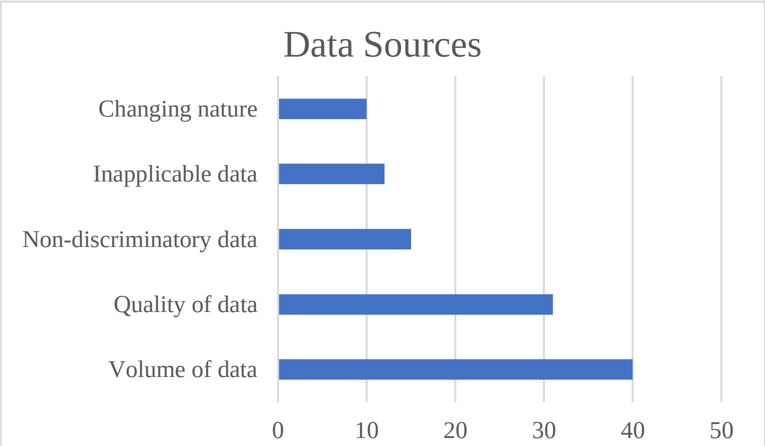

Figure 6.10| *Data sources number of votes*

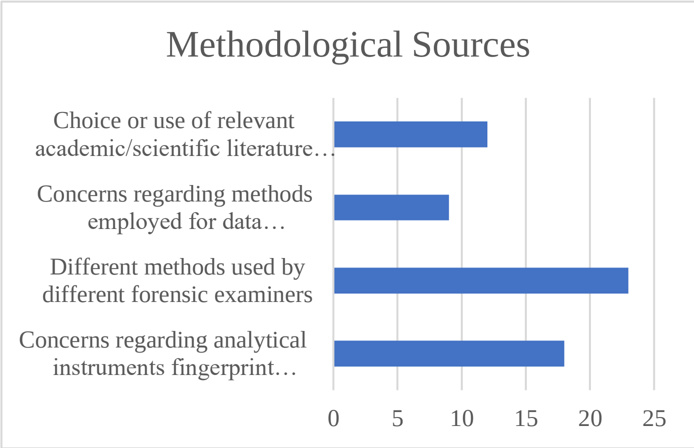

Figure 6.11| *Methodological sources number of votes*

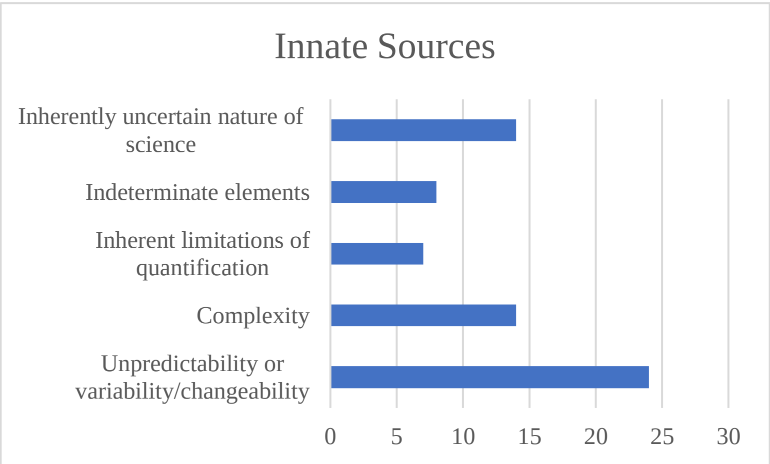

Figure 6.12| *Innate sources number of votes*

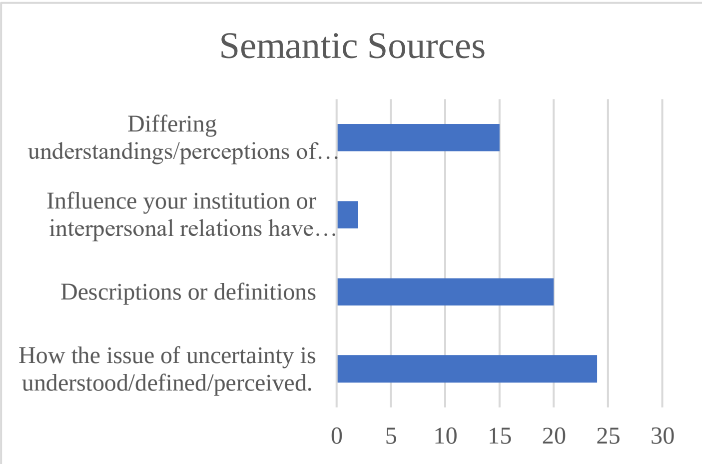

Figure 6.13| *Semantic sources number of votes*

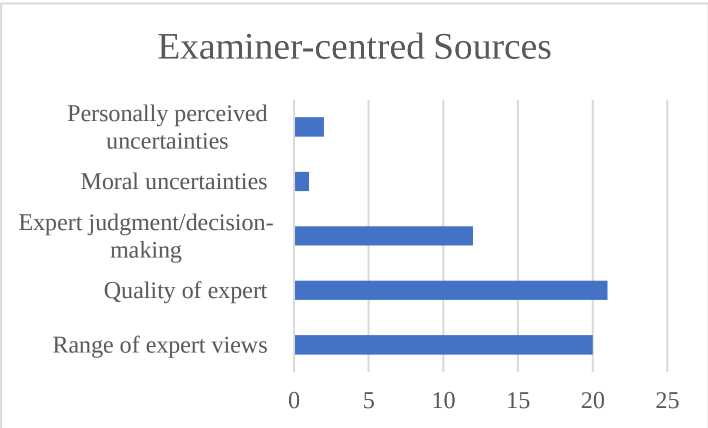

Figure 6.14| *Methodological sources number of votes*

An additional category was created named ‘Miscellaneous’. This category was created to capture those sources of uncertainty that had not been identified through the interdisciplinary configurative review, and which had emanated from the responses of participants in the open-ended questions of the survey. Three further sub-themes were developed to organise the responses of survey participants under the category of ‘Miscellaneous’. The sub-themes relate to uncertainties arising due to lack of exchange of ideas, practical uncertainties around reporting examiners’ findings, and difficulty drawing meaningful conclusions from the available data. These sub-themes can be viewed in Figure 6.15.

Figure 6.15| *Miscellaneous sources number of votes*

The purpose of the numerical vote counting was to select three sources from each of the different source areas for presentation in the prioritisation workshop. Twenty-four specific source priorities resulted from this process, including the three sources that had not been previously identified in the interdisciplinary configurative review, organised under the theme ‘Miscellaneous’. Table 6.3 provides an overview of these 24 specific sources of uncertainty.

Top 24 sources for prioritisation workshop	
A. Data	
A1	Uncertainties arising due to the quality of the data (e.g. inaccurate data, unclear, vague, complex etc.).

A2	Uncertainties arising from the volume of the data (e.g. data unavailable, very little or too much data, etc.).
A3	Uncertainty arising from non-discriminatory nature of data (i.e. data that cannot assist in discriminating between features, hypotheses, etc.).
B. Knowledge	
B1	Progress in knowledge (e.g. knowledge in the field constantly progressing, being updated, etc.).
B2	Lack of theoretical understanding (i.e. inadequate common understanding in the field, imperfect common knowledge in the field, etc.).
B3	Limited underpinning science.
C. Methodological	
C1	Uncertainty arising due to concerns regarding analytical instruments (i.e. precision of analytical instruments/methods; model uncertainties, such as algorithms used for automated fingerprint comparisons, etc.).
C2	Uncertainty arising due to different methods used by different forensic science experts.
C3	Uncertainty arising from the choice or use of relevant academic/scientific literature in the case in hand.
D. Innate	
D1	Unpredictability or variability/changeability (i.e. degradation or cross-contamination of physical evidence; unpredictable behaviour of first responders to crime scene, etc.).
D2	Complexity (i.e. complex case, layers of interpretation to the problem, complex behaviour of trace evidence, etc.).
D3	Inherently uncertain nature of science (i.e. science can never be separated from its social context; provisional nature of knowledge; scientific knowledge cannot entirely correspond to objective truth, etc.).
E. Semantic	

E1	Uncertainty about how the issue of uncertainty is understood/defined/perceived.
E2	Uncertainty arising due to descriptions or definitions (i.e. vagueness of language, ambiguity of language etc.).
E3	Uncertainty arising due to differing understandings/perceptions of the problem (i.e. different stakeholder perceptions about which exhibits are critical to the case and should thus be analysed/prioritised for analysis, etc.).
F. Probability	
F1	Uncertainty around the precision/validity of probabilities (i.e. precision/validity of probability/range of probabilities of a DNA match if the prosecution proposition were true).
F2	Uncertainty arising due to difficulties of assigning probabilities (i.e. to events, propositions, hypotheses, etc.).
F3	Uncertainty arising due to unknown probabilities (i.e. unknown probative value of comparison between two patterns).
G. Expert	
G1	Uncertainty arising from range of expert views (i.e. disagreement between experts, conflicting findings/views, equally valid but differing frames of knowledge, etc.)
G2	Quality of expert (i.e. experience, training, lack of knowledge, etc.)
G3	Uncertainty arising from expert judgment/decision-making (i.e. mental shortcuts, assumptions, etc.).
H. Miscellaneous	
H1	Lack of exchange of ideas and knowledge between practitioners, as to best practice.
H2	Practical uncertainties about giving evidence/reporting.
H3	Difficulty of drawing meaningful conclusions and interpretations from the evidence.

Table 6.3| *The 3 sources with the highest number of votes from each source area, taken forward to prioritisation workshop*

Table 6.3 also served as one of the preparatory materials that had been provided to the prioritisation workshop participants, as part of a pre-ranking exercise prior to the actual workshop (see Appendix D).

6.3.3 Final Priority Setting Exercise

6.3.3.1 Demographics

There were initially six participants that joined the online final priority setting exercise (prioritisation workshop). One of the participants was unable to continue beyond the first introductory part of the workshop due to technical difficulties, while the second participant had to leave after the first round of consensus building. Information regarding the professional fields and countries of practice of the five participants who contributed towards reaching a consensus can be found in Table 6.4.

Expert	**Professional Field**	**Country of practice**
A	Forensic Geneticist	Italy
B	Academic/Researcher & Forensic Toxicologist	UK
C	Academic/Researcher & Forensic Voice Comparison Expert	UK
D	Barrister – Criminal Litigation	UK
E	Quality Control Forensic Police	Spain

Table 6.4| *Professional fields of expert participants at the prioritisation workshop*

6.3.3.2 Analysis

The analysis that took place during the prioritisation setting exercise was mostly organic, as participants were encouraged to discuss the sources and prioritise as they went along during each of the rounds. There were, nevertheless, prescribed quantitative elements to the analysis as well. The quantitative analysis consisted primarily of converting Group A's group ranking into numerical values, while also calculating Group B's individual votes and then converting these into a group ranking and in turn into a numerical value. The numerical values of each group for each source of uncertainty were aggregated in order to produce a final sum for each source reflecting the collective perspective of both groups.

Following the aggregate values, the sources were prioritised from highest to lowest priority. The source with the highest numerical value was granted the rank of 1, while the source with the lowest numerical value was granted the rank of 24. Following the presentation of the top 16 priorities to participants, no further analysis was required. Participants entered into a conversation, in which they expressed their agreements and disagreements regarding the top 16 and all reached a consensus on the top ten. These discussions were recorded, transcribed and thematically analysed. The results of the thematic analysis are presented in Section 6.3.4.

Figure 6.16 provides a visual outline of the three different rounds, as well as the analyses that took place in each round. The quantitative analysis was undertaken only during Round 1. Round 2 consisted of a more organic prioritisation arising through the discussions of the workshop participants. No further analysis was undertaken in Round 3, as its purpose was to confirm and validate the final priorities following the completion of the workshop.

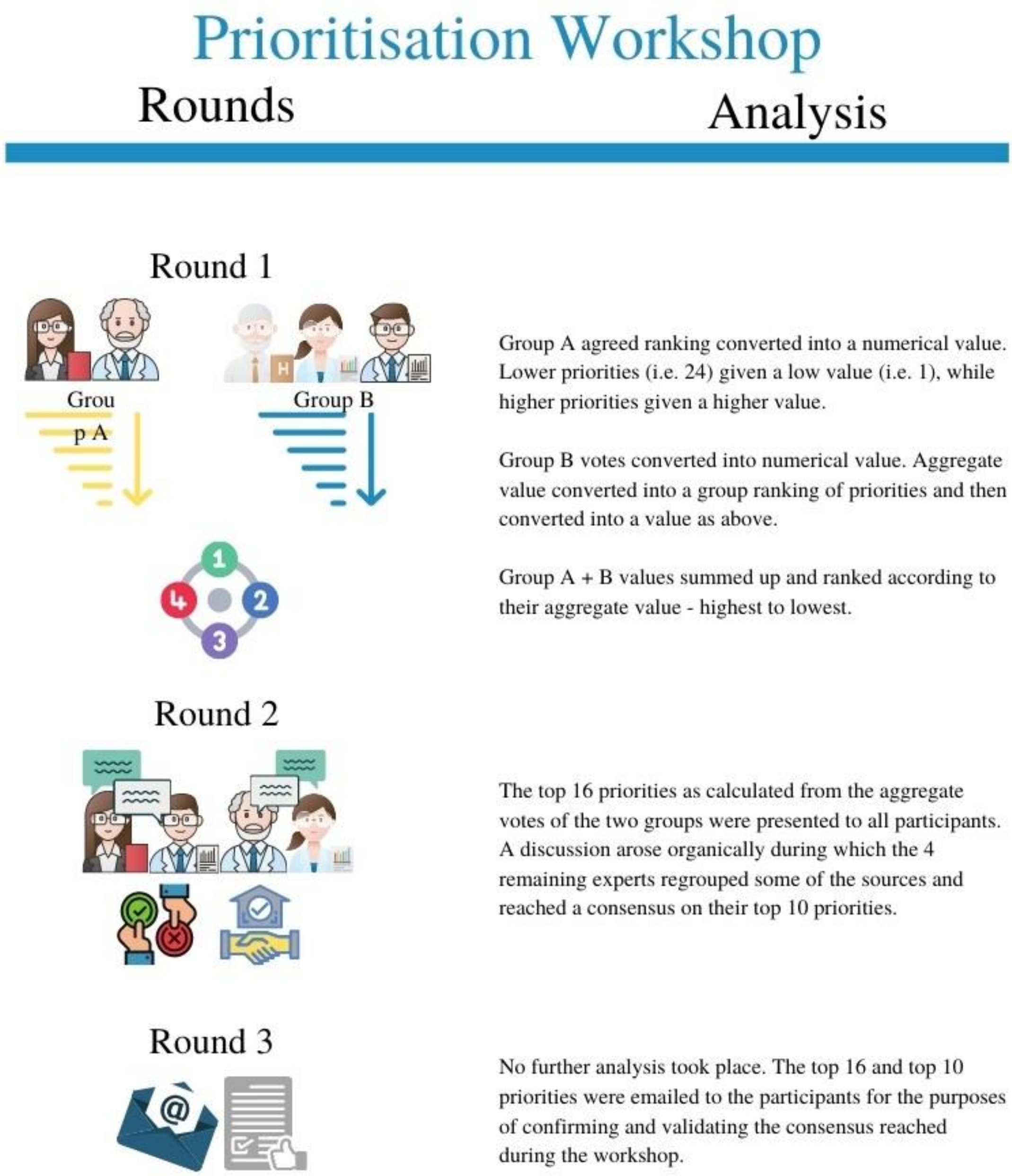

Figure 6.16| Prioritisation workshop rounds

6.3.3.3 Results

The quantitative results, in terms of the stakeholders' top agreed priorities arose by the end of the workshop. Further validation and confirmation of their individual perspectives was sought following the prioritisation workshop, through email. Figure 6.17 captures the top 24, top 16 and top ten priorities as brought about by each stage of the modified NGT exercise. All source areas are represented in the top 16, while all but the miscellaneous area represented in the top ten stakeholder priorities. The most represented source area in the top ten is that of 'Methodological' sources of uncertainty, with all 3 specific sources presented at the workshop selected within the top ten. Two specific 'Data' and two 'Probabilistic' sources of uncertainty were selected in the top ten, while one of each from the source areas of 'Knowledge', 'Semantic' and 'Expert' were also included in the top ten. Even though the source area of 'Inherent' uncertainties does not exist as a source area on its own in the final top ten, two of its sources 'Complexity' and 'Variability' were merged with 'Data quality', following agreement between the workshop participants. Further sources that were subject to merging were 'Range of expert views', merged with 'Different methods used by experts', and 'Understanding of uncertainty' merged with 'Uncertainty about descriptions and Definitions' (see Figure 6.17).

Figure 6.17| *Priorities of Sources of Uncertainty in Forensic Science as established through the survey and prioritisation workshop*

6.3.4 Qualitative Analysis and Findings: A holistic picture

6.3.4.1 Analysis

In order to provide a more detailed and holistic account of the experiences of stakeholders with uncertainty in forensic science, qualitative data were collected both at the stages of the interim priority setting exercise and the final prioritisation workshop. The online prioritisation workshop was recorded with the consent of participants and the recordings were later transcribed with the use of the online software 'Otter ai' (See Appendix E).

Typically, the open-ended questions of a survey forming part of an NGT technique serve the purpose of gathering uncertainties. Given that the uncertainties for this consensus building exercise had already been gathered through the interdisciplinary configurative review, the open-ended questions, along with the transcripts from the prioritisation workshop, provided a source for delving deeper into stakeholders' perceptions and experiences of scientific uncertainty.

The data collected through the participants' responses to the open-ended survey questions, as well as the transcripts of the prioritisation workshop were analysed conjunctively with the assistance of the NVivo software. Following the consideration of several available qualitative analysis methods, including content analysis and grounded theory, thematic analysis was considered the most suitable approach for addressing the aims of this study. Thematic analysis, despite its more descriptive nature in comparison to grounded theory, purports to achieve of a more in-depth and interpretive understanding of the meaning of the collected data and the emerging categories, than content analysis (Neuendorf, 2019). As such, the six steps developed by Braun & Clarke (2006) for thematic analysis were followed. The six steps include familiarising oneself with the data, followed by code generation, search, review and defining of the themes and finally writing up.

Adherence to most steps, as part of the Braun & Clarke (2006) process, is self-explanatory. However, the process does not prescribe an approach with regards to whether the themes that emerge should be exhaustive and/or mutually exclusive. Content analysis and grounded theory were consulted when determining the best approach with regards to this. Traditionally, quantitative content analysis requires the existence of exhaustive and mutually exclusive categories, for ensuring that the statistical assumptions relied upon are not violated (Zhang & Wildemuth, 2005). There is some debate as to whether qualitative content analysis requires the mutual exclusivity of categories, with some arguing that it does (Drisk & Maschi, 2015) and others that it does not (Tesch, 2013). Grounded theory does not require categories being mutually exclusive, as such categories should simply emerge from the data (Willig, 2013). Given that thematic analysis was selected due to its focus on elicitation of meaning from the data, grounded theory, with its emphasis on interpretation and theory development, was deemed the best paradigm in this instance when it came to informing the decision on whether the themes should be mutually exclusive. As such, even though most of the themes that emerged were mutually exclusive, on certain occasions there were overlaps in relation to the codes they encompassed.

While searching and reviewing for themes, some of the themes that pre-existed as part of the survey arose again. These were retained but, where appropriate, their titles were slightly modified, in order to more accurately capture the experiences of participants as expressed through their open-ended survey responses and workshop discussions. For example, the sub-theme of 'Underpinning Science' (in the theme of Knowledge) was reworded to 'Underpinning science/research'.

The thematic analysis, also allowed for the identification of certain links between codes, sub-themes and themes (See Figure 6.18). The links were drawn as a result of the remarks and observations made by participants in the open-ended survey questions, or their discussions in the prioritisation workshop. For example, a survey participant noted '…knowledge of statistical models is lacking…', who goes on to explain that this, in conjunction with the limited data available, prevents the statistical evaluation of features. As such, the lack of knowledge of statistical models, was captured through the use of the code 'poor knowledge of statistical models' which relates both to the 'Knowledge of probabilities by experts' (sub-theme of 'Theoretical understanding' under the theme of 'Knowledge') as well as to 'Limited use of probabilities by experts' under the sub-theme of 'Difficulty assigning probabilities' within the general theme of 'Probabilistic' sources of uncertainty. The decision not to require mutual exclusivity between sub-themes and themes, was also beneficial as it allowed for the emergence of such links, through the identification of sub-themes with overlapping codes.

6.3.4.2 Results

The coding process resulted in 167 codes from the interim priority setting exercise, and 35 codes from the final priority setting exercise transcripts. The stages of searching, reviewing and generating themes, gave rise to nine themes, seven of which are the main source areas that had emerged from the interdisciplinary configurative review and which were used to guide the survey structure. 'Practical' uncertainties and 'External forces' were the two new themes that arose from the analysis of the open-ended questions and the workshop transcripts. A few links were also identified between certain codes and sub-themes, which links have been captured in Figure 6.18.

6.3.4.2.A. Main Themes, Sub-themes and Codes

The nine main themes that emerged from the underlying qualitative data were captured in tables (Tables 6.4-6.12). The codes that make up the sub-themes are represented in the lighter coloured boxes, while the darkest coloured boxes on top of each table signify the 9 main themes. What follows is a brief description of the findings for each of the main themes, along with the relevant table consisting of the sub-themes, sub-sub-themes (where applicable) and their codes.

Data:

The 5 data sources of uncertainty that had been provided as options for prioritisation in the survey were consistent with the qualitative data and were thus retained as sub-themes. A few of the codes had not been previously encountered in the interdisciplinary configurative review and were, therefore, particularly useful for adding further detail and context to the sub-themes. One such example, is the changing nature of data being a particularly strong concern in the sub-disciplines of handwriting and speech analysis. The absence of available databases was an equally important realisation, with participants identifying a number of uncertainties arising as a result of this lack, such as the hindrance of the execution of statistical tests and the execution of comparisons between crime scene traces against sample features.

DATA				
Quality	**Volume**	**Changing**	**Non-discriminatory**	**Inapplicable**
Inferior/poor quality of data	Very little, few samples from which to draw conclusions	Examples from handwriting or speech features changing over time	Data cannot help you differentiate between different hypotheses	Absence of comparable data from previous cases
Incomplete or missing	Too much data (of little quality)	Inter and intra-speaker variability	Non-discriminatory elements/features of the CS (crime scene) sample	Unavailable databases can prevent the comparison of CS traces against existing features
How determinate is the sample	Volume affecting models, too much or too little data			Unavailable databases preventing the execution of statistical tests

Cross-Contamination				Bad sampling
				Little sampling used as reference for all English Speakers

Table 6.5| *Data uncertainties (sub-themes and corresponding codes)*

Methods:

The main sub-themes relevant to methodological uncertainties that existed in the survey were also represented in the qualitative data. In addition to the 4 main sub-themes, a sub-theme highly interlinked to the first sub-theme of analytical instruments/methods also arose; that of quality of methods. Similarly to the Data uncertainty codes, the codes of Methodological uncertainties made a valuable contribution towards extrapolating each of the main sub-themes. For example, survey and workshop participants discussed the unequal access to literature across labs, a code that illuminates the sub-theme of choice/use of relevant literature. There were additional codes that emerged from the open-ended questions, which had not previously been identified. These include, overconfidence in the methods, absence of standardisation and transparency in the use of methods, and the impact of lack of training when it comes to data storage and use.

METHODOLOGICAL			
Analytical Instruments/ Methods	**Use of different methods**	**Different methods for data storage and use**	**Choice/use of relevant literature**
Analytical uncertainty related to measurement	How to combine different analyses	How data is collected or captured (photos)	Access to literature varies according to the lab
Uncertainty related to equipment (access to equipment)	Different methodologies, methods used by different examiners	How data is stored	Uncertainty on how to extrapolate/apply research
Quality of methods:	Methods for estimating uncertainty	Configured/ enhanced	

Bad/science, absence of scientific methodology	Analysis discrepancies	Packed	
Methods tested on variable data	Methods produce different results	Transported/ transferred	
Poor quality analysis	Absence of standardisation and transparency	Disseminated	
Too much confidence in methods		Lack of training	

Table 6.6| *Methods uncertainties (sub-themes and corresponding codes)*

Knowledge:

The sub-themes for the theme of 'Knowledge uncertainties' that had been included in the survey remained largely the same through the analysis of the qualitative data. However, a new sub-theme emerged which had not been previously included as an option for prioritisation in the survey, that of 'Knowledge of probabilities'. This sub-theme is highly related to the pre-existing category/sub-theme of 'Theoretical understanding'. The new sub-theme was formed so as to recognise the importance of a lack of theoretical understanding specifically with regards to the use of probabilities.

As can be observed from Table 6.7, the majority of the codes belong to the sub-theme of 'Limited underpinning science/ research', encompassing concerns regarding the lack of research culture in labs, the relationship between researchers and practitioners, as well as the quality of research, among others.

KNOWLEDGE		
Theoretical Understanding	**Progress in Knowledge**	**Limited underpinning science/research**
Understanding of subject of examination	Progress highlighted previous uncertainties	Absence of research to help evaluation
Understanding of systems, automatic methods, software	Difficult to keep abreast with advancements (often due to lack of access)	Research (knowledge about topic of study, experimental studies)

Knowledge of Probabilities	New areas of knowledge lead to overconfident assertions	Nature, quality of research, including conditions of research
Poor knowledge of statistical models	Changing standards of analysis and evaluation	No research in uncertainty treatment
Experience in assigning priors to parameters		How to apply/extrapolate research
		Lack of research culture in labs
		Closer bond is required between researchers and practitioners
		We need databases of underpinning science

Table 6.7| *Knowledge uncertainties (sub-themes and corresponding codes)*

Expert-Centred

All the original options for prioritisation under 'Expert-Centred' uncertainties have been retained, as they aligned well with the qualitative data. These include uncertainties arising as a result of difference in opinions, the quality of the expert, the judgment of the expert, moral uncertainties and personally perceived uncertainties.

In relation to the differing opinions between experts, participants were concerned, among other things, about the lack of exchange of ideas between experts, as well as the disagreement between experts when it comes to qualitative analyses. Uncertainties as perceived (or experienced subjectively) by the expert, included uncertainties as to how much information to give, how to communicate weight and who their audience is. A few specific examples were also provided with regards to uncertainties associated with the quality of the experts, such as placing more weight on experience rather than research, testifying outside expertise, or avoidant attitudes towards uncertainty evaluation. Judgment uncertainties were also expressed, including in relation to cognitive bias and misunderstandings of the relevant literature. The sub-theme which seemed to have been of the least concern was that of moral uncertainty, with only one code corresponding to it, that of 'Noble cause corruption'.

Four sub-sub-themes emerged, for the better organisation of the sub-themes under 'Expert-Centred' uncertainties. Specifically, the sub-sub-themes of 'Experience' and 'Expertise', appeared to be related to the ‘Quality of the Expert’ and were thus placed under this sub-theme. Two additional sub-sub-themes were placed under ‘Judgment’, to capture those codes that related to uncertainties as a result of ‘Bias’ or, more generally, the expert’s ‘Decision-Making and Assumptions.’

EXPERT-CENTRED				
Difference in opinions	**Quality of expert**	**Judgment**	**Moral Uncertainty**	**Personally Perceived**
Different descriptions and interpretations	**Experience**	**Bias**	Noble cause corruption	Difficulty explaining probabilities in accessible way, presenting, explaining theoretical understanding
Same assessment, different findings	Experience given more weight than data & research	Cognitive bias		How much information to give
Huge disagreements especially in qualitative analysis	Interpretations influenced by experience	Influenced by party instructing them		How to communicate weight
Lack of exchange of ideas	There are opinions based mostly on personal experience	Specific focus or selective attention, missing other considerations		Who is the audience?
	Lazy or avoidant attitude towards uncertainty calculation			How is the evidence going to be understood/considered by stakeholders?

	Expertise	**Decision-Making and Assumptions**		Jury adequately equipped to handle divergence in opinions
	Assumed expertise	Speculation and assumptions		
	Little qualification	Subjectivity		
	Who and which organisations can act as experts	Interpretations (of analytical results, data)		
	No real scientific training	Misunderstanding of literature		
	Testifying outside expertise			
	Varying expertise and qualities of expert			

Table 6.8| *Expert uncertainties (sub-themes and corresponding codes)*

Probabilistic:

There were initially 3 specific sources of uncertainty under the general source area of 'Probabilistic', that had been presented at the survey. Two of these were merged during the qualitative analysis ('unknown probabilities' and 'difficulty assigning probabilities') as they could better capture the opinions and experiences of stakeholders as reported in the qualitative data, as a single sub-theme rather than two distinct.

An additional sub-theme emerged, highly interlinked with 'Difficulty Assigning Probabilities'; that of 'Limited use of probabilities by experts.' The latter was developed and placed under the former, so as to recognise and better reflect the experiences of stakeholders, as such difficulty is not always inherent or empirical (i.e. limits of quantification), but rather due to the limited experience or poor knowledge of experts in relation to the use of statistics.

PROBABILISTIC	
Difficulty Assigning Probabilities	**Validity/Precision of or Unknown Probabilities**
Limits of quantification	Probabilities that are unknown
Subjective parameters	No frequency data
Complex processes cannot always be quantified	Lack of background statistics
Qualitative elements cannot always be quantified	Frequencies of certain features are unknown
Limited use of probabilities by experts	Limited empirical data to inform statistical evaluation
Poor knowledge of statistical models	
Not in use in some fields	
Experience in assigning priors to parameters	

Table 6.9| *Probabilistic uncertainties (sub-themes and corresponding codes)*

Semantic:

'Influence of institution' was the only specific source found under the source area of 'Semantic' uncertainty, which did not correspond with the experiences of stakeholders as expressed in the survey and the prioritisation workshop.

The sub-theme that was of particular concern to stakeholders was that of 'Descriptions or definitions', as can be observed from the disproportionately large number of codes encompassed under this, in comparison to the other sub-themes. More specifically, experts were concerned with the uncertainties arising due to the lack of precision in verbal scales, the difficulty of translating numerical values into words, as well as the difficulty of explaining technical terms to lay stakeholders.

SEMANTIC			
Uncertainty Understanding	**Descriptions or definitions**	**Influence of institution**	**Different understanding of problem**
Difficult to describe uncertainty	Difficult to explain the difference between points on a verbal scale		Limited information about the project or the situations involved
Difficult to put uncertainty in words	Verbal scales not precise, exact or scientific		Data presented from different angles
	Verbal scales are blunt instruments		Different stakeholders have different perceptions of best forensic strategy (i.e. driven by cost, turnaround time, understanding, context).
	Difficult putting numerical values into words		
	Lack of uniformity in range & descriptions of probabilities		
	Difficult to translate between probabilities and dry propositions		
	Need for better descriptions of probabilities		
	Difficulty explaining technical language/terms to stakeholders		

Table 6.10| *Semantic uncertainties (sub-themes and corresponding codes)*

Innate:

All the specific sources of 'Innate' uncertainties presented as options for prioritisation in the survey, also arose as sub-themes from the thematic analysis. More specific examples were provided in relation to the inherently uncertain nature of science, with codes including the uncontrolled conditions of the crime scene, evidence dynamics, destruction of traces, how long traces can be stored before not being usable, as well as the uniqueness of each crime reconstruction case.

INNATE				
Variability	**Complexity**	**Inherent limitations of quantification**	**Uncertain nature of science**	**Indeterminate elements**
Examples from handwriting or speech	Complex processes	Subjective parameters	Uncontrolled conditions of crime scene	When not enough is known
Inter and intra-speaker variability	Complex interpretation	Complex processes cannot always be quantified	Evidence Dynamics	
	Complex cases	Qualitative elements cannot always be quantified	How long do collected and stored traces last before not being usable?	
			Destruction of traces due to natural conditions, ie fire	
			Uniqueness of each crime reconstruction	

Table 6.11| *Innate uncertainties (sub-themes and corresponding codes)*

Practical:

This main theme constitutes an original theme that arose during the qualitative analysis. There was no pre-existing category of practical uncertainties presented as a main source area in the survey, nor in the prioritisation workshop. The survey responses gave rise to the collection of miscellaneous sources of uncertainty that were gathered from the answers of participants in the final open-ended question.

The new theme of 'Practical' uncertainties was created so as to capture some of the sources that were identified as 'miscellaneous' from the survey, as well as additional sub- themes and codes that emerged from the thematic analysis of the qualitative data. The sub-themes that make up the 'Practical' sources of uncertainty theme, include uncertainties relating to 'Stakeholders and experts', such as exerted pressure or limited understanding, 'Principles of Evidence', such as reasonable doubt and the respective roles of the expert and the jury and 'Transparency' regarding sources of uncertainty relating to transparency issues. An additional sub-theme was developed, namely 'Testimonies and reports', divided into the sub-sub-themes: 'Practical uncertainties in giving evidence' and 'Certainty in giving evidence'. Some of the practical uncertainties in giving evidence include, questions as to how much information is appropriate to give to stakeholders, as well as how to best communicate the weight of the evidence. Stakeholders also highlighted the overstated confidence of experts as another practical source of uncertainty relating to testimonies and reports.

PRACTICAL			
Stakeholders & Experts	**Principles of Evidence**	**Testimonies and reports**	**Transparency**
Pressures from stakeholders	Reasonable doubt	**Practical uncertainties in giving evidence**	Lack of transparency over methodological choices
Pressure in the witness box	Role of expert - jury information - burden of proof	Difficulty explaining probabilities/ propositions/ theoretical understanding in in accessible way	Missing algorithms
Stakeholder intolerance of uncertainty, confusion over it		How much information to give?	Incomplete reports of experts
Limited understanding by stakeholders:		How to communicate weight to the jury	
(misunderstandings, difficult to evaluate, difficult		Who is the audience?	

to understand, oversimplification of science)			
Fallacies of infallibility		How is the evidence going to be understood/considered by stakeholders?	
		Incomplete reports by experts	
		Certainty in giving evidence	
		Uncertainties are meaningless	
		Unwarranted confidence of expert	
		Talk of myths as if they are scientific findings	
		Presentation of evidence as objective truth	
		Dogmatic expert	
		Overestimation by experts of their own knowledge	
		Exaggerated self-confidence	

Table 6.12| *Practical uncertainties*

External Forces:

A final original theme emerged, consisting of two sub-themes: human and natural external forces. Human external forces influencing the quality and quantity of the data, and natural forces such as evidence dynamics, were a particularly prominent topic of concern, especially among survey participants. This theme captures factors that are highly interlinked with certain sources of uncertainty and which have a strong impact upon them (i.e. data, methodological).

EXTERNAL FORCES	
Human	**Natural**
How data is collected	Uncontrolled conditions of crime scene
How data is stored	Evidence Dynamics
How data is configured/enhanced	How long do traces last before not being usable?
How data is packed	Destruction of traces due to natural conditions, i.e. fire
How data is transported/transferred	
How data is disseminated	

Table 6.13| *External Forces having an impact/being interlinked with uncertainty sources*

B. Links between codes, sub-themes and themes

A diagram was developed in order to visually represent the links between codes and their corresponding sub-themes and themes (Figure 6.18). The hierarchy of codes > sub-themes > themes is represented by the different colour shadings, with codes being captured in the smaller circles with the lightest colour and the themes in the bigger circles with the darkest corresponding colour. External forces that may have an impact upon certain sources of uncertainty are signified through the orange and brown triangles.

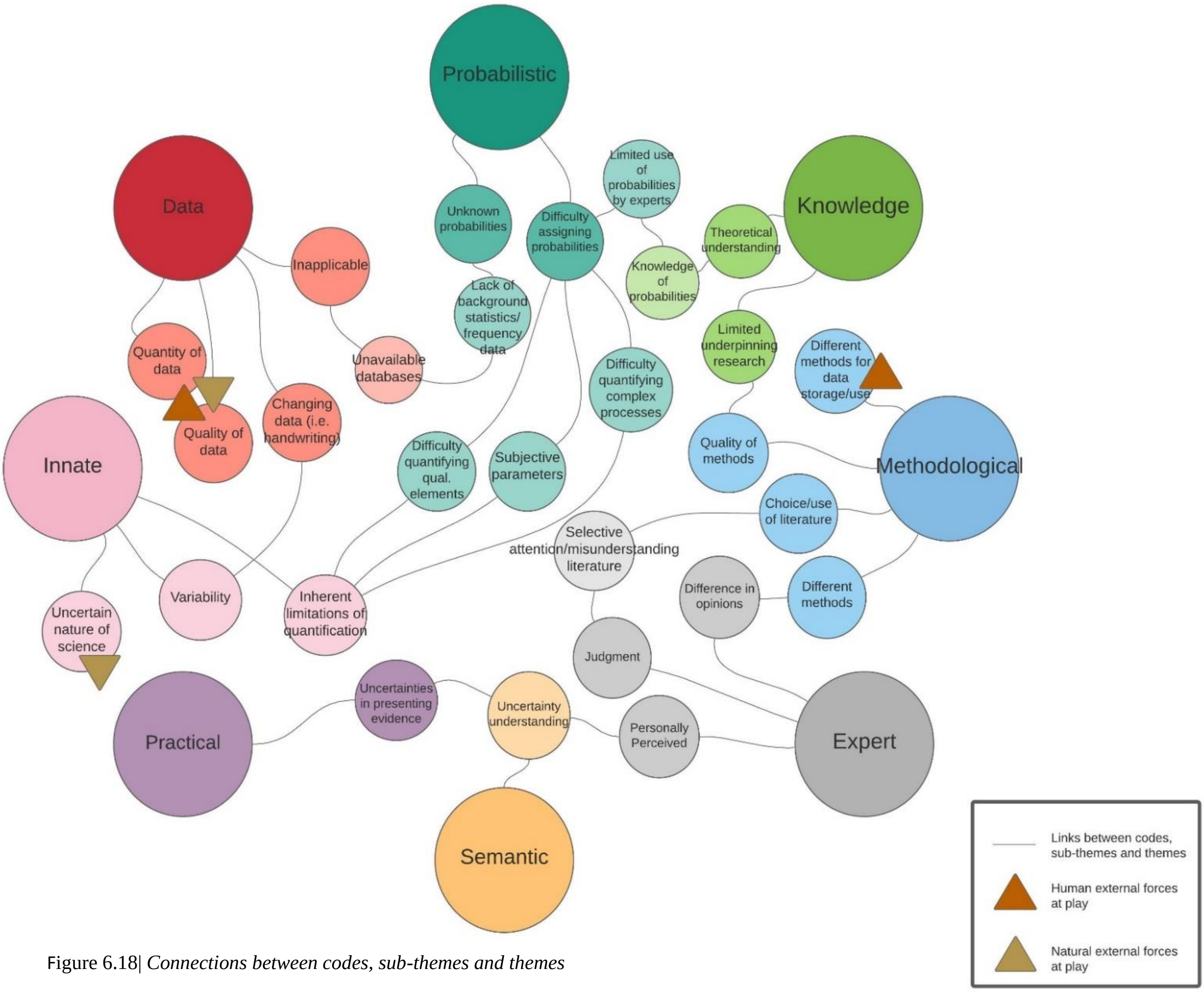

Figure 6.18| *Connections between codes, sub-themes and themes*

A number of connections arose between the sub-themes and themes that were developed as a result of the qualitative data collected from the prioritisation workshop and the open-ended questions of the survey. As is demonstrated in Figure 6.18, even though most specific sources of uncertainties can largely be categorised under one source area, they do not exist in silo. They are highly interlinked with other sources, as they can give rise to subsequent uncertainties. For example, even though the unavailability of databases can largely be considered as a data related uncertainty, it has an impact upon the evaluation of probabilities, thus giving rise to probabilistic sources of uncertainty. Similarly, uncertainties arising as a result of the choice and use of literature have been described as methodological, yet they may lead to further uncertainties in relation to the judgment of forensic science experts as a result of their individual reading and understanding of the literature. Furthermore, uncertainty arising due to lack of knowledge of probabilities and statistics can give rise to probabilistic uncertainties as a result of the difficulty of assigning probabilities.

Innate sources of uncertainty seem to permeate the source areas of ‘Data’ and ‘Probabilistic’. For example, the inherent variability of phenomena is also applicable in relation to data, because of the innate variability that is observed with regards to specific types of data (i.e. handwriting or speech). Similarly, the inherent limitations in quantifying or measuring complex processes or qualitative types of uncertainty, can give rise to further probabilistic uncertainties.

6.4. Dissemination

The final step in an NGT method is dissemination. NGT techniques seek to build consensus among stakeholders, for the purposes of establishing research priorities and allocating funding where most appropriate. As such, it is vital that the findings and the final priorities are publicised and disseminated as widely as possible. The final top ten priorities, as well as a brief overview of the results of the thematic analysis were initially shared with the participants of the prioritisation workshop, as well as any survey participants who had expressed an interest in being kept up to date with the progress of this study. The study was also drafted in the form of a journal article to be submitted for publication in a peer-reviewed journal. A summarised version of the study will also be promoted to different online newspapers and blogs with an appeal to the three main different stakeholder groups, so that the final top ten priorities can have as much of an impact as possible.

6.5. Discussion

6.5.1. Summary of Findings

This study sought to establish the interests and priorities of stakeholders in relation to the evaluation and communication of uncertainty in forensic science. The top ten priorities of forensic scientists, lawyers and judges were identified through the use of a modified NGT, in which 66 stakeholders contributed to the survey and five (subsequently four) experts reached a consensus on their final top ten priorities (Figure 6.17). Following the numerical ranking, a qualitative analysis of the open-ended survey responses and the prioritisation workshop transcripts was carried out. Nine themes emerged, corresponding largely to the source areas that had been developed in the interdisciplinary configurative review, and which guided the structure of the survey. These nine themes, along with their sub-themes, sub-sub-themes and codes, capture in more detail the experiences of stakeholders with uncertainty in forensic science.

6.5.2. Modified NGT & numerical ranking

The interim priority setting exercise – the survey – and the final priority setting exercise – prioritisation workshop –resulted in the identification of the top 24, 16 and final 10 priorities of stakeholders; namely judges, lawyers and forensic science experts (Figure 6.17). The three specific sources of uncertainty from each of the source areas of the survey with the highest number of votes were selected for presentation in the prioritisation workshop. Every source area that had resulted from the interdisciplinary configurative review was purposefully represented in the prioritisation workshop, so as to encourage the development of a holistic evaluation and communication framework. The first round of the prioritisation workshop resulted in the voting of a top 16, followed by a second round in which a consensus was reached by all participants on their top ten priorities.

The top ten priorities in terms of sources of uncertainty are: 'Data quality, including complexity and variability', 'Data volume', 'Lack of theoretical understanding', 'Analytical instrument concerns', 'Expert choice of different methods/ range of views', 'Choice/use of literature', 'Understanding of uncertainty, including descriptions and definitions', 'Precision and validity of probabilities', 'Difficulty assigning probabilities' and 'Quality of expert'.

Uncertainty arising from the expert judgment/decision-making of the expert, which encompasses issues of cognitive bias, was perhaps the most notable absence from the top ten list of priorities. Out of the 5 priorities in the source area of 'Expert-centred' uncertainties, this particular source of uncertainty ranked third on the basis of the survey participants' votes, whereas the 'Quality of expert' and 'Uncertainty arising due to range of expert views' ranked first and second respectively. Similar stakeholder perceptions were observed in the prioritisation workshop, as even though the experts voted 'Judgment' uncertainties as a priority in the top 16, they did not agree on its inclusion in the top ten.

Even though experts in the workshop had not been directed to select sources from each source area in the final top ten, all but the 'Miscellaneous' source area were included in the top ten. Such representation reinforces the identification of the 7 source areas as the main facets of uncertainty in forensic science, even on the basis of stakeholders' practical experience.

6.5.3. Thematic analysis

Nine main themes were identified through the thematic analysis of the responses to the open-ended questions and the discussions from the prioritisation workshop. Even though the original categories of sources of uncertainty, around which the survey was formed, did not guide the process of thematically analysing the qualitative data, there was a significant overlap between these and the themes and sub-themes that emerged from the thematic analysis. A potential reason behind this is that the open-ended questions of the survey, as well as the discussions in the prioritisation workshop, were largely based on and thus revolved around the initial categories.

Despite this, due to the reflexivity that was maintained throughout the thematic analysis stage, two additional themes emerged; those of 'Practical' uncertainties and 'External Forces'. In addition, not all the sub-themes were identical to those found in the original categories. For example, the analysis of the qualitative data did not give rise to codes relating to the validity or precision of probabilities. Similarly, a sub-theme of quality of methods was developed, which even though closely related to the 'analytical instruments' original category, was sufficiently distinct to warrant the formation of its own sub-theme.

In addition to the formation of new sub-themes and the two new themes, the qualitative data was particularly valuable as it allowed for the identification of links between different codes, sub-themes and themes (Figure 6.18). An example of this, is the specific source of 'inherent limitations of quantification.' This specific source that can be found under the theme of 'Innate' sources of uncertainty, is related to 'difficulty of quantifying qualitative elements', 'subjective parameters' and 'difficulty quantifying complex processes'. All three codes can be found under the sub-theme of 'Difficulty of assigning probabilities' and thus the theme of 'Probabilistic' sources of uncertainty. Effectively, these links cast light on stakeholders' perceptions and understandings of uncertainty based on their practical experience with the phenomenon as it arises in forensic science. At the same time, they demonstrate the intricate relationship, not only between codes, but also more widely between themes, highlighting the pervasive nature of uncertainty in the crime reconstruction process (Morgan et al., 2018).

6.5.4 Stakeholder tensions & Uncertainty

One of the main purposes of the modified NGT was to encourage stakeholder collaboration and to ensure that their experiences and interests are voiced and considered. At the same time, however, certain tensions that exist between stakeholders – specifically between the courts and forensic science experts – became apparent. The thematic analysis of the qualitative data was particularly useful in identifying and highlighting these tensions, and how such tensions can give rise to uncertainty. The theme that exemplified this to the greatest extent was that of 'Practical' sources of uncertainty. Certain codes and sub-themes that underpin this theme are in line with some of the most prominent topics of discussion found in the current literature with regards to the admissibility of expert witness evidence in court. Two such points of tension have been identified and will be discussed here: the certainty of law and the uncertainty of science; and the gap in the understandings of lay and expert stakeholders.

6.5.4.1 Certainty of Law vs Uncertainty of Forensic Science:

The certainty required by law and the uncertainty inherent to forensic science may give rise to pressures and tensions between the courts and forensic science experts. Forensic science experts taking part in the survey highlighted pressures from stakeholders and in the witness box, as some of the factors leading to uncertainty in their decision-making. As one participant noted (see comment report Appendix F):

‘Not so much with defence work but when conducting police work there is very often an underlying requirement to 'find evidence to demonstrate guilt' ’.

Indeed, as has been suggested in scholarly work there are often ‘systemic pressures encouraging some decisions more than others’ (Ulery et al., 2017, p.66), while recent empirical research has demonstrated that some forensic science experts strongly feel that police, courts and investigative stakeholders show greater appreciation for findings of higher certainty (Almazrouei et al., 2020). The cultural incompatibilities between the certainty expected by the adversarial criminal system, and the uncertainty in science, may be another reason behind the pressures identified by forensic science experts. The certainty required by the law and the uncertainty inherent to science has been expressed as a concern giving rise to uncertainty by survey participants (Table 6.12). Such concerns echo similar observations in academic work, in which the categorical atmosphere of trials and the expectations of certainty in the prosecution’s case, are identified as potential reasons for discouraging expressions of uncertainty by forensic science experts (Chisum & Turvey, 2011; Ellsworth, 2012; Faigman, 2000; Loevinger, 1992)

Closely related to stakeholder pressures exerted on forensic science experts for findings of greater certainty, are issues surrounding the confidence exhibited by some forensic science experts. Survey participants highlighted that forensic science experts present their findings with greater confidence than warranted, they often appear dogmatic, overestimate their own knowledge or present their findings as if objectively true. Such sources of uncertainty which can cast doubt or create uncertainties around the reliability and probative weight of the evidence, provide support for wider discussions in the literature regarding overclaiming by forensic expert witnesses (Friedman, 2002).

6.5.4.2 Lay vs expert stakeholder understandings

The limited understanding of legal actors was also highlighted as another practical source of uncertainty, with regards to the generation and presentation of evidence. Participants suggested that issues such as the nature of the audience receiving the evidence, and how the evidence – as well as any uncertainty around it – will be considered or understood by stakeholders gave rise to uncertainty. It is worth noting that the overwhelming majority of these remarks were made by forensic science experts. As such, these sources of uncertainty are not uncertainties in the decision-making of experts when analysing, evaluating and interpreting traces, but rather personally perceived uncertainties (Table 6.8).

These common codes regarding the personally perceived uncertainties of experts regarding the presentation of evidence, are encompassed both under ‘Practical uncertainties’ and ‘Expert-centred’ (Tables 6.7 and 6.11), thus highlighting links between these two source areas (see Figure 6.18).

Moreover, uncertainties around how to present evidence are closely tied to ‘Semantic’ sources of uncertainty, particularly with regards to the use of descriptions and definitions. As exhibited through the codes and sub-themes of the ‘Semantic’ sources of uncertainty, concerns exist over the use of verbal scales, the absence of precise or scientific wording to convey the findings of forensic science experts, difficulty translating numerical values into words and the challenging nature of explaining technical language to lay stakeholders (see Table 18). These concerns reflect wider discussions in the existing literature, regarding the absence of scientific education in judges, lawyers and jurors and their generally limited understanding of forensic science evidence (Edmond, 2015a; Findlay & Grix, 2003; National Research Council, 2009; Shuman et al., 1996). In addition, a lot of the semantic uncertainties revolve around the challenging use of verbal scales and verbal descriptors by forensic science experts, thereby lending support to arguments against the use of verbal scales for conveying uncertainty in forensic science (de Keijser & Elffers, 2012; Martire, et al., 2013).

6.5.5 Synthesis

The numerical ranking exercise and the thematic analysis provided some interesting insights into the experiences, wishes and interests of stakeholders in relation to uncertainty in forensic science. As was observed from the top ten stakeholder priorities and the running themes from the qualitative data, there is high degree of correspondence between stakeholders’ practical experience and the wider published literature on forensic science evidence. This is perhaps an encouraging indication that forensic science experts, lawyers and judges are aware of some of the most pressing issues in relation to forensic science evidence in criminal trials, but also that the topics with which empirical and scholarly work has been engaging are not dissociated from the lived experiences and concerns of forensic practitioners and legal actors. However, as demonstrated by the absence of ‘Judgment’ related sources of uncertainty in stakeholders’ priorities in the top ten, there is still room for bridging the gap between practice and research, both ways. This study represents a contribution towards bridging this gap, by providing insights into the interests of stakeholders with the potential of guiding future research. At the same time, it may also have served as a tool for raising greater awareness in forensic science experts, lawyers and judges regarding the topic of uncertainty, and the need to more fully and holistically evaluate and communicate it in courts.

6.6 Limitations and Methodological rigour evaluation

6.6.1 Limitations

One of the main limitations of this study was the number of survey participants. Even though the number of participants for the prioritisation workshop was within the recommended guidelines, there were 66 survey responses, of which 45 were in full. The number of participants was not significantly lower than that recruited in other empirical studies engaging forensic science experts (Nakhaeizadeh et al., 2014). Yet, given that other legal stakeholders were also targeted and encouraged to participate, the number of participants in the survey may not be sufficiently representative of the forensic science and legal community. Nevertheless, this study constitutes the first attempt, to date, to engage legal and forensic stakeholders in order to elicit their wishes and priorities with regards to uncertainty. As such, the findings can provide some novel insights for guiding future research and informing the allocation of research funding.

Moreover, given the largely qualitative nature of this study, there is always the possibility of the researcher's beliefs, biases and experiences to influence the manner by which the research is conducted, particularly during the stage of qualitative analysis (Berger, 2015). In order to mitigate such risk, the researcher practiced reflexivity throughout the different research stages, recognising her subjectivity and questioning the assumptions and inferences made (Russell & Kelly, 2002). Contemporaneous notes were also kept to assist with being reflexive and maintaining a constant awareness of the subjectivity of the researcher (Cruz, 2015).

6.6.2 Methodological rigour framework

Finally, in order to optimise the methodological rigour of the consensus building exercise (Søndergaard et al., 2017), a set of criteria developed by Humphrey-Murto et al. (2017) were identified and implemented to this study. These criteria are presented in the form of a checklist, along with examples demonstrating full or partial adherence throughout the study (see Table 6.18).

Criterion	*Satisfied?*	*How?*
1. Define study purpose/objective	Yes	See section 2.1., also included briefly in survey and in workshop preparatory materials.

2. *Outline each step of the process*	Yes	Figure 2 & preparatory workshop materials.
3. *Describe selection and preparation of scientific evidence for participants*	Yes	Study 1 & preparatory workshop materials.
4. *Describe how items were selected for inclusion in questionnaire*	Yes	Study 1, Section 2.2.A & preparatory workshop materials.
5. *Describe how participants were selected and their qualifications*	Yes	Section 2.3 & document with bios sent out in preparation for workshop.
6. *Describe number of rounds and termination of process*	Yes	Section 2.2.B & Figure 2
7. *Describe how consensus was defined*	Yes	Section 2.2.B
8. *Report response rates and results after each round*	Yes	See Results Section
9. *Describe the type of feedback after each round*	Yes	See Results Section
10. *Describe how anonymity was maintained*	Partly	Full anonymity for survey respondents, full anonymity for workshop participants in the retention and analysis of data, as well as the presentation of results. The voting process during the workshop was also anonymous. However, the JLA process recommends that

		participant bios are provided to everyone prior to the workshop. In addition, participants' names were used to address them during discussions throughout the workshop.
11. Discuss methodological limitations in discussion	Yes	Yes, see Discussion Section.

Table 6.14| *Consensus methods criteria for evaluation of methodological rigour, applied to this study.*

6.7. Conclusion

The aim of this study was to engage stakeholders – particularly forensic science experts, lawyers and judges – in order to elicit their priorities with regards to those sources of uncertainty they would like to see evaluated and communicated to lay decision-makers. The process of encouraging stakeholders to express their interests in relation to uncertainty in forensic science, resulted in a final consensus on their top ten uncertainty source priorities. Valuable insights were also drawn through the qualitative elements of this process, with regards to stakeholders' experiences with uncertainty in forensic science more generally.

This study was significant in developing further the conceptualisation framework that resulted from the interdisciplinary configurative review (Chapter 5). The conceptualisation of uncertainty, including the identification of its sources, is often a prerequisite for the development of effective frameworks for evaluation and communication (Wardekker et al., 2012; Lazarides, 2019). As such, this study was also important in furthering the overall aims and objectives of this thesis, as it provided the foundations upon which the selection, synthesis or improvement of the most appropriate tools and approaches for the evaluation and communication of uncertainty can be based.

More specifically, the process of reaching the top ten priorities, as well as the final priorities themselves, have assisted in refining the conceptualisation framework that resulted from the interdisciplinary configurative review (Chapter 5). The original framework consisted of 84 sources of uncertainty, which were based upon those sources that are frequently encountered in the 'neighbouring disciplines' of medicine, environmental science and economics. As such, it was first necessary to ensure that these sources corresponded with the experiences of forensic science stakeholders. The refinement process was also necessary, not only in ensuring that it reflected the experiences of forensic science stakeholders, but also in narrowing down the number of source of uncertainties that will be targeted for evaluation and communication. The development of uncertainty evaluative and communicative frameworks can be very resource and time intensive (Fischhoff & Davis, 2014). Developing frameworks to address 84 sources of uncertainty may be extremely onerous, if not unfeasible. As such, the identification of a list of the top ten priorities of stakeholders, along with a more detailed account of stakeholders' experiences, in relation to sources of uncertainty, can assist in the development of viable, targeted and effective frameworks for the evaluation and communication of uncertainty.

Moreover, the modified NGT constituted a fruitful ground for effective collaboration between different stakeholders with vested interests in forensic science. It provided an avenue for expressing their wishes and concerns, so that these can further guide and inform future research. The active engagement and collaboration encouraged in this study is also a significant step in changing perceptions regarding the identity of forensic science towards recognising it as a holistic interdisciplinary discipline (Morgan, 2018a). Such an identity would no longer associate forensic science with a strictly analytical, laboratory-based practice (Roux et al., 2015), but would instead recognise its complex, multifaceted, yet cohesive nature, directed towards the reconstruction of crime. The wider implications of this thesis on the identity of forensic science are explored further in the Synthesis chapter that follows (see specifically Section 7.3.1).

Chapter 6 – Key points:

- The modified Nominal Group Technique resulted in the identification of ten priorities of sources of uncertainty in forensic science, that stakeholders would like to see evaluated and communicated to lay decision-makers.
- The top ten priorities include, data quality and volume, lack of theoretical understanding, expert choice of different methods – range of views, choice/use of literature, understanding of uncertainty, precision/validity of probabilities, difficulty in assigning probabilities, and quality of expert.
- The thematic analysis of the qualitative data led to the identification of nine main themes. Eight of these themes concerned sources of uncertainty, including data, knowledge, methodological, innate, semantic, probabilistic and practical. An additional theme arose relating to external forces – human or natural – that have an impact upon sources of uncertainty.
- The qualitative findings provided insights into the experiences of forensic science stakeholders with uncertainty in forensic science, and assisted in establishing links between different codes, sub-themes and themes.
- The qualitative findings also revealed the existence of tensions between the courts and forensic science experts, that can give rise to uncertainty. Tensions were identified between the certainty of the law and the uncertainty of science, as well as between lay and expert stakeholder understandings.

7. Integrating research with stakeholder priorities: A path forward for dealing with uncertainty in the post-normal scientific context of forensic science

‘Inspect every piece of pseudoscience and you will find a security blanket, a thumb to suck, a skirt to hold. What does the scientist have to offer in exchange? Uncertainty!’

– Isaac Asimov, ‘Past, Present, and Future’, 1987, p.65

‘Frailties and uncertainties associated with the use of procedures are not abstractions. They inform how we should understand results obtained using those very procedures.’

– Edmond et al., 2019, p.915

7.1 Certainty & Science

The 20th century marked a significant transition away from science offering perceived objectivity and certainty to predict and control the world around it (Arthur, 1998; Peat, 2002). In the discipline of physics, the rise of quantum theory was a significant catalyst the the drift between Niels Bohr, and the father of special relativity, Albert Einstein (Peat, 2002). For Einstein uncertainty was merely the by-product of human limitations in measuring the objective elements of the systems under study, while quantum theory revealed that uncertainty could take a much more fundamental form, inherent to the very nature of the universe (Peat, 2002).

Einstein’s insistence on objectivity and certainty was not only in relation to the systems under study, but also in relation to the epistemology of science. For Einstein, a scientist was seen as completely severed from the context in which they operated; separate from values, emotions and beliefs (Peat, 2002). Questions over such an understanding regarding the production of knowledge and the pursuit for truth, began to arise towards the end of the 19th century with Nietzche, and peaked in the middle of the 20th century with the works of philosophers such as Derrida and Foucault (Welch, 2011). Nietzche doubted the crude epistemological dichotomies between objectivity and subjectivity that had permeated traditional western thought (Nietzsche, 1887/1967), while Derrida and Foucault, rejected the notion of an absolute Truth, and instead emphasised the importance of revealing and recognising the contextual matrix in which knowledge is produced (Derrida, 1973; Foucault, 1975). The prominent shift observed in the 20th century in the way truth and the pursuit of truth were approached and understood, allowed for a greater acceptance of uncertainty, and for the recognition of uncertainty not merely as an inevitability of the nature of the world (Oppenheimer, 1955), but also as a prerequisite to truth (Welch, 2011).

7.2 Forensic science & Certainty: Challenges to the discipline and the legitimacy of verdicts

Despite the notable shift in the 20th century in the way science, truth, knowledge and certainty were construed, the discipline of forensic science continued to operate under the guise of certainty for much of the 20th century, and arguably even today (Bali et al., 2020). Overclaiming, the phenomenon whereby forensic science experts present their findings in a manner that implies greater confidence than that supported by the underlying evidence, is commonly observed, with recent empirical research indicating that forensic science experts overwhelmingly use categorical conclusions to express their opinions to legal stakeholders (Bali et al., 2020). Attention has been drawn by a number of academics to the prejudicial and potentially dangerous effects of such practices in criminal trials (Friedman, 2002; Cole, 2007; Edmond, 2015b).

Even though reports regarding the phenomenon of overclaiming were largely based in Australia and the United States (Friedman, 2002; Cole, 2007; Berger, 2002; Edmond, 2015b; Saks et al., 2016), they may still be relevant in the context of the criminal justice system in England and Wales, where it has been acknowledged that discussions around uncertainty in forensic science evidence in court are often absent (Chisum & Turvey, 2011). Practices of overclaiming have also been observed in criminal trials in England and Wales (R. v Smith; R. v Dlugoz; see s.2.1.2), while prominent types of uncertainty – such as sampling uncertainty – are considered to be underreported by forensic science experts in the UK (Curran & Buckleton, 2011).

Notions of certainty in forensic science are also exacerbated by myths of infallibility. Fingerprint evidence was perceived as the gold standard of forensic science, and thus also infallible. More recently such beliefs of infallibility have been attached to DNA analysis (PCAST, 2016). Myths surrounding the infallible nature of fingerprint analysis have long been dispelled (Cole, 2005), while the fallible nature of DNA analysis is also widely recognised within the scientific community (Ribeiro et al., 2019; Thompson, 2013). Yet, policy makers seem to be concerned that jurors may be less alert to the fallible nature of forensic science evidence (PCAST, 2016). Lay stakeholders' lack of awareness in relation to the nuances and limitations of forensic science – and oftentimes their misconstrued understanding of forensic science as infallible – may be exacerbated by the tendency of some experts to overclaim or avoid altogether discussions regarding the limitations and uncertainties of their findings (Edmond, 2020).

Maintaining a guise of certainty in how forensic science evidence – and arguably any evidence – is presented and communicated to lay stakeholders may give rise to three specific and inextricably interlinked challenges:

1. Undermining the decision-making of lay stakeholders with regards to matters of reliability and probative weight of the evidence.
2. Reinforcing power inequalities,
    a. The ‘inequality of arms’ between prosecution and defence
    b. The inequality of knowledge and understanding between expert and lay decision-makers.

7.2.1 Lay stakeholder Decision-making: Reliability & Probative weight

7.2.1.A. Certainty, Confidence & Misrepresentation

One of the first challenges emanating from the insistence that forensic science should provide certainty relates to lay stakeholders’ perceptions and evaluations of the reliability and the probative weight of the expert witness evidence. Among considerations regarding the relevance of the evidence (R. v Dallagher, 2002), its usefulness (R. v Turner, 1975) and the impartiality of the expert (Field v Leeds, 2000), judges are called to decide on the reliability of expert witness evidence, prior to such evidence being admitted (R. v Dallagher, 2002; R. v Reed, 2010). The role of the jury is then to evaluate and attach a probative weight to the evidence presented to them, in the context of the case and in relation to other evidence (R. v Atkins, 2010; R. v Kempster (No.2), 2008). Providing crucial information that can attest to the limitations and hence the respective probative weight of the evidence is therefore necessary for the decision-making of both judges and jurors (Mnookin, 2010). Without transparency regarding the limitations and uncertainties of the forensic science evidence and the science informing it, jurors and judges can merely assume or infer the reliability and probative weight of the evidence or defer their own evaluations to the opinion of the expert witness (Edmond, 2020).

Allowing juridical stakeholders to assume or infer matters of reliability and probative weight or defer to the evaluations of the expert witness regarding these, is particularly problematic given the sometimes categorical and overconfident expressions of forensic science experts (Bali et al., 2020; Edmond 2015b). The atmosphere of certainty that has prevailed over the use of forensic science evidence in court, not only fails to achieve sufficient levels of transparency regarding the limitations and uncertainties associated with the evidence, but it can also inadvertently reinforce erroneous beliefs, potentially held by jurors, regarding the infallible nature of forensic science evidence (PCAST, 2016). Failure to ensure that fact-finders are in a position to properly understand the evidence and evaluate its probative weight, in accordance with their obligations, can erode public confidence in the adversarial process, hence placing at risk the legitimacy of the criminal justice system as a whole (Biedermann & Kotsoglou, 2018).

7.2.1.B. Uncertainty, Transparency & Enhanced decision-making

Juridical stakeholders can only discern the quality and probative weight of the evidence if a sufficient level of transparency is achieved through the effective identification and communication of the 'frailties and uncertainties' associated with the different factors and stages involved in the crime reconstruction process (Edmond et al., 2019, p.915). Disclosure of the uncertainties associated with the forensic science evidence in a criminal prosecution is, therefore, a vital component of ensuring that lay juridical stakeholders are properly informed (Edmond, 2020).

Further support for the importance of communicating 'frailties and uncertainties' (Edmond et al., 2019, p.915) can be found in section 5.3.3.D. A review of relevant contributions in the 'neighbouring' disciplines of medicine, environmental science and economics, indicated that in the interactions of experts with lay stakeholders, the proper disclosure of uncertainties in the findings and opinions of the former, can have a significant beneficial impact upon the decision-making of the latter (see Figure 5.9). The interdisciplinary configurative review was also significant, as it laid the foundations for achieving greater transparency in criminal trials, through the evaluation and communication of uncertainties associated with forensic science evidence. The three toolsets that were the main products of the review identified a combination of useful and transferable tools and approaches to assist with the assessment and disclosure of uncertainty. Such tools and approaches can provide the basis upon which a set of recommended practices are built and implemented, with the potential to improve the quality of the evidence presented, achieve better informing of lay juridical stakeholders, and hence avoid threats to the accuracy of verdicts and the effectiveness and legitimacy of the criminal justice system as a whole.

7.2.2 Certainty & Power inequalities in the Criminal Justice System:

Strongly related to the issue of stakeholders' understanding and evaluation of the reliability and probative weight of the evidence, are the power inequalities that are already in effect in an adversarial trial setting. There are two forms of power struggles relevant to the role played by forensic science evidence in court; both of which are exacerbated by sustained beliefs over the certain nature of forensic science evidence:

a. The 'inequality of arms' between prosecution and defence, and

b. The inequality of knowledge and understanding between expert and lay decision-makers.

7.2.2.A. Certainty exacerbating ‘inequality of arms’

The first power struggle that has been identified, is that of the ‘inequality of arms’. It is necessary to identify how this ‘power struggle’ is already at play in the context of the adversarial criminal trial, and how maintaining an aura of certainty around forensic science evidence can intensify the power inequalities between the prosecution and the defence.

An inequality of arms is a form of power inequality between prosecution and defence, inherent to the nature of the adversarial process. This inequality arises as a result of the prosecution having access to greater resources, and as such being in a more favourable position to argue their case, as compared to the defence. This is also the case when it comes to the use of expert witness evidence in court, as the prosecution’s greater resources are particularly valuable when it comes to challenging expert evidence adduced by the defence (Edmond & Roach, 2011). Furthermore, the defence – with the exception of high profile cases – is not in a position to acquire its own expert (Vuille, 2019), thus being in a detrimental position when casting doubt on the prosecution’s adduced expert evidence.

The inequality of arms that is already in existence due to the unequal resources available to the prosecution and the defence (Roberts, 2015; Edmond, 2015a), at least in most cases, should theoretically be counteracted by the trial safeguards that are in place. The trial safeguards in place, relevant to expert witness evidence, include the burden and standard of proof, the evaluation of admissibility requirements by judges, judicial instructions and cross-examination. Trial safeguards have, nevertheless, been widely criticised for their failure to ensure that only reliable pieces of evidence are admitted and that jurors are in a position to properly assess the probative weight of the evidence presented to them (Roberts & Zuckermann, 2010; Edmond, 2020; Edmond et al., 2019). As a result, an unreasonable amount of trust and confidence is placed on the prosecution and its forensic science expert to present findings with integrity (Ward, 2015), demonstrating the requisite amount of confidence and certainty that the evidence warrants (Law Commission, 2011). As the findings in Chapter 6 indicate, such trust may not only be unreasonable, but it may also be misplaced.

The prioritisation exercise in Chapter 6, revealed that there are several patterns of behaviours and practices with which forensic science experts and legal stakeholders engage which can be inhibiting towards achieving greater transparency and tolerance with regards to uncertainties associated with forensic science evidence. For example, participants to the prioritisation exercise have reported that experts present their findings with exaggerated or ‘unwarranted confidence’ (Table 6.12). Moreover, they have noted that experts can appear to be dogmatic or ‘overestimate’ their own knowledge, as well as produce incomplete or opaque reports (Table 6.12). In addition, certain behaviours by judges and prosecutors have been identified as potential inhibiting factors to the expression of uncertainty in forensic science evidence. According to the qualitative data collected, forensic science experts have suggested that some court agents perceive forensic science as infallible and demonstrate intolerance to expressions of uncertainty in the courtroom (Table 6.12). Forensic science experts have also reported feeling pressure by legal stakeholders to find evidence of guilt, as well as pressures in the witness box (Table 6.12). Such remarks are aligned with arguments expressed in scholarly work, regarding 'systematic pressures' by lay stakeholders, favouring one outcome over another (Ulery et al., 2017, p.66).

As demonstrated by the qualitative findings of the prioritisation exercise, certain practices adopted by expert and lay decision-makers have been contributing towards the reinforcement of a misplaced atmosphere of confidence and certainty when it comes to the presentation of forensic science evidence in court. Such atmosphere exacerbates the already unmitigated inequality of arms, as it prevents a transparent dialogue regarding 'frailties and uncertainties' from taking place in the courtroom (Chisum & Turvey, 2011; Edmond, 2020). As such, forensic science evidence adduced by the prosecution is often allowed to be presented in a categorical manner (Bali et al., 2020), thus leaving the defence with little recourse to ensuring that the fact-finders are fully and properly informed.

7.2.2.B. Certainty exacerbating knowledge 'power imbalance':

The second power imbalance relates to the power of experts as a result of their possession of specialist knowledge. This examination is based on Bacon's famous maxim: 'Ipsa scientia potestas est' (Bacon, 1597/1985). There are different interpretations to this maxim (García, 2001), some of which are particularly relevant and insightful when reflecting on the role of forensic science experts in court. Here, two interpretations are addressed that can be considered to be the most applicable to the reception of scientific evidence by legal actors; i) power in the form of a special status conferred to them by the courts due to their expertise, and ii) power over the decision-making of lay legal actors. Both forms of power will then be discussed in relation to their implications on jury decision-making, specifically with reference to jury deference and how the certainty of knowledge can exacerbate pre-existing power imbalances between expert and lay decision-makers.

According to the first interpretation to Bacon's maxim, experts were to enjoy a form of special status in the governance of states, as a result of their knowledge and expertise (García, 2001). Even though, expert witnesses, including forensic science experts, do not enjoy such status when it comes to the governance of a state, they are nevertheless accorded a form of special status, merely as a result of their assumed expertise (Hamer & Edmond, 2019). According to the current admissibility rules in England and Wales, expert witness evidence is admissible in trials as an exception to the opinion rule (Davie v Magistrate of Edinburgh, 1953), when the expert can assist in providing information that is beyond the experience and knowledge of the judge or jury (R. v Turner, 1975; Criminal Procedure Rule Committee, 2015)).

The special status afforded to forensic science experts, merely as a result of the admissibility rules in England and Wales, is further reinforced by the deference model that permeates popular philosophical thinking (Roussos, 2020). According to this model, lay individuals should defer to an expert's position and adopt it as their own (Roussos, 2020). Failure to adhere to the expert deference model is often perceived as irrational (Lengbeyer, 2016). The deference model is also of relevance when it comes to expert witness evidence in courts. The deferential model is one of two predominant schools of thought regarding the role and reception of expert witnesses in court; the other being that of education (Miller & Allen, 1993). Despite academic scepticism surrounding the operation of the deference model (Ward, 2015), and despite the existence of an alternative model, the former constitutes the most accurate representation of the interaction of lay legal actors with expert evidence (Roberts & Zuckermann, 2010).

Even though the deference model may be encouraged in popular philosophical thinking regarding forms of expertise operating beyond the scope of the court, its predominant position in the legal arena may not be as openly or directly encouraged. Instead, it seems to be an inadvertent by-product of a combination of factors currently in operation in adversarial trials, which nevertheless reinforce the power afforded to forensic science experts as a result of their special knowledge and experience. Such power reinforcement manifests in the form of experts enjoying a special form of status in court, whereby they are allowed to express their opinions, and those opinions are deferred to by judges and jurors. The most dangerous consequence of the deferential model, however, is the power afforded to forensic science experts due to their special knowledge, as examined through the second interpretation to Bacon's maxim, with its influences deeply rooted in post-structural thinking (García, 2001); namely the power to direct the minds of those being dominated (García, 2001). The deferential position often adopted by the lay fact-finders suggests that instead of independently evaluating the probative weight of the opinion of forensic science experts, in light of the all the available evidence in the case, they uncritically accept the opinion of the forensic science expert (Roberts & Zuckerman, 2010). Therefore, the minds of the jurors are directed on a much more subtle and inadvertent manner, than that suggested by common post-structural schools of thought.

According to a stricter post-structuralist interpretation of Bacon's maxim, pedagogical institutions would seek to direct the minds of individuals through noxious instruments of coercion or manipulation (García, 2001). Instead of perceiving forensic science expert opinions as a direct instrument of coercion or manipulation, it is argued that the manner by which such opinions have been expressed traditionally, leaves little room for critical evaluation of the reliability and probative weight of the evidence, and as such the decision-making of jurors is directed as a result of their deference. The findings of the prioritisation exercise provide support for such a position. The thematic analysis on the basis of the qualitative data collected by stakeholders, revealed that there is a tendency on behalf of forensic science experts to present their evidence as objective truths, to be dogmatic, overestimate their own knowledge and present their opinions with exaggerated self-confidence (see Table 6.12). Similarly, concerns have been raised over the demonstration of insufficient transparency by forensic science experts, with specific examples including cases of incomplete reports, avoidant attitudes towards the evaluation of uncertainty, missing algorithms, as well as failure to report on their methodological choices. Stakeholders also highlighted issues regarding the limited understanding of lay decision-makers, jurors fallaciously believing in the infallibility of forensic opinions, as well as the importance of maintaining expert independence without usurping the role of the jury (Table 6.12).

Even though no direct links were expressed by the prioritisation workshop participants between the certainty of forensic opinions and lay stakeholders' deference (section 6.3.4.), it may be argued that such deference may not simply be the result of the deference widely expected of lay individuals when it comes to expertise beyond the context of the courtroom (Lengbeyer, 2016; Roussos, 2020). Instead, 'the power and prestige of certainty' (Rubino, 2000, p.504) reportedly found in the opinions of forensic science experts, potentially reinforces fallacious notions of absolute and infallible forensic science evidence, thus convincing jurors and judges to uncritically accept their findings (Mann, 2006).

The specialist knowledge possessed by forensic science experts may afford them with a special status and encourage deference, thus placing them in a uniquely powerful position within the setting of a criminal trial. However, the certainty with which their opinions are expressed arguably reinforces and consolidates such power. This power can have consequences for the decision-making of fact-finders, as it is often highly interlinked with the lack of appropriate disclosure of limitations associated with the evidence, and it further discourages jurors from forming their own informed evaluations regarding the probative weight of the evidence in light of the other available evidence and facts in the case (Law Commission, 2011; Edmond et al., 2016). This does not only have a direct implication on the accuracy of the verdicts, but it undermines the legitimacy of the criminal justice system (Biedermann & Kotsoglou, 2018). The reason for this, is that the unique power of forensic science experts, can result in a confounding of the boundaries between the role of the expert and the role of the jury, with the expert potentially infringing or the jury choosing to renounce their obligation under the ultimate issue rule (Davie v Edinburgh Magistrates, 1953), with regards to evaluating the probative weight of the forensic science expert opinions (Law Commission, 2011). Moreover, given that defence lawyers are frequently underfunded and struggle to hire their own experts (Wilson et al., 2014), forensic science experts acting for the prosecution are more likely to be the ones who are in possession of power as a result of their specialist knowledge, exacerbating thus the inequality of arms as discussed in section 7.2.2.A.

When discussing the power imbalance resulting from the possession of specialist knowledge by an expert decision-maker, it is important to note the recent 'populist backlash' against expertise (Grundmann, 2018). Even though the distrust in experts has been more prevalent in policy-making, it is not unlikely that similar trends may be observed in the context of juridical proceedings in the foreseeable future.

7.2.3 Uncertainty as power

Forensic science opinions themselves can give rise to or reinforce power dynamics, and the certainty or confidence that underpins such opinions may exacerbate the inequality that can manifest. Specifically, it has been argued that the certainty with which forensic science experts communicate their evidence can exacerbate the already existing inequality of arms between the prosecution and the defence. Moreover, the specialist knowledge that forensic science experts are in possession of, endows them with power over legal stakeholders, due to the special status they enjoy with regards to being allowed to express opinions in court, often with little gatekeeping in place. In addition, their specialist knowledge also affords them power over the 'minds' or decision-making of juridical fact-finders, as judges and jurors usually defer to their opinions and abdicate their duties to independently evaluate the probative weight of the evidence in light of the other pieces of evidence in the case.

Actively endorsing and encouraging an openness and acceptance by all stakeholders to the uncertainties that are associated with forensic science evidence, can be a form of empowerment. As has been revealed by the interdisciplinary configurative review (Chapter 5), when uncertainty is communicated to lay stakeholders by experts, this can have significant empowering effects for the lay decision-makers. The communication of uncertainty, particularly in the field of medicine, has been found to be empowering for patients, as it promotes agency, it recognises and respects lay decision-makers as active participants in the decision-making process and encourages their engagement in a dialogue and a public debate. As a result, power imbalances between expert and lay decision-makers are believed to be reduced (Figure 5.9, and section 5.3.3.D.).

The studies comprising this thesis have sought to mitigate and even reverse the power imbalances, particularly between expert and lay decision-makers, and by extension between the prosecution and the defence. According to Foucault, the problem is not so much when those in possession of knowledge direct those who are not, but rather when such direction takes the form of 'arbitrary and unnecessary authority' (Foucault, 1997, p.298-299). The interdisciplinary configurative review has contributed towards ensuring that there is no 'arbitrary and unnecessary authority', by providing conceptual, evaluative and communicative tools through which to regulate the testimonies and reports of forensic science experts, and therefore the power afforded to them and exercised by them in the courtroom. By encouraging the adoption of a standardised framework through which experts can qualify their usually categorical opinions (Bali et al., 2020), they are provided with the means through which they can evaluate and express uncertainties associated with their opinions. The qualification of their opinions can ensure that their testimonies or reports are not communicated with greater certainty or confidence than they merit (Law Commission, 2011). This in turn can assist jurors in making better use of the evidence presented to them (Bali et al., 2020), as well as empower them to fulfil their duty of attaching their own probative weight on the forensic science evidence and considering it within the entirety of the case (Biedermann & Kotsoglou, 2018).

Moreover, the aim of Chapter 3 was to identify the narratives that are currently in play when it comes to the manner by which uncertainty in forensic science is considered by policy-makers, the courts and academics. The identification of these narratives – in terms of definitions, typologies and characteristics of uncertainty – has contributed towards the development of a more concrete and consistent understanding of uncertainty in forensic science. Additionally, the mapping of the diverse understandings of uncertainty as held by different stakeholders will prove to be beneficial when developing specific evaluative and communicative frameworks for the disclosure of uncertainty. Being aware of the current understandings and perceptions of stakeholders can allow for more informed and targeted strategies to be developed, when seeking to change current stakeholder attitudes and beliefs regarding uncertainty in forensic science and when promoting the use of novel evaluative and communicative frameworks, as those identified by the interdisciplinary configurative review in Chapter 5.

Finally, a different form of stakeholder empowerment has been achieved through the selection of a modified Nominal Group Technique, as the most appropriate method for the study in Chapter 6. One of the main aims of the prioritisation exercise was to identify the priorities of stakeholders in relation to those sources of uncertainty they would like to see evaluated and communicated, so as to guide and make more feasible the development of a more targeted evaluative and communicative framework. A significant outcome of this exercise, however, was not merely the greater insights that were gained with regards to the experiences of stakeholders with uncertainty, but rather their active engagement and involvement in the production of knowledge, and providing them with a platform through which to express their values, beliefs and interests in a way that can influence the future direction of research. The power dynamics are thus reversed, not just as a result of the efforts to achieve greater transparency with regards to uncertainties associated with forensic science evidence, but also by ensuring that the approach to knowledge and expertise is one based on a framework of public ethics of care (Stensöta, 2015). The emphasis of such a framework based on public ethics of care, is the inclusion of all stakeholders, nurturing of their relationships and substantively involving them in the development of frameworks, regulations and policies that directly affect them, as well as the criminal justice system as a whole.

7.2.4. Uncertainty as paralysis

Even though a focus on uncertainty can be a driver for change, both in the empowerment of all relevant stakeholders, but also for the discipline of forensic science itself, it has the potential to be disempowering as well. Participants to the prioritisation exercise highlighted that a certain degree of intolerance to uncertainty can be observed in stakeholders, as well as confusion over it (Table 6.12). These sentiments are also reflected in the results of the interdisciplinary configurative review, which revealed a number of obstacles which would have to be overcome when striving for a successful communication of uncertainty (Figure 5.9). A significant obstacle among these, is making sure that the amount and nature of the information provided to lay stakeholders by experts regarding the uncertainty of their opinions, is not such so as to lead to lay decision-making avoidance (Han et al., 2011), decision-making uncertainty and conflict (Bansback et al., 2016) or even to decision-making paralysis (Damodaran, 2013).

It can be a very fine line to tread, between providing sufficient information regarding the limitations and uncertainties of forensic science evidence which would guide the decision-making of lay legal stakeholders (Edwards, 2019; Edmond et al., 2019) and providing too much information which can lead to an information overload (Han, 2013). Such information overload runs the risk of inhibiting the decision-making of legal stakeholders. As legal stakeholders are not the most accepting of uncertainty (Table 6.12), it is crucial that future research for the development of standardised uncertainty communication frameworks, is focused on examining what amount of uncertainty information can be tolerated by stakeholders without causing negative affective responses (Han, 2013), but also what type of uncertainty information stakeholders require (Pidgeon & Fischhoff, 2011).

The prioritisation exercise (Chapter 6) has paved the way in gaining better insights towards preventing information overload, when considering the development of evaluative and communicative frameworks for uncertainty. The modified Nominal Group Technique has assisted in narrowing down which facets or sources of uncertainty would be most beneficial for disclosure. Indeed, even though some of the prioritisation workshop experts agreed that there are sources that are more prominent in specific cases or specific forensic sub-disciplines (see Transcripts Appendix E), they nevertheless managed to arrive at a consensus on the top ten sources of uncertainty associated with forensic science evidence that could be the most beneficial if they were to be evaluated and communicated to lay stakeholders in criminal trials (Figure 6.17). Even though the vast majority of survey respondents showed their support for the disclosure of uncertainty in forensic science evidence in criminal trials through their selection of priorities and their responses to the open-ended questions, there was also a cautionary opinion from one of the participants. According to this opinion '…technical or scientific aspects like what are the contributors to the uncertainty and what are the weight of them in the result should not appear in reports and should not be communicated to them [lay decision-makers]' (Appendix F). Such a stance is aligned with the concerns that have been identified in relation to the dangers of disclosing information regarding uncertainties, and highlights yet again the importance of carrying out further empirical research in order to establish the most appropriate way of communicating uncertainties to lay stakeholders, before any standardised evaluative and communicative frameworks are developed and implemented.

7.3 Other implications and outcomes of the thesis

7.3.1 Uncertainty, identity of forensic science and bridging cultural divides

The primary studies of this thesis (Chapters 3, 5 and 6) have contributed to a great extent towards rectifying certain power imbalances that may have already been at play when it came to the interaction of forensic science experts and lay legal stakeholders. An emphasis on the open acknowledgement of uncertainty, however, also has direct implications upon the identity of forensic science as a discipline, and its interactions with the discipline of law. This section examines how this thesis – particularly Chapter 4 – has made a valuable contribution to assisting forensic science with establishing an independent identity as an interdisciplinary discipline, as well as with bridging any cultural divides that may have hindered its effective collaboration with the legal actors.

Forensic science has traditionally been considered as being at odds with the legal system (Haack, 2009; Wonder, 1989). The arguments that have been put forward in support of such a position, are also revealing of how the identity of forensic science has been constructed. Some of these arguments have revolved around the constantly evolving and tentative nature of science (Kaye, 1992), which contradicts the certain and categorical atmosphere of an adversarial trial (Faigman, 2000; Loevinger, 1992; Ellsworth, 2012). Other cultural incompatibilities include, science's goal to generate general scientific principles through continual revision (Gallopín et al., 2001; Kaplan & Puracal, 2018), placed against the backdrop of law's concern with successfully resolving individual cases in a timely manner (Haack, 2009; Lord Dyson, 2015). An equally important consequence of cultural incompatibilities between law and forensic science, is the misunderstanding and miscommunication between lawyers and judges, and scientists (Roberts, 2013).

It has been argued that these contradictions are based on sparse empirical research and anecdotal accounts, due to a significant gap in the available research with regards to the use of forensic science evidence in criminal trials (Roberts, 2013). The qualitative findings of the prioritisation exercise provide support for some of the contradictions that have been identified. What is of relevance to this discussion and which could potentially have its origins in such cultural incompatibilities, are the pressures exerted on forensic science experts by stakeholders, including in the witness box (Table 6.12). Indeed, these pressures could be the result of a cultural incompatibility, rooted at the adversarial nature of criminal trials. More importantly, cultural incompatibilities have been noted to manifest in the form of misunderstandings between forensic science experts and lay decision-makers in criminal trials. Such misunderstandings seem to flow both ways (Roberts, 2013), with participants to the prioritisation exercise expressing concerns regarding the limited understanding of lay stakeholders and their intolerance to uncertainty, but also experts testifying beyond their bounds of expertise (Table 6.12).

Such issues may on the surface appear to be the result of cultural incompatibilities. Yet, they could also be the result of the absence of a coherent and standardised framework that could guide the communication of uncertainties in the courtroom, so as to assist the understanding of lay decision-makers and allow them to consider the evidence within the wider context of the case. Indeed, it has been highlighted that the communication of uncertainties by forensic science experts is a very challenging and, as of yet, unresolved concern (Ward, 2015). According to the forensic science experts that contributed to the prioritisation exercise, the way they communicate their findings in court is a major concern (Table 6.12). More specifically, they expressed feelings of uncertainty as to how much information is appropriate to be given, how to communicate the weight of their findings, who their audience is, and how is the evidence going to be considered by juridical stakeholders. The three frameworks that were developed following the interdisciplinary configurative review, can provide a basis for further research and even constitute the foundations upon which targeted frameworks for the effective evaluation and communication of uncertainty are based (Chapter 5). Such targeted frameworks can have the beneficial impact of guiding the communication of forensic science experts, and thus reducing their concerns and uncertainties over this topic.

Developing a coherent and consistent framework for the evaluation and communication of uncertainty, however, may not suffice. It may also be necessary to work towards creating a more deep-rooted change in the manner by which all forensic science stakeholders, including the courts, perceive the identity and role of forensic science, as well as their relationship with it (Morgan, 2019). As the findings of the prioritisation exercise indicate, there are still occasions of legal stakeholders holding beliefs regarding the infallible nature of forensic science, while intolerance is also observed when it comes to the disclosure of uncertainty (Table 6.12). As such, in order to achieve a more open and accepting stance towards transparent forensic reporting (Earwaker et al., 2020), it may be necessary to work towards achieving a shift in stakeholders' beliefs regarding the identity of forensic science, as well as their expectations from it.

An emphasis on the recognition and acknowledgement of the pervasive uncertainties permeating every stage of the crime reconstruction process, may prove to be of assistance when it comes to achieving the shift that is required in the way forensic science is perceived, as well as how its evidence is received and evaluated. As a matter of fact, some of the cultural incompatibilities identified in the beginning of this section, are the result of a misconstrued understanding of the identity of forensic science as a discipline (Roberts, 2013). Forensic science was defined as the 'science constructed in the image of criminal law' at the end of the 20th century (Saks, 1998, p.1090), a conceptualisation of forensic science reiterated throughout the years (Roberts, 2013). The culture of forensic science has been distinguished from the culture of other research sciences (Cole, 2013), as well as other applied sciences (Roberts, 2013). Unlike traditional scientific approaches, forensic science can hardly be perceived as operating within a pristine laboratory environment. Instead, it is deeply embedded within the legal environment and exhibits strong interactions with other stakeholders within the criminal justice system (Roberts, 2013; Almazrouei et al., 2019). As such, forensic science experts are required to function within the complex system of 'values, objectives and timetables of the law' and the criminal justice system, more generally (Roberts, 2013, p.55).

The theory of post-normal science, introduced by Funtowicz and Ravetz (1994), places a significant emphasis on the development of problem-solving strategies for disciplines that operate within a value-loaded context, and which are defined by high levels of uncertainty and decision-stakes. This theory has been argued to be of value when it comes to defining, or re-defining, the identity and role of forensic science (Chapter 4), and could also assist in achieving the deep-rooted change necessary for more effective collaboration and understanding between the different stakeholders of forensic science. The theory of post-normal science may be a better fit in the way we perceive and think of forensic science and can even assist in its reconceptualisation as a coherent independent interdisciplinary discipline (Morgan, 2019). The theory put forward by Funtowicz and Ravetz (1994), argues against a reductionist perception of those scientific disciplines deeply ingrained with a social context, and instead supports a more system-based, humanistic, and holistic conceptualisation of them. Such a theory can prove useful when it comes to reconceptualising forensic science, as it allows for the embracement of the inevitable and irreducible uncertainties, as well as the diversity of stakeholder values, interests and beliefs that operate at each stage of the crime reconstruction process. Hence, it can discourage a conceptualisation of forensic science as a 'fragmented ecosystem', and instead promote a truly integrative and holistic approach from crime scene investigation all the way to evidence presentation in court (Morgan, 2019). Moreover, this new, democratic conceptualisation of science as placed in the centre of society rather than separate from it (Funtowicz & Ravetz, 1994), would no longer consider the existence of a range of stakeholders as an obstacle to the identification of a specific field as a scientific discipline. Instead, it can strengthen the case for the recognition of forensic science as an independent discipline, and encourage true collaboration between its different stakeholders, through the exchange of ideas, values and beliefs. It can also support the conceptualisation of forensic science, as a discipline that holistically incorporates 'human decision making, context, and evaluative interpretations, and uncertainty.' (Morgan, 2019, p.241).

This new way of identifying and defining forensic science, can have significant practical implications when it comes to the communication and reception of forensic science evidence in court. More specifically, it can assist in developing strategies which, instead of avoiding and being resistant to uncertainty, are fully accepting of it. The acknowledgement of stakeholder interests and values can also encourage a collaborative research culture, whereby strategies for managing and fully disclosing uncertainty are developed; strategies which would be reflective of and compatible with the values, beliefs and interests of all stakeholders. At the same time, stakeholders such as legal actors, would unavoidably have to adjust their beliefs regarding the nature of forensic science, as well as their expectations of how science evidence is communicated in criminal trials. True collaboration and involvement of legal actors in the development of uncertainty management strategies would also result in enhancing their tolerance to uncertainty, as their interests would have been taken in account when developing frameworks for its evaluation and communication.

7.4 Path forward: Recommendations for the development of targeted evaluative and communicative frameworks:

There are significant benefits to be gained by achieving greater clarity in our understanding of uncertainty in forensic science. There are also benefits to be gained by seeking to identify innovative and holistic instruments through which to evaluate and communicate it in criminal trials. Chapter 5 expanded beyond the current frames of reference that can be found in discussions in the academic, policy and legal fields regarding uncertainty (Chapter 3), by extracting and synthesising potentially valuable approaches, methods, tools and instruments through which to conceptualise, evaluate and communicate uncertainty. The three toolboxes that were developed provide a wealth of such instruments, and they can be consulted by individual laboratories or individual forensic science experts, when seeking to achieve greater transparency in their opinions, despite the current absence of formal requirements to do so. However, when considering the development of a standardised targeted evaluative and communicative framework, which could potentially be enforced as a mandatory requirement for inclusion in forensic science expert reports or testimonies, a narrowing down process is necessary.

The prioritisation exercise in Chapter 6, marked the beginning of this refinement process, as it established a list of top ten priorities in terms of sources of uncertainty that stakeholders would like to see evaluated and communicated. As such, this list, is the first point of reference when thinking of which instruments and approaches would be more suitable for evaluating and communicating uncertainties associated with forensic science evidence. An noteworthy outcome of the prioritisation exercise was that each of the main categories of sources of uncertainty that had been developed through the interdisciplinary configurative review in Chapter 6, were represented in the final top ten list (Figure 6.17). Therefore, the priorities of stakeholders reinforce the understanding of uncertainty as a complex, multifaceted phenomenon (Flage et al., 2014) which arises at every stage of the crime reconstruction process (Morgan et al., 2018). Some of the sources of uncertainty that were prioritised by stakeholders – such as data quality and data volume – could be more amenable to quantitative instruments of evaluation. Yet, there is also a significant number of sources, including uncertainty arising due to the choice and use of literature, or the quality of the expert, which may not be suitable for quantitative evaluation.

In order to capture the multifaceted nature of stakeholders' interests, it is recommended that the evaluation structures that were identified through the interdisciplinary configurative review would be the most suitable approach (Table 5.5). Four of the evaluation structures that were identified in the interdisciplinarity configurative review, combined elements of both quantitative and qualitative metrics to capture the uncertainties associated with the findings of experts in the fields of medicine, environmental science and economics. The evaluation structures implemented by a number of domestic and international agencies, such as the IARC, the IPCC and the OBE, could be used as guidance when deciding how to construct a similar evaluative structure for forensic science.

Moreover, it is recommended that the selection of an evaluation structure for the purposes of capturing and disclosing uncertainty in forensic science, should be geared towards structures that are fully qualitative rather than quantitative. Concerns over the use of probabilistic methods for assessing uncertainty in forensic science have been expressed over the years by academics. Such concerns include, the generation of numerical evaluations based on the experience of forensic science experts, rather than reliable databases (de Keijser & Effers, 2012; Risinger, 2013), as well as the difficulty of fact-finders in understanding such probabilistic expressions and effectively incorporating them in their decision-making (Ligertwood & Edmond, 2012; Martire, 2018). Therefore, it is advisable that structures such as the one used by the OBE would be better models, upon which to base the development and construction of evaluative and communicative frameworks in forensic science. The OBE uncertainty structure uses a table to present the three different metrics on which the evaluation of uncertainty is based (data, modelling and behavioural) and each metric is subject to a 6 point scale of qualitative evaluation, ranging from very high to low uncertainty. Moreover, each metric is assigned a level of importance; Low, Medium or High. Similarly, given how experts in the prioritisation exercise recognised that not all sources of uncertainties are as prevalent in each case, a level of importance could be assigned initially to each of the sources, followed by an individual assessment of their level or magnitude against a qualitative scale (Figure 5.6). Table 5.3 that was developed as part of the interdisciplinary configurative review, identifying characteristics associated with the nature of uncertainty, could also be an additional element that could be incorporated in such a framework. This could encourage the forensic science expert to reflect on each type of uncertainty, so as to recognise whether it is a form of uncertainty that lies within or outside their own sphere of influence, and whether steps can be taken to reduce such uncertainty, prior to evaluating and disclosing it.

Based on the recommendations for the adoption of a largely qualitative evaluative structure for assessing uncertainty in forensic science, the following recommendations are made when considering the different facets of uncertainty communication (Figure 5.8). Given that the evaluation of the level of each uncertainty source should be made against a qualitative scale, numerical representations would probably not be a good fit. Instead, in light of significant support by the authors of the contributing materials for the use of a visual framework (Beck et al., 2016; Bostrom et al., 2015; Han et al., 2011), a visual representation of each source of uncertainty and its level or magnitude, would possibly be a valuable aide. The node and arrow diagram developed by Chen et al. (2007) and as identified through the included contribution of Makinson et al. (2012), could be a useful addition to the written reports and verbal testimonies of forensic science experts. The nodes could assist in identifying different sources of uncertainty, while the arrows could visually indicate the location of each of the sources of uncertainty (see Table 5.5). When drafting expert witness reports or preparing for a testimony in trial, experts should be made aware of the significance of using a 'narrative language' to convey their uncertainties, as it can be helpful in bridging the divide between their level of understanding and that of the lay stakeholders (Litre, 2014). Even though experts are encouraged to be transparent, the manner by which they frame their narrative of uncertainties can have significant implications on how it will be perceived by lay decision-makers. As such, it is important that emphasis should also be placed on the robust aspects of their decision-making (Kundzewicz et al., 2018), so that the disclosure of uncertainties does not undermine the credibility of the expert or the confidence of the lay decision-makers in the expert.

As a final recommendation, interactive media could be an innovative medium through which to convey a visual representation of the sources of uncertainty and their magnitude, allowing for different levels of information to be embedded in different layers of the interactive representation (See Table 5.6). Judges and jurors can, thus, have the power of choice over how much information they expose themselves to. This can potentially prevent information overload, by allowing forensic science experts to be as transparent as possible, but at the same time ensuring that each individual legal stakeholder receives as much information about uncertainty as they wish to and can tolerate. Furthermore, it has been argued to be a useful tool when appealing to a diverse audience (Jensen et al., 2013).

8. Conclusion

8.1. Overall Purpose of the Thesis

The overall purpose of this thesis was to heighten current awareness around the issue of scientific uncertainty in forensic science. This thesis sought to encourage a fruitful exchange of ideas with 'neighbouring' disciplines, which could initiate a dialogue within the discipline of forensic science with regards to how uncertainty can be conceptualised, evaluated, and communicated in new and innovative ways. A greater awareness to the complex and nuanced nature of uncertainty in forensic science, as well as a motivation to identify novel pathways to holistically address it, can provide the foundations for greater transparency in the communication of forensic science evidence in court, informed decision making of juridical stakeholders, and reflective forensic science practices.

Three primary studies were conducted in order to address the overarching aim of the thesis (Chapters 3, 5 and 6). Two additional chapters contributed towards the development of method (Chapter 4) and theory (Chapter 7), necessary for the execution of the primary studies (Chapters 3, 5 and 6) and further development of their findings. Chapter 3 focused on the identification of the main conceptual instruments through which academics, policy-makers and the courts understand uncertainty in forensic science. Chapter 5 recognised the fruitful ground that existed beyond the sphere of the available forensic science literature with regards to scientific uncertainty, and explored the 'neighbouring' disciplines of medicine, environmental science and economics, for the purposes of retrieving and synthesising instruments and approaches for conceptualising, evaluating and communicating uncertainty. Chapter 6 focused on eliciting the experiences and interests of, primarily, forensic science experts, lawyers and judges with regards to which sources of uncertainty they would like to see evaluated and communicated in court. Chapters 4 and 7 contributed towards method and theory development. Chapter 4 reported the methods that were developed for the execution of the interdisciplinary configurative review (Chapter 5), while Chapter 7 considered the wider implications of a more careful consideration of uncertainty in forensic science for the discipline itself, as well as for its interactions with other stakeholders in the criminal justice system.

8.2 Research Questions & Individual studies

The following sub-sections present the key research questions that have contributed in the pursuit of the overarching aim of the thesis. Each of these research questions will be followed by a summary of how they have been addressed by the individual studies.

8.2.1 What narratives are deployed by academics, policy-makers and the courts when considering uncertainty in forensic science?

Chapter 3 was primarily concerned with addressing this research question. The study in Chapter 3 reviewed academic, policy and case law materials and identified the current challenges in reaching a coherent understanding of uncertainty in forensic science in terms of its definition, types and characteristics. A shifting narrative was identified, with a shift away from avoidance of uncertainty towards an increasing awareness of its nature and how it arises throughout every stage of the forensic science process. Despite this promising shift, the review revealed that there is still significant progress to be made in order to reach the requisite level of clarity in how uncertainty is understood and conceptualised for the purposes of effectively evaluating uncertainty and achieving standardisation in its reporting.

More specifically, this study identified the gaps in terms of the current definition of uncertainty in forensic science, while it also demonstrated the inconsistent and scattered nature of how uncertainty is described by policy makers, academics and the courts in relation to its types and characteristics. Furthermore, the review collected the different types and characteristics identified, and mapped them across each stage of the crime reconstruction process. The collection and mapping exercise provides a first step towards developing a coherent and consistent understanding of scientific uncertainty in forensic science across institutions and stakeholders. In addition, engaging with the topic of uncertainty in forensic science as it is currently understood, revealed that uncertainty is often spoken about in colloquial terms, while it is also confused with the term 'error'. This can have significant implications, not only in ensuring congruency of understandings across stakeholders, but also in the selection of methods for evaluating and communicating it.

Overall, this study provided a report of the current attitudes and narratives that are deployed by academics, policy-makers and the courts in relation to the conceptualisation of uncertainty. Identifying such patterns of thought and narratives is helpful in recognising misunderstandings and confusions over the definition, types and characteristics of uncertainty, which can have significant implications upon future efforts to achieve standardisation in evaluating and communicating uncertainty. Moreover, the better insights that are gained with regards to how different institutions and stakeholders consider uncertainty, can also be valuable when developing a more standardised vocabulary for describing uncertainty, as well as when developing evaluative and communicative frameworks. Such better insights can assist in designing conceptual, evaluative and communicative frameworks in such a way, so that they can address the gaps in the current understanding of stakeholders, while at the same time promote such frameworks in a way that will lead to less resistance and more acceptance by different institutions and stakeholders.

8.2.2 What instruments or tools are used to conceptualise, evaluate and communicate uncertainty in the 'neighbouring' disciplines of medicine, environmental science and economics, that can inform forensic science?

Chapters 4 and 5 were the primary chapters directed towards exploring this research question. These chapters consist of the preliminary method development chapter and the interdisciplinary configurative review. Given the dearth of available information on the selection of disciplines for inclusion in interdisciplinary or multidisciplinary reviews, the development of a method was required. Chapter 4 reports on the method development process. As part of this process, significant issues relating to the identity of forensic science were also explored and discussed; including the characterisation of forensic science as a discipline, instead of a general field of study, as well as its potential identification as a professional consultancy through an application of the theory of post-normal science (Funtowicz & Ravetz, 1994; Ravetz, 1999). Therefore, Chapter 4 contributes to the current body of knowledge, both through the developed method, as well as through its discussion regarding the nature and identity of forensic science as a discipline.

Following the preliminary chapter, an interdisciplinary configurative review was carried out, constituting the primary study and most important pillar of this thesis. The interdisciplinary configurative review in Chapter 5 provides a set of tools for conceptualising, evaluating and communicating uncertainty in forensic science. Given that the concept of uncertainty is one that transcends disciplinary boundaries, an interdisciplinary configurative review was carried out incorporating the disciplines of medicine, environmental science and economics, in order to identify common themes which could have valuable applications to the discipline of forensic science. Critical Interpretive Synthesis was used to develop sub-synthetic and synthetic constructs which interpreted and synthesised the underlying evidence and codes. This study provides three toolkits, one each for conceptualisation, evaluation and communication. The study identified an underlying theme concerning the obstacles that would need to be overcome for the effective application of these toolkits and achieving effective conceptualisation, evaluation and communication of uncertainty in forensic science to lay stakeholders. These toolkits offer a starting point for developing the conversation for achieving greater transparency in the communication of uncertainty. They also have the potential to offer stakeholders enhanced understanding of the nuances and limitations of forensic science evidence and enable more transparent evaluation and scrutiny of the reliability, relevance and probative value of forensic materials in crime reconstruction.

8.2.3 What sources of uncertainty are most frequently experienced and/or are of most interest to forensic science stakeholders for the purposes of evaluation and communication in court?

This research question was addressed predominantly through the study in Chapter 6, as well as partly through the interdisciplinary configurative review in Chapter 5. The primary purpose of Chapter 6 was to elicit a list of priorities from relevant stakeholders – mainly forensic science experts, lawyers and judges – with regards to the sources of uncertainty that had been identified, synthesised and/or developed in the interdisciplinary configurative review in Chapter 5. Through the use of a Modified Nominal Group Technique, 66 stakeholders expressed their uncertainty source priorities by responding to a set of close and open-ended questions online. A verification and organisation process followed, which resulted in 24 interim uncertainty sources priorities. These 24 priorities were then presented to the five (later four) participants to the synchronous online prioritisation workshop. Through a series of consensus building exercises, the participants reached a consensus relating to their top ten priorities with regards to those sources of uncertainty they would like to see evaluated and communicated.

One of the most significant outcomes of this study was its refinement of the long list of sources of uncertainty that had been identified or developed in the interdisciplinary configurative review. Conceptualising uncertainty is an integral part of evaluating and communicating it, as the selection of appropriate strategies to respond to uncertainty depends heavily upon gaining a good understanding of its nature (Wardekker et al., 2012). Moreover, the development of any evaluative and communicative framework needs to be feasible and operable (Flage et al., 2014). Through its refinement of the wide range of sources of uncertainty that resulted in Chapter 5, Chapter 6 directs future efforts towards the identification and development of more targeted evaluative and communicative instruments or frameworks, which will directly respond to the wishes and experiences of forensic science stakeholders.

The study in Chapter 6 is also significant as it constitutes a move away from a top-down approach to research. It encouraged the active engagement and involvement of stakeholders in the process of producing knowledge; knowledge that can have a direct impact on their professional lives. Such active involvement can contribute towards the development of research products that reflect and respond to the needs, interests and expectations of those who are at the receiving end of research (Burger, 2011; Yoshida et al., 2016). An evaluative and communicative instrument or framework that is based upon the priorities of stakeholders, is also expected be met with a lot less resistance by them. Moreover, the active engagement of stakeholders is greatly beneficial to the discipline of forensic science as a whole, as it fosters an environment of true collaboration between its diverse stakeholders, enhancing thus their highly complex and interconnected operations, and even reinforcing the status of forensic science as an interdisciplinary discipline (Morgan, 2018a; Morgan, 2019; Earwaker et al., 2020).

8.2.4 What are the wider implications of a more precise and consistent consideration of uncertainty in forensic science?

Chapter 7 constituted the synthesis of the preceding chapters and was concerned with addressing the final research question. The overarching aim of the final chapter was to synthesise the findings and observations emanating from Chapters 3 to 6, in order to explore how they relate to broader discussions regarding the nature of the discipline of forensic science, as well as the relationships and power dynamics between different stakeholders within the criminal justice system. At the forefront of the discussions in this chapter, is the argument that greater tolerance and engagement with uncertainty in forensic science can be truly beneficial for the criminal justice system as a whole and the identity of forensic science.

More specifically, this chapter has demonstrated how a failure to engage with uncertainty can inhibit the ability of legal stakeholders to independently and informedly make decisions regarding the reliability and probative weight of the evidence (Edmond, 2020). This, in turn, can erode public trust in the adversarial process and even the legitimacy of the criminal justice system (Biedermann & Kotsoglou, 2018). Instead, disclosure of uncertainties associated with forensic science evidence can inform and enhance the decision-making of lay stakeholders, discouraging their deference to the forensic science expert. Furthermore, greater transparency with regards to the uncertainties and limitations of forensic science evidence can also be valuable when it comes to overturning certain power imbalances already in existence in the criminal justice system. More specifically, it no longer places unreasonable – and arguably naïve – levels of confidence on the prosecution's expert witness voluntarily communicating the limitations of their own evidence. Instead, it takes it for granted that such uncertainties exist and requires their disclosure. This can reverse the inequalities of arms between prosecution and defence, as a result of the latter's limited resources preventing the acquisition of its own expert that could expose limitations or uncertainties in the prosecution's expert witness. Finally, it can reverse power imbalances, resulting from the specialist knowledge that experts are in possession of, in contrast to the lay legal actors. Such power imbalances may manifest in the form of a special status enjoyed by the expert in court, encouraging a laissez-faire approach with regards to the admissibility of their opinion evidence (Law Commission, 2011) and deference by jurors.

Two further implications of this thesis were also considered in this chapter. More specifically, the theory of post-normal science – with its emphasis on uncertainty – (Funtowicz & Ravetz, 1994; Ravetz, 1999) was presented as the driving force towards redefining the identity of forensic science as an interdisciplinary context-laden discipline, fostering greater collaboration between stakeholders, as well as increased tolerance and acceptance of uncertainty. Finally, specific recommendations were also made for the selection of the most appropriate evaluative and communicative instruments, as collected in Chapter 5, in light of the empirical evidence in Chapter 6.

8.3 Contributions and Implications of this thesis

The most important contribution of this thesis has been its development of a conceptual framework through which scientific uncertainty in forensic science can be understood in a more consistent and coherent manner. This is an important contribution, as the current frames of thinking, understanding and speaking of scientific uncertainty in the discipline of forensic science have been lagging behind conceptualisation developments in other disciplines, such as environmental science (Georgiou et al., 2020). Chapter 3 laid down the groundwork for the development of a standardised, holistic conceptualisation framework through its identification of the definition, typologies and characteristics of uncertainty in forensic science as held by academics, policy-makers and the courts. It recognised that a shifting narrative is currently underway, from avoidance towards greater awareness and acceptance of uncertainty. It also highlighted that there is still significant progress to be made in order to achieve a coherent holistic understanding of uncertainty across different institutions and organisations. Furthermore, the contribution of Chapter 5 towards the development of a conceptual framework was notable. It acknowledged that scientific uncertainty is a phenomenon that transgresses disciplinary boundaries, and as such an exchange of ideas, methods and approaches between disciplines could be fruitful (Bammer & Smithson, 2012). Through a review of the relevant materials from the professional consultancy or post-normal scientific disciplines of environmental science, medicine and economics, it collected and synthesised a number of terms, definitions and concepts that are in regular use when defining and seeking to build an understanding regarding the different facets and characteristics of scientific uncertainty. To a large extent, the collection and synthesis of the conceptual instruments was captured by the 'Uncertainty Map' (Figure 5.5); a visual instrument that can be useful when seeking to identify different sources of uncertainty and determine their location in relation to the decision-making process of experts. Finally, the conceptual contribution of the modified Nominal Group Technique in Chapter 6 was also significant, as it allowed for the refinement of the conceptual framework developed in Chapter 5, by establishing the top ten priorities of lay stakeholders in relation to sources of uncertainty they most frequently experience or are most interested in seeing evaluated and disclosed.

Significant progress has also been achieved in developing evaluative and communicative frameworks for dealing with uncertainty in forensic science. The interdisciplinary configurative review resulted in the development of three toolkits, one each for the conceptualisation, evaluation and communication of uncertainty. The evaluation and communication toolkits can be of value to individual forensic science experts, or laboratories, when seeking to identify innovative instruments for assessing or reporting uncertainties associated with their decision-making and findings. These toolkits provide a wide range of tools and instruments, that span beyond the predominant methods currently in use or recommended for the evaluation and communication of uncertainty in forensic science – such as the Bayesian theorem (Fenton et al., 2013; Lagnado et al., 2013), the likelihood ratio and verbal scales (Berger et al., 2011).

Moreover, the identification of stakeholder priorities through the modified Nominal Group Technique, constitutes an additional step towards the development of a specific targeted framework for the evaluation and communication of uncertainty in forensic science. Establishing stakeholder interests and priorities allowed for the refinement of the conceptual framework developed in Chapter 5, thus narrowing down on those sources of uncertainty that should be the focus of evaluation and communication frameworks and rendering the development of such frameworks a lot more feasible (Flage et al., 2014). Finally, the synthesis chapter reflected upon the nuanced nature and role of uncertainty in forensic science and the criminal justice system, and on the basis of such reflection provided a set of recommendations for the selection of the most appropriate – and innovative – ways in assessing and reporting the uncertainties associated with forensic science evidence.

The implications of this thesis have been both theoretical and practical. With regards to the theoretical implications, the studies making up this thesis have most significantly initiated a fruitful dialogue on the topic of scientific uncertainty in forensic science. By encouraging an exchange of ideas and methods between 'neighbouring' disciplines, the thesis has opened new pathways for thinking about and discussing uncertainty in forensic science, with a focus on achieving consistency and standardisation in the definitions and terms that are being deployed to describe the multifaceted and nuanced nature of scientific uncertainty. Furthermore, the wider theoretical implications of bringing uncertainty in forensic science to the forefront of stakeholder discussions, were also explored in the synthesis chapter. Uncertainty was recognised as a valuable mechanism in reversing power inequalities already in existence within the criminal justice system, as well as in reiterating the identity of forensic science as an independent interdisciplinary discipline (Morgan, 2018a; Morgan, 2019).

The practical implications are particularly visible through the three toolkits that were developed in Chapter 5 and the prioritisation exercise in Chapter 6. The three toolkits are useful in allowing for the selection of different instruments to assess and communicate uncertainty in forensic science, but also for assisting forensic science experts, lawyers and judges to gain a more in depth understanding regarding the uncertainties and limitations of forensic science. Moreover, the practical significance of the prioritisation exercise does not only rest upon the refinement of the sources of uncertainty that had been identified in the interdisciplinary configurative review, but also on its direct engagement of lay stakeholders. By encouraging relevant stakeholder to actively engage in a dialogue and directly participate in the production of research, it is ensured that any future targeted frameworks are adjusted to the needs and experiences of all stakeholders, thus rendering them a lot more user-friendly and operable.

8.4 Future Work

The most significant contribution of this thesis has been the new pathways that it has opened when it comes to the way we think about and discuss uncertainty in forensic science. It has provided new frames of reference for defining, characterising and thus understanding uncertainty, in light of the predominant narratives that are currently deployed by courts, policy-makers and academics. It has also provided a wealth of resources from which to select innovative, and previously hardly used or known in forensic science, tools for the evaluation and communication of uncertainty. At the same time, it provided an avenue through which the experiences and interests of stakeholders as they relate to uncertainty could be expressed and taken into account.

However, there is still significant progress to be made towards developing a consistent, coherent and standardised framework for dealing with uncertainty in forensic science. As the synthesis chapter has discussed, uncertainty can be a double-edged sword. It may have the ability to reverse power imbalances, yet it may also result in inadvertently disempowering those it seeks to assist. Providing too much information about uncertainties in the evidence of forensic science experts, can overwhelm legal stakeholders, potentially leading to decision-making uncertainty or even paralysis (Bansback et al., 2016; Damodaran, 2013). As such, the focus of future studies should be on empirically examining what types and amounts of information relating to uncertainty lay stakeholders wish to be exposed to and can tolerate. Furthermore, empirical research could also explore which of the available evaluative and communicative instruments are more user friendly and result in enhancing, as opposed to inhibiting or stifling, the decision-making of lay legal actors.

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Appendix A: List of Interdisciplinary Configurative Review Included Contributions

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Appendix B: Search Terms and Strings

Search Terms Table:

	Concept 1	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**
	Uncertain*	Decision-mak*	Finding$	Assess*	Communicat*
Synonyms		Determin*	Conclusion$	Evaluat*	Disclos*
			Prognos*	Estimat*	
			Diagnos*	Quant*	
			Forecast*		
			Predict*		

Search Strings

Main search string for evaluation of uncertainty, as used in Scopus:

1. Medicine:

uncertain*W/4 ('decision mak*' OR conclusion* OR finding* OR prognos* OR diagnos* OR determin* OR assess* OR evaluat* OR estimat* OR quant*)

2. Environmental Science & Economics:

uncertain*W/4 ('decision mak*' OR conclusion* OR finding* OR forecast* OR predict* OR determin* OR assess* OR evaluat* OR estimat* OR quant*)

Main search string for communication of uncertainty, as used in Scopus:

uncertain*W/4 ('communicat*' OR 'disclos*')

Appendix C: Opinio Survey – Interim Prioritisation Exercise

Uncertainty in Forensic Science: Stakeholder Priorities

This survey forms part of a PhD project at the Centre for Forensic Sciences (Department of Security and Crime Science) at UCL, with the title: "Uncertainty in forensic science: Conceptualisation, Evaluation and Communication in court". The purpose of this survey is to elicit stakeholder priorities in relation to the sources of uncertainty in forensic science which should be conceptualised, evaluated and communicated to court-related stakeholders.

We are very grateful for your input on this survey. Online meetings will be arranged in May 2020, in which we would love to hear your thoughts and experiences in more detail. If you would be interested in attending please provide your email address at the end of this survey, or get in touch with us at: nicola.georgiou.16@ucl.ac.uk

This survey should take about 10-15 minutes to complete. By completing and submitting this online survey you consent to taking part in this research project.

If you have any concerns or complaints do not hesitate to contact us (nicola.georgiou.16@ucl.ac.uk).

Start

Uncertainty in Forensic Science: Stakeholder Priorities

Background Information

1. Which of the following best describes your current profession?

- ◯ Laywer
- ◯ Judge
- ◯ Forensic Scientist
- ◯ Other

11%

Back Save Next

Uncertainty in Forensic Science: Stakeholder Priorities

Data Sources of Uncertainty

Sources of uncertainty relating to the data (i.e. number of specific types of footwear, number of clothing with a specific type of fibre, etc.) informing the forensic examiner's work.

2. **Select UP TO TWO of the following data sources of uncertainty that you encounter most frequently and/or you would like to see evaluated and communicated to all stakeholders (judges, lawyers, jurors).**

- ☐ Uncertainty arising from volume of data (i.e. data unavailable, very little or too much data, etc.)
- ☐ Uncertainty arising due to the quality of the data (such as inaccurate data, unclear, vague, complex etc.)
- ☐ Uncertainty arising from non-discriminatory nature of data (i.e. data that cannot assist in discriminating between features, hypotheses, etc.)
- ☐ Uncertainty arising from inapplicable data (i.e. irrelevant, unrepresentative of entire population, unreliable etc.)
- ☐ Uncertainty arising from changing nature of data (i.e. data that is revised, variability of data etc.)
- ☐ Other
- ☐ None of the above

3. Could you provide specific examples from your professional experience in which you encountered the types of sources of uncertainty you selected as priorities?

Uncertainty in Forensic Science: Stakeholder Priorities

Knowledge Sources of Uncertainty

The following sources of uncertainty relate to the knowledge base informing the forensic examiner's work.

4. Select **UP TO TWO** of the following knowledge sources of uncertainty that you encounter most frequently in your work and/or you would like to see evaluated and communicated to all relevant stakeholders (judges, lawyers, jurors).

- ☐ Progress in knowledge (i.e. knowledge in the field constantly progressing, being updated, etc.
- ☐ Lack of theoretical understanding
- ☐ Limited underpinning science
- ☐ Other
- ☐ None of the above

5. Could you provide specific examples from your professional experience in which you encountered the types of sources of uncertainty you selected as priorities?

Uncertainty in Forensic Science: Stakeholder Priorities

Methodological Sources of Uncertainty

These sources of uncertainty relate to the methods employed by forensic examiners.

6. Select **UP TO TWO** of the following methodological sources of uncertainty that you encounter most frequently in your work and/or you would like to see evaluated and communicated to all relevant stakeholders (judges, lawyers, jurors).

- ☐ Uncertainty arising due to concerns regarding analytical instruments (i.e. precision of analytical instruments/methods; model uncertainties, such as algorithms used for automated fingerprint comparisons; etc.)
- ☐ Uncertainty arising due to different methods used by different forensic examiners
- ☐ Uncertainty arising due to concerns regarding methods employed for data management and storage (i.e. tools/databases selected to store and manage data; methods selected to enhance photographs of trace evidence taken at the crime scene, etc.)
- ☐ Uncertainty arising from the choice or use of relevant academic/scientific literature in the case in hand
- ☐ Other
- ☐ None of the above

7. Could you provide specific examples from your professional experience in which you encountered the types of sources of uncertainty you selected as priorities?

Uncertainty in Forensic Science: Stakeholder Priorities

Innate Sources of Uncertainty

Sources of uncertainty that are inherent in nature; often permanent or unavoidable.

8. Select **UP TO TWO** of the following innate sources of uncertainty that you encounter most frequently in your work and/or you would like to see evaluated and communicated to all relevant stakeholders (judges, lawyers, jurors).

- ☐ Unpredictability or variability/changeability (i.e. degradation or cross-contamination of physical evidence; unpredictable behaviour of first responders to crime scene, etc.)
- ☐ Complexity (i.e. complex case, layers of interpretation to the problem, complex behaviour of trace evidence, etc.)
- ☐ Inherent limitations of quantification (such as unquantifiability of events/propositions, model results inherent approximations, etc.)
- ☐ Indeterminate elements (aspects in the case study that are not exactly known, established or defined)
- ☐ Inherently uncertain nature of science (i.e. science can never be separated from its social context; provisional nature of knowledge; scientific knowledge cannot entirely correspond to objective truth, etc.)
- ☐ Other
- ☐ None of the above

9. Could you provide specific examples from your professional experience in which you encountered the types of sources of uncertainty you selected as priorities?

Uncertainty in Forensic Science: Stakeholder Priorities

Semantic Sources of Uncertainty

Sources of uncertainty relating to definitions or individual perceptions.

10. Select **UP TO TWO** of the following semantic sources of uncertainty that you encounter most frequently in your work and/or you would like to see evaluated and communicated to all relevant stakeholders (judges, lawyers, jurors).

- [ ] Uncertainty about how the issue of uncertainty is understood/defined/perceived
- [ ] Uncertainty arising due to descriptions or definitions (i.e. vagueness of language, ambiguity of language etc.)
- [ ] Uncertainty as a result of the influence your institution or interpersonal relations have on the understanding/definition/perception of elements that form part of your work
- [ ] Uncertainty arising due to differing understandings/perceptions of the problem (i.e. different stakeholder perceptions about which exhibits are critical to the case and should thus be analysed/prioritised for analysis, etc.)
- [ ] Other
- [ ] None of the above

11. Could you provide specific examples from your professional experience in which you encountered the types of sources of uncertainty you selected as priorities?

Uncertainty in Forensic Science: Stakeholder Priorities

Probabilistic Sources of Uncertainty

Sources of uncertainty relating to any probabilities involved in the approach adopted by the forensic examiner.

12. Select **UP TO TWO** of the following probabilistic sources of uncertainty that you encounter most frequently in your work and/or you would like to see evaluated and communicated to all relevant stakeholders (judges, lawyers, jurors).

- [ ] Uncertainty around the precision/validity of probabilities (i.e. precision/validity of probability/range of probabilities of a DNA match if the prosecution proposition were true)
- [ ] Uncertainty arising due to unknown probabilities (i.e. unknown probative value of comparison between two patterns)
- [ ] Uncertainty arising due to difficulties of assigning probabilities (i.e. to events, propositions, hypotheses, etc.)
- [ ] Other
- [ ] None of the above

13. Could you provide specific examples from your professional experience in which you encountered the types of sources of uncertainty you selected as priorities?

Uncertainty in Forensic Science: Stakeholder Priorities

Examiner-centred Sources of Uncertainty

Sources of uncertainty relating to the forensic examiner

14. Select **UP TO TWO** of the following expert-centred sources of uncertainty that you encounter most frequently in your work and/or you would like to see evaluated and communicated to all relevant stakeholders (judges, lawyers, jurors).

- ☐ Uncertaintu arising from range of expert views (i.e. disagreement between experts, conflicting findings/views, equally valid but differing frames of knowledge, etc.)
- ☐ Quality of expert (i.e. experience, training, lack of knowledge, etc.)
- ☐ Uncertainty arising from expert judgment/decision-making (i.e. mental shortcuts, assumptions, etc.)
- ☐ Moral uncertainties (i.e. lack of moral rules, inability to apply moral rules, etc.)
- ☐ Personally perceived uncertainties (existing in the mind of the forensic scientist)
- ☐ Other
- ☐ None of the above

15. Could you provide specific examples from your professional experience in which you encountered the types of sources of uncertainty you selected as priorities?

Uncertainty in Forensic Science: Stakeholder Priorities

Other Sources of Uncertainty

16. Are there any other sources of uncertainty that you encounter frequently in your work and/or you would like to see evaluated and communicated to all relevant stakeholders (judges, lawyers, jurors), which have not been mentioned above? If so, please use the space below to list and describe these

94%

Back Save Next

Uncertainty in Forensic Science: Stakeholder Priorities

17. This survey is part of a larger ongoing project at the UCL Centre for Forensic Sciences seeking to gain a better understanding of uncertainty in forensic science. We would be really interested to hear more from you. If you would like to find out out more information about the project, or get more involved by speaking to us please leave your email address below (otherwise leave blank and proceed).

100%

Back Save Finish

Uncertainty in Forensic Science: Stakeholder Priorities

Definitions & Instructions

Uncertainty for the purposes of this survey is defined as: "anything that falls short of determinism (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 by the forensic scientist in relation to interpretation at the source, activity and offence level."

If you are a lawyer/judge, please select those sources of uncertainty concerning aspects of forensic science/evidence that you encounter most frequently in your work and/or you would like to see evaluated and communicated to all relevant stakeholders involved in criminal trials (judges, lawyers, jurors).

If you are a forensic scientist, please select those sources of uncertainty that correspond best to your casework experience and/or which you would like to see evaluated and communicated to all relevant stakeholders involved in criminal trials (judges, lawyers, jurors).

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Back Save Next

Appendix D: Workshop Materials

The following link provides access to a google drive folder named 'Uncertainty in Forensic Science Prioritisation Workshop'.
https://drive.google.com/drive/folders/132N9klugseDbxl3zJGS4yiTOxRv13Xj3?usp=sharing

This folder contains the following materials that were used before or during the prioritisation workshop:

- Facilitators Guidance
- Discussion Cards
- Workshop Agenda
- Pre-workshop exercise
- Workshop Guide

There was an additional document provided to the participants: Participant Biographical Information Sheet. For purposes of confidentiality and data protection, this document has not been included in the google drive folder.

Appendix E: Transcripts of Prioritisation Discussions

The following excerpts constitute the transcripts of the discussions of each group (Group 1 and 2) during Round 1, and the final discussion in Round 2. The experts (E 1, 2, 3, 4, 5) and the second facilitator (Facilitator B) have been anonymised.

Group 1 Round 1 Discussion

E4 00:00
And to try and categorise 24 things and sort of juggle them. And I was trying to think about whether these things are particularly salient issues in individual cases, or whether things that keep coming up. Yeah, across the board. So I sort of thought in my head about scoring it in a sort of risk assessment way. So thinking, you know, this might only happen in a few cases, but it's a bigger impact, or it's something that happens, you know, across the board that we're constantly worried about. And I think that the biggest things for me were the A category about having sufficient data. vision or make assessments, whether that be the quality or the size of this and, and, I guess that ties into the, the F category as well. So how we assign those probabilities. based on the data, as well, and probably a third area that I would have, I was quite surprised it wasn't much about was just uncertainty about how forensic evidence is understood by us it, which I guess comes under Section E

01:18
semantic. Um, so the reason for that is because the, we were more concerned with the uncertainty that is in the data, and in the evidence that will be presented to the jurors, and the judges and the lawyers. So that's why it didn't come up is a very big topic. But yeah, you're right. It could be encompassed under the E, and the descriptions and definitions that are being used.

E4 01:48
Yeah, so that's something that we've talked about quite a lot is, whatever we do in our lab, might be very technical and, and whatever. But actually, if we don't communicate it well and It doesn't have any impact.

Nicola Georgiou 02:03
And which are the ones that you would least important and that you don't actually get them?

E4 02:13
Yeah. So I mean, some of the items that were relating to disagreements between different examiner's these are different methodologies. And I think they were, for example, C two.

Nicola Georgiou 02:26
Mm hmm.

E4 02:27
Maybe h1.

Nicola Georgiou 02:29
Yeah.

E4 02:30
And it might just be because from our background, there's quite a small field isn't too much debate or controversy between different experts on what methods to use Really?

Nicola Georgiou 02:44
Yeah. And before we move on to E5 and Mr. F* has just joined again, so I'm going to try and see if I can get him to sign

E5 03:05
New psychoactive substances coming out, we don't really know and if we measure something what that means we're difficult to interpret it and so lack of finances is the other big one for me. It was

Nicola Georgiou 03:18
Nicola, we we started the session, which to find that Prof F* he is there but I don't think he has managed to join your he hasn't right? No. Okay, I'll see if I can find him. Okay, sorry you can carry on. So Prof F*

E4 03:45
Hello Hello.

Nicola Georgiou 03:51
Hi Prof F*

E4 03:54
hi Prof F* hello

Nicola Georgiou 03:59
hello

E5 04:02
I'm not sure my computer. My internet connection is going to be up to this. It just repeatedly cuts out. And I haven't been able to join a breakout room.

Nicola Georgiou 04:12
I see. That's a shame. I'm really sorry if you close the camera would it work better?

E5 04:19
Let me try. Let me try. Where are we here? Stop video. Yep.

E4 04:24
Okay.

Nicola Georgiou 04:25
Yeah, have you? Let's see. Is it let you go into the breakout rooms?

E5 04:31
I'm not seeing the link to the breakout rooms. Let me have a look.

Nicola Georgiou 04:35
Okay, let me get a link now. Ah,

E4 04:44
no, I'm

E5 04:46
still here, but I can't even seem to connect with where we were. Okay,

Nicola Georgiou 04:58
maybe I can move Everyone into them

E3 05:05
No, nothing

E5 05:07
at all now No,

Nicola Georgiou 05:09
it doesn't come up.

E5 05:11
Nope, there's nothing coming up whatsoever now

E4 05:20
no afraid nor

Nicola Georgiou 05:23
strange. And

E5 05:27
what I would says I mean, I don't have any broadband where I am. The only way that I've got this computer connected to the internet is through my mobile phone. And my mobile phone has a very poor signal here. And I suspect that I'm just haven't got where I am at the moment and technology to to do this that it's just too poor. So I think probably the fairest thing on everybody would. Well given that we're already a quarter past 12 and I'll have to leave before one, I think maybe the fairest thing on everybody would be to say, well, please just get on with it. And I'd be very interested to hear an update on what you're doing and what the outcome of the meeting was. But maybe we could. And also, if you're forming a group to be part of the group, I mean, it would be great to do that, you know, a more long term research group or, or whatever or discussion group or whatever you have in mind, don't be very keen to do it. But I don't think I'm going to be able to do this.

Nicola Georgiou 06:37
Absolutely fine. Thank you very much. And we sorry, we didn't manage to figure this out. And I hope you have a lovely lecture and a lovely rest of your day.

E5 06:46
I hope the lectures more successful in terms of getting online and this is okay. Thank you. Have a nice day.

E4 06:53
Bye You too. Bye. Participants by

Nicola Georgiou 06:58
Sorry Sorry for the delay. He doesn't have good bandwidth to find the job to join the room. So he has just left. I'm really sorry. I think we were just that Mr. Jarvis, who was going to express his own strongest areas of interest and least strong sources of uncertainty.

E5 07:16
Yeah, well, I'm not I come at this from the point of view of a trial lawyer who may be prosecutes. Yeah. So the thing that that I pick up on, I think, a one and a two. Mm hmm. about quality and volume of data, I think is an important area. And I'm thinking here really about some of the cases I've been involved in where we've had expert evidence about paint flick comparison or fingerprint Comparison, where there's been a question arising about what is the data that enables you to draw the comparison that you do between the two objects that you've seen?

Nicola Georgiou 07:53
Yeah.

E5 07:54
I also think just running down my list. d3, I think is something that's come up in cases that I've been involved in. But I'm thinking more about the objective truth aspect of it in terms of how we present science and what is scientific, and whether our understanding of science chimes with what members of the public thinks science ought to be. Yeah. And I think also e2.

Nicola Georgiou 08:22
Mm hmm.

E5 08:24
And I only say that, because of the, I think sometimes a disconnect between the very precise language that scientists employ and in their reports and in their evidence and whether that language necessarily carries the same meaning to the people who need to understand it. So terms like diagnostic or consistent, I know what they are. But I think the best experts that I've seen in court are the ones who can change the way they express themselves into a language that juries can very easily understand. I think the areas that I'm less concerned about is probably G and A. If I'm being honest, because so far as G's concerned that I think it's, it's understood that two, three more people might disagree about an area of science, I'm not sure that necessarily gives rise to uncertainty is just a conflict that a tribunal of fact has to resolve. And quality is of experts, again, can be variable, but again, it's something that we trust juries to maintain and understand. So from my experience of these sorts of cases, I'm less troubled by the G and H uncertainties and more troubled by, I'd say A1, A2 D three and E two.

09:43
Hmm. Okay. Well, thank you very much for that. E3, How about you How, how do you see things from your perspective?

E3 09:53

Okay. First of all, sorry for my English andFor my classification, I put the first marks To B2 and E1 and D one and especially for E one I, I would like to spend a few words please because my field is a genetics, yeah forensic genetics okay. This is one of our main problems because a phenomenon that is a biological phenomenon undergoes a first mathematical conversion and in a value. Subsequently this value is reconverted with a verbal scale according to the FC guidelines, which often fail To exactly specify the degree of the result. And this is key, which is valid for DNA but also for higher order forensic sciences. For example, Air and Air volume greater than 10 raised to 3rd uses the word strong within the verbal predicate to support to the prosecution hypothesis. Specifically use a strong with an LR of 10 raised to a third, or very strong for an LR of 10 raised to four or extremely strong support with an LR of a 10 raise to six and over. I experience speaking with the judge, and the lawyers I realise that the word strong is a perceived how the person of interest is a within of the mixture. It's easy, despite of difference between the objective very strong, strong and extremely strong. This could be a big problem because for example, the random match probability, that is the for a single evidence, the maximum weight I evidence is perceived like weight about the evidence for a mixer with the for example, the person of interest is that the minor contributor and with very different results, for example, 10 raise to third greater rather than 10 raised to 26th. And the fact that lawyers And juries may consider this value in the same way. I don't think I don't I don't like it very much.

Nicola Georgiou 13:09

Okay. So you think that doesn't actually interpret really well to how it is perceived and understood by the lawyers and judges?

E3 13:17

Yes, yes. Because for us is a usually deal with numerical value. Uncertainty probabilities are value but for a jury is less common to interpret this, this type of concept.

13:43

Yeah. And, E5, would that be something that you have experienced from your cases?

E5 13:52

Yeah, we've come up

13:55

with a lot before so the random occurrence ratio is so Something that prosecutors often get quite badly wrong in terms of how we try and present the data to to the jury. Yeah, I'm not sure it's a lack of understanding about what the science is telling us, it's probably a lack of our ability to properly understand it and communicate it in a way that makes sense. But I think in terms of the way things are expressed, and we come across this in a number of different fields, about whether you can take your scientific understanding and translate it into words and phrases, which retain their accuracy, but are more easily understood. And I recognise that problematic. So in pathology, we often ask questions of what level of force was deployed by the use of the weapon to cause the injury. And almost pathologists with a certain degree of reluctance have been forced to characterise it by reference to three grades of force which aren't precise or exact or scientific, but necessary in order to communicate to the jury What we're trying to say. And so I don't think they give the evidence reluctantly, but you do have slight schism in between how the signs would interpret it, and how we try and describe it. So the members of the public can make some sense of it.

Nicola Georgiou 15:16
Okay. So it seems that the E category is it is a concern for all three of you. So if we start trying to put the categories into a sort of ranking system, and then try to see which of those are most important so that we can reach an agreement. And if we cannot reach an agreement, then if we can get your individual votes, and see how as a team, we would rank the priorities. So so far, I see that the categories A when it comes to data are really important for all of you, and we also have the category of E which is the congruence of understanding between how the scientists wish to express their own opinions and their own findings and how it can be communicated in a more personalised manner, but also easy understandable to the juries. We also have the category B, which is the underpinning science and generally the knowledge category. And category E D also came up which is semantic and no the inherent uncertainties, while G and H do not seem to be particularly important for anyone. Would you agree with that with G and H be the least important categories?

E4 16:55
I wonder just about G three actually. I think I would like that quite highly from the point of view of ehhh there's been quite a lot of focus and quite a steep learning curve about internal biases and cognitive biases recently. And it's starting to get a lot of attention in cases that we've been involved in. And so from our point of view, and from the courts point of view, it does seem to be quite a sort of salient issue.

Nicola Georgiou 17:24
Do you have anything to say about that, E5? Is that something that comes up quite frequently in your concerns regarding the expert?

E5 17:33
We've certainly seen it so with with fingerprint comparison, when you follow the AEV model, the final part of it is, is verification you're supposed to give your results to an associate. Yeah. And and we assume that we'll be blind but in a lot of instances it it's not. And so you're saying I have found the following match, what do you think? And then of course, it will come back and say what I agree With you, then that raises a cognitive bias question. So it's probably not as well understood, as I think it ought to be. And I'd be interested to see from other science report how much if it features, I think one of the things that we do see on a practical level around expertise is whether you have particular experts who routinely are used by particular firms to say particular things, and whether what they're doing in reality is rather than giving objective expert opinion, are trotting out what has become for them an occupation. And I don't think jurors necessarily understand, or you can question that you can say to somebody, well, you're just a mouthpiece rather than an independent individual. Whether that question of bias is necessarily as well understood as it as it could be.

18:55
So how about you E3, what do you think about bias is that is something that You that your lab takes into account Have you got any pressing cases and is it something that you would like to see better communicated and to raise more awareness when it comes to lay decision makers?

E3 19:14
Oh yeah. Yeah in my in my lab when we finally rewrite a report. So, difficulty is like I say before to express numerical value in words. So sometimes and sometimes it can often that

we we go to testify many years later so are not so the persecutor base. They have the session only on the on my report not to testify. So it's impossible to explain during the trials my perfect point of view the perfect explanation of the of the case. So, he has to decide only based on the report and after he cannot run that there is a misunderstanding between the perfect concept expressed in a numerical value.

Nicola Georgiou 20:46
Okay. Do you deal with the issues of bias though. If you're the way you see things could be affected by the context that you're given about the case. Do you think That's something that can affect the validity of your results And is that something that you would like to see communicated to lay decision makers?

E3 21:11
So, sorry, can you repeat

Nicola Georgiou 21:13
so contextual bias? So there have been quite a lot of academic studies lately that indicate that forensic science experts can be vulnerable to information that is given about the case and that they can perceive certain things the way they would like to see them. Is that something that comes up in forensic genetics and would you like to see it evaluated and communicated?

E3 21:38
Yes, I think that it can be better to give give, give jurists a bias previous, previous concept before to arrive more difficult concepts For example another value so before we have to give other information because I think that there are people that is good for understand this, but other other one aren't.

Nicola Georgiou 22:22
Okay. Okay, great. So it seems that G3 is indeed a concern. And it would you see it in the top 10 then?

E3 22:35
g three? no I put, I put it low, low score 19

Nicola Georgiou 22:45
Okay, how about you, E4 and E5? How would you how high up the scale would you see G three?

E4 22:55
I think it was towards it was a number eight for me. And part of the reason for that is it there seems to be a bit of a topic. * topic at the moment, because it's coming up in a lot of trials. But yeah, whether that makes you score higher, I'm not sure

23:14
about you, E5. Whereabouts would you score that?

E5 23:18
I had it at nine? Me? I mean, I'm it's an incredibly difficult exercise, I think is which is already touched upon to go through this list and work out what the top 10 are, if you were to say to

me is, is this something which I think could comfortably fall within the top 10? I think it could. I think quite a few of these things could. But if it is something which you're saying is quite topical, within the expert community that it's only a matter of time before it's going to trickle down, I think to people in my position who are going to want to know a bit more about it in relation to all of the areas of work that we do and I'd have thought that the most opposite opposite things to look into Probably those that all are more topical rather than others. Hmm.

24:03
Okay. And so if we were to sort of start seeing how we're going to rank this shall I get your scores, and then we can see where we've got areas of disagreement and areas of agreement? So we can we can start deciding as a group, and hope we reach consensus. Let's start with E4. How did you what were the scores that you gave the ranks?

E4 24:34
Should you want me just to run down? Yeah, so from a one down. So for the A's, it's 1 2 3. Mm hmm. For Bs 16 15 and 24 for B3, I didn't quite understand the question.

Nicola Georgiou 24:51
Mm hmm. Okay. And so let's see. And these are some quotes from C three, no wait B3 right?

E4 24:59
B3 yeah.

Nicola Georgiou 25:00
B3 so limited underpinning science? So these are some of the quotes that came from the survey from participants who respond to the open ended question. So basically, whether there is any science to inform the decisions of experts.

E4 25:17
Okay. Yeah, I mean, I'd obviously be concerned about that. And that might cause me to pick that one higher if you know something was based on junk. Maybe I'll come back to that one. And for C I had 2120 and then 12, for D 22, 14, and then 22 to 14 and 23. I mean, again, I would maybe revisit the d3 23 we're including in that explain the difference between objective truth and uncertainty but for E I've got 17, 9 and 11. Mm hmm. F 13, four and five, then G 26 and eight and for H of 19, 12 and seven. Okay.

Nicola Georgiou 26:12
And let's go to E5

E5 26:17
So I... Oh, and so I think once I got beyond that it was very difficult to, for me to work out where I thought I had three one and five for a one a two a three. Yeah. I had eight for B two. This is just my, again, just the top 10 Yeah. DI had 5 for D1, sorry, 6 for D1, 7 for D2 and then, sorry, my computer's a bit stuck. And then so and then E, I went 8 for E2, nine for E1 and 10 for E three. And like I said the others I didn't. Yeah. There'll be sure about GG three. Yes. Sorry. 11 for G3, three. So that was what we were talking about for a little beyond that. I just, yeah, that was probably the best thing to do.

Nicola Georgiou 27:32

Yeah, that's fine and good. How about you E3?

E3 27:36
okay, for my top 10. Yeah. For me, the first one is the B two.

Nicola Georgiou 27:46
Yeah.

E3 27:50
E one as the score of two. D1 three Yep. Okay, E2 as 4, E3 as five, And C 2 as six. Yep, D two as seven and C one as 8, D three as nine, and finally F1 as 10.

Nicola Georgiou 28:39
Okay, so it looks like all three of you agree on E three being in the top 10, E2 being in the top 10 and and that's about it pretty much when it comes to how much you agree. I think there's more agreement between E4 and E5. When it comes to your top five, I see there's a lot of concern about data uncertainties. So A1, and A2, and A3. You both put these in your top five. E3 would that be good, are data uncertainties not something that you are that concerned about?

E3 29:27
Yeah, for the data, I put in this in this point, a low score 17, 18 and 22. Yes, because, for example, for a one, I think that this can be this aside in my field. Because when analyzer activates it's a fundamental that they have been taken according to correct procedures. But unfortunately, sometimes it's impossible to trace, for example, those who had access to the crime scene as first responders for example, who can compromise the quality of the final data. This is important but in my opinion in my field that other ones are more important than this. I think that this can be explained. But it's not crucial to put it up for example, in our in our report. And the same, the same thing is for the volume of data, not much volume but in my field to very little or too much data, too many data. For example, the quantity of DNA is crucial point, because if you have a lot of very little quantity of DNA or you can obtain a partial or negative profile, but is a simple to understand this this from the my from my report, it's not so also this concept crucial to explain a more in a manner bigger, but it's simple to put the quantity in my report so a simple to understand for jurists per sample.

Nicola Georgiou 31:46
I see where you're coming from. And okay, so I I think we might need to do a vote on this because I don't see We can reach a consensus on all 24. So it might be easier for this bit where we have quite a lot to just do a vote and then in the next process, where it's going to be fewer of us and fewer uncertainties to consider to agree as a group on the top 15. Top 10. So would you like to send me your votes? If you can think about it and if some of these have changed through the discussions, if you want to reconsider them, and if you could send me a private message, and then we can meet back again at around one. Well, I'll, I'll present the results from the first round and we can go into the second round of discussion. Does that sound good?

E5 32:45
Yeah.

Nicola Georgiou 32:46

Okay, great. Thank you. I shall be waiting for your your private messages.

Group 2 Round 1 Discussion

E2 00:00
Not I'm very sorry, because of the work through due to the * But what I can do? Yeah, the number and the quality are more or less two on three of the three, three and two in our Yeah, right. Right.

Facilitator B 00:18
Yeah. And in this respect, I can see that there is actually I agree with you the volume of the data, how much drugs you have, and the quality of that seems to be within this category. So between you which one do you think? I mean, do you both agree that is A 1and A 2, aren't you? Kind of number two, right?

E1 00:42
A2 and 3,

Facilitator B 00:45
which one is two to three up?

E1 00:48
I think probably a two is number two, because that one seems to be about the volume, which I think is really what we're saying is having enough.

Facilitator B 00:57
Yeah. So A2 is number two

E2 01:00
Yeah, and A3 it's number three. Yeah. Look, yeah.

Facilitator B 01:02
Okay, we're getting there. So what about the other priorities? uncertainties? You have the comments *.

E1 01:18
Yeah. So I try to see which one I put a number 4 now.

E2 01:26
Well, maybe f3. I suggest I suggest f3 because unknown probabilities values are very, very has has a little weight to consider because I'm, let me explain. Do you have to understand the statistical treatment of the data and you can't measure, you can't evaluate all the probabilities because some of them are unknown. You have a problem. Maybe you are lucky. And this probability of these things are very low and doesn't affect. But if not What? What do you do? I think f3 Could be number four, I don't know what do you what do you think?

E1 02:19
So, I had put uncertainty over to C2 and uncertainty arising due to different methods. And because although it doesn't affect necessarily an individual case, when you, for example, try and compare proficiency tests or you know, the inter laboratory tests across labs, and people who are using different things, and although like accrditing bodies and professional bodies are trying really hard to get people to use a standard set, and to say like, this is the top one and then sort of going down counting, there is still a really big difference and it comes down to things Like money, you know what the lab can afford to buy, and, you know, training, whether they've got someone who can use this latest machine. So I think in that way then becomes difficult to compare what you're doing with them other labs and also to compare papers to compare against the literature and say, What does this mean? And But yeah, I think the probability is one Is it good? I had that one quite. I don't want to like number six.

Facilitator B 03:32
So we're having one would you be able to agree on number four or we can do

E1 03:39
Yeah that's fine

Facilitator B 03:42
So which one do you think is number four both of you,

E1 03:48
F3.

E2 03:49
F3,

Facilitator B 03:51
f three f3. The uncertainty of unknown probability. Ok. And then after that, so we're having the the C two as well in the high category. But so we are now four *** and four, five and six. So which one do you think is next? So we can categorise the different methods used by different forensic science experts.

E2 04:30
I will put it in as number five,

Facilitator B 04:33
right?

E2 04:34
Okay.

E1 04:34
Yeah fine.

Facilitator B 04:37
So now we are at number six. Well, which one do you think? e2? What do you think about number six?

E2 04:48
Let me find my notes

Facilitator B 04:53
you have four or five here now six.

E2 04:55
Yeah, yeah, six number six. I lost it are here. Here. Well, I trust number six but maybe I'm not agree with my self now. Yeah, when I when I did it, I did a lot of things surrounding me and well I put my number 6 in the C, three

Facilitator B 05:22
c three.

E2 05:23
Yeah. But maybe really neat again. Maybe I would like to hear E1 election

E1 05:34
my must be one, which is I'm sorry. No, it's B three for limited underpinning science. So it's quite similar in terms of what you know what science is actually available, and what you choose to look at. And also some labs you have access to lots of journals, and other labs won't have access to lots of journals who actually can only see certain literature. I think something about the literature is a good one to come now. And yeah, mine was C2, c2.

Facilitator B 06:10
Okay.

E2 06:13
So this do you choose B three,

E1 06:17
C three?

E2 06:18
c three like me?

E1 06:20
Yeah.

E2 06:21
Hmm. So maybe I wasn't wrong. Right, right but the number six, for c three is okay.

E1 06:31
And I think B for me these because it's related.

E2 06:36
Yeah, yeah, that's that's what I think. Now B3 is more or less the same but more. Okay. Excuse me, my English, E1 but sometimes I lose words to express myself. So if you agree, number six could be this

E1 07:01
Number 7 B3.

E2 07:02
Number seven, B three. Yeah.

Facilitator B 07:05
So number six is C three. And number two is B three, B three. Yes.Okay. What do you think about the next uncertainty? E1?

E1 07:25
Let me find it. So is e1. And so when, when we started using uncertainty on drunk driving certificates, it was a really big problem with the police because they said, like, particularly if your uncertainty is very, very close to the limit, or drink drive limit, and you say, Well, I'm not that certain. And your plus or minus could take you underneath the limit. That was a real problem for the police and they also didn't understand why we have been certain last week, and now this week, we're not certain. So all you know, for decades, we've been so certain about them being over the limit. And now we will suddenly say that we're not and it was really just get across to them that actually we've always had uncertainty. It's just that we now have to be upfront with you about it and admit that we are uncertain. So that took a lot of a lot of problems with the police that we won. Is, is how you explain it to the customer. I spoke to the person who's got to make sense of that result.

Facilitator B 08:34
What do you think E2?

E2 08:39
Well, this point I think I had is not disagree on the points of view of e1 is right, but Well, I put f1 of the yes because again, The position of probabilities is important. Because all the things we we have said before, and this is a point we haven't consider. If I'm not wrong its' a point we haven't considered. Now, I put I put F1. after all the things we have said, I will maybe I wanted to close all the things related to the, the mathematical aspects of the data. And I put f1 and f2 in this ranking and in this in this point is So, I don't know if maybe I'm wrong you're not yeah sorry.

E1 09:59
In my fields, which don't really use probability. Thank you. Well, not yet. I think we're probably will end up using it. But at the moment, we don't estimate anything like a likelihood ratio, or it's just not really a thing in tox at the moment. But yeah, it's probably gonna come in the future.

Facilitator B 10:20
All right, sorry to interrupt, would we be able now spend 20 minutes of discussion. We have 10 minutes

E1 10:31
Hurry up

Facilitator B 10:32

To finish the rest.

E1 10:33
Yeah.

E2 10:34
Okay.

Facilitator B 10:36
If we, I hopefully will agree on the prior writings. If we don't, we have a backup plan. Let's Let's see,

E1 10:45
but I'm happy to have f one and F two there. Because they recognise, it will come eventually.

Facilitator B 10:52
Okay, so f1 would be now we're in seven, right? Seven and F2 would be number eight. You both agree on that.

E2 11:04
I agree. Yes.

Facilitator B 11:06
All right. Well, what about number nine?

E2 11:11
Number nine that the the point is she said you will be E1. Yes.

E1 11:20
E1. Yeah.

E2 11:22
Yeah.

E1 11:24
So number 10 I had. We're at number 10 now?

Facilitator B 11:30
Yes ten.

E1 11:31
Yeah. I had a G1 for different experts piece.

E2 11:37
G1

11:40

Facilitator B 11:42
What do you think E2?

E2 11:47
Basically, too much papers on. Yeah. The one I put I put b1, B1 because the the unpredictability of the degradation of the of the samples in my experience is important. Here in Spain we use to analyse lots of hashish and they have very, very affected by the temperature, the humidity Yeah. And the condition of place where where you put to waiting for the moment of analysis I can remember the word in English is this condition control these conditions are very important. So I think I put the one.

E1 12:52
that affects us, as well. You know, what people have done with the samples and that kind of thing, how they store them.

Facilitator B 13:00
Philosophy. Is it the one we're talking about

E1 13:02
D one? Yeah

Facilitator B 13:03
D1. Okay. So that's

E1 13:04
D for delta

E2 13:06
that's number 10. And number 11. The uncertainty arranging for range or for views? Yes, yes. Yes, of course. Yes. At some, some days we have a very, very huge discussion in the labs… different points of view, especially in quality in qualitative analysis. Yeah, I agree with E1's number 11. Could be a D1. If,

E1 13:33
yeah.

Facilitator B 13:38
What's the letter again?

E1 13:41
G for golf.

Facilitator B 13:42
GG, okay, because D and G sounds the same. Okay, we agree. We have a few more to go. Okay,

E2 13:53
well, for number 12 going on with the expert influence.I put g two and G three.

E1 14:04

Yeah Same.

Facilitator B 14:07
Okay.

E2 14:08
Nothing to the scale.

Facilitator B 14:12
Okay, so g two, g three are done. Number 14,

E1 14:19
I had put him I was in the H Now I put an h2, which is I suppose it follows on a bit from the experts

E2 14:33
Well H2? I really that doesn't really don't understand properly this this the sense of this particular uncertainties about giving evidence supporting it doesn't related about them.

Facilitator B 14:49
I'll show you an example maybe to clarify it.

E2 14:52
Yeah, please

Facilitator B 14:52
H2 right?

E2 14:54
Mm hmm.

Facilitator B 14:55
H2 would be So this is the like community. These are examples. misunderstanding statistics courts don't tolerate uncertainty.

E2 15:09
Oh, yeah. Well, well. This is something I answer in the survey. From my my experience when I was at the court is I never thought about how to explain the way I calculate my uncertainties where the uncertainties come from the lawyers the dots, the people there don't want to miss their or set themselves in this forest. No. So yeah, I agree with with E1 h2 is a very, very important point to consider here. Yeah.

Facilitator B 15:57
Let's do it. Number 14. What about number 15?

E2 16:02
15. Yeah. Have we considered A3?

Facilitator B 16:24
No, we haven't

E2 16:25
No. Yeah.

E1 16:27
Yeah.

E2 16:29
Yeah, I put a three in a number lower but here I think is a moment to consider the uncertainty arising from non discriminatory nature of data. If you are in front of the problem with this situation you can't imagine in hypotheses different hypotheses because the data cannot help you in this way. I think could be Then the next one. Yes.

E1 17:02
Yeah, that's right.

E2 17:04
Yep.

Facilitator B 17:05
So that's number 15 Yeah 15. And now,

E1 17:12
the next one I had was an H 3. So m h for hotel. Difficulty drawing meaningful conclusions.

E2 17:22
Hmm. Yeah, yeah.

E1 17:25
You Agree?

E2 17:26
Totally. Yeah.

Facilitator B 17:28
Okay. And 17?

E2 17:49
17? No, we haven't considered B2, lack of theoretical understanding.

Facilitator B 17:56
No, we haven't.

E3 17:58
Yeah,

E1 17:58
yeah. That's fine. Could be back around here.

E2 18:02

Yeah.

Facilitator B 18:07
So b two is 17. Yeah, what's about 18?

E1 18:12
I had B1 after that so the progress in the field

E2 18:18
B1

Facilitator B 18:21
what do you think E2?

E2 18:24
B1 progress in knowledge

E1 18:26
Yeah. Yeah.

E2 18:28
Yeah. I put it like 18 is the next one, right? Yes.

Facilitator B 18:34
The knowledge would be a *.

E2 18:36
Yeah, yeah. Yeah. I put this point. I have here something for 19. I suggest D1, D2.

Facilitator B 18:51
D as in delta.

E2 18:54
Yeah, in Delta in that in 19. Because Well, it's very difficult to make this ranking in some some some some cases, D2 is not exactly the most important thing to consider, but in other problems I could. I may say yes. Oh, we are in number 19. Yeah, so I don't know what E1 really thinks. But I put it here.

E1 19:31
Yeah. I had it at 20 so it's fine.

E2 19:34
20 or 19

Facilitator B 19:37
D2 we agree to be 19

E1 19:39
Yeah.

Facilitator B 19:41
Now we have

E1 19:44
so the one I had was E3, e for Echo, and different understandings of the problem.

E2 19:52
E3 Yeah, I put it as 19 also

Facilitator B 20:01
Okay, so 21

E2 20:05
and 21

Facilitator B 20:08
we're missing h2 h1, h2 h1

E1 20:21
D 3 I think

Facilitator B 20:23
Yeah,

E2 20:25
d3 the integrity of certainty with natural sense of science.

Facilitator B 20:29
Yeah.

E2 20:31
Yeah. 21

Facilitator B 20:33
Okay.

E1 20:36
I then had E2 E for Echo, which was uncertainty rising to descriptions or definitions.

E2 20:42
Yeah 22 I put exactly 22 for this point. Yes.

Facilitator B 20:48
It seems like you talked to each other before

E1 20:53
Similar jobs I think

E2 20:54
I can show you I can see

Facilitator B 21:00
Okay, H1

E2 21:03
23, 23. Yes. Have we lost?

Facilitator B 21:09
We are missing H1

E1 21:14
Count? Yeah, we were short by one or? We got one. We got two with the same number.

Facilitator B 21:24
Did we?

E2 21:29
I put h1 as as the 24th. It was the last one? Yes. But I lost a number. Yeah, we added 23.

Facilitator B 21:45
Let me Yeah, let me double check 1... How come we lost a number? 1, 2, 3, 4... 5, 6, 7, 8, 9, 10...

E1 23:11
what was number four?

Facilitator B 23:12
What was number 4?

E1 23:13
I found it don't worry about it

Facilitator B 23:16
In 18 19 20...I'm not sure what is missing.

E1 23:32
What was the number eight?

Facilitator B 23:33
Number eight,

E2 23:35
f two?

Facilitator B 23:37
Yes, f two. Can we have a 1, a 2, B 3, B, C, one c two, C three...

E2 24:01
Which one

Facilitator B 24:02
okay 1234561 and let's look at page one, two and three. Yeah 23 actually

E1 24:24
I don't have 24

Facilitator B 24:26
you have 24?

E1 24:31
Erm 1, 2, 3...

E3 24:34
I have 24 it's B3 looks to me it must be B3 I think

Facilitator B 24:50
this is 24 Yeah.

E2 24:53
Ah yes could be, B3 have we put any number at B3?

Facilitator B 25:01
B3 is 7

E2 25:03
7?

Facilitator B 25:04
Yeah,

E2 25:05
yeah, yes. What I have

E1 25:08
so which one doesn't have a number?

E2 25:09
So we have two sevens. I found that we have two sevens. f1 I put it as as f1 and b3. I don't know.

Facilitator B 25:22
Yes, yes, you're right.

E1 25:26
How many times does it take to count to 24? Apparently Three

Facilitator B 25:32
Yeah, no, between these two I'm gonna fix them now. between this one and

E1 25:41
the I think f one was the first seven. Yeah, and then B3 was the second seven.

Facilitator B 25:50
Yeah, I'm gonna change everything accordingly. Now.

E1 25:55
This leaves us with the final one is h1 24.

Facilitator B 25:57
Yes, final one is 24.

E1 25:59
Yeah,

Facilitator B 26:00
Sorry about the confusion. I didn't know I didn't I think i'ts time and then we're gonna come back in about 15 minutes I think,

E1 26:14
Okay, do we press leave room?

Facilitator B 26:16
I think is let me double check because I didn't know how to go back to the main I don't have the control to go back to the main room. Would it be easier for you to leave or just to leave your laptop and come back? Maybe it's easier that way. So they have it like this and Nicola will connect us back in 10 minutes. That's easier. Thank you. I will organise this so if you want to take away a toilet and it can get We should go back at 1pm and about seven minutes to the main room.

Round 2 Discussion

Nicola Georgiou 41:00
Hi, I'm E1 will you have to go?

E1 41:09
Oh yeah. Very nice to meet you all but I have to go now,

Nicola Georgiou 41:12
Thank you very much. Have a good rest of your day. Bye

E3 45:19
Nicola Hello.

Nicola Georgiou 45:29
Hi Yeah, I'm just doing the final calculations, find the top 15 and I'll be with you in a minute. Okay, and I've got the results, sorry about the wait. Can you all hear me?

E4 49:07
Yep. Okay, great. So now I'm going to share my screen. And you'll be able to all see the top 15 that came from the voting and the ranking from the two from the two groups. So in the first places, we've got a one, which is the volume of the data and a two, which is the quality of the data, we've got e one in position three e one was uncertainty about how the issue of uncertainty is understood and defined. We've got c one uncertainty arising due to concerns regarding analytical instruments in position 4 C two and uncertainty arising due to the different methods that are being used. f two in position six, which is uncertainty arising due to the difficulty of designing probabilities. In position seven, we've got g two, which is the quality of the expert. In position eight, we've got f one, which is uncertainty around the precision and validity of probabilities. And then we've got B two in position nine. Regarding lack of theoretical understanding. C three in position 10 uncertainty arising from the choice of, or use of relevant, academic, or scientific literature. And then we've got in position 12 H2, which was practical uncertainties around giving evidence and reporting. We've got B3 in position 13 which is limited underpinning science E2 in position 14 uncertainties around the descriptions and the definitions that are being used. And lastly in position 15, we've got g one about the uncertainty arising from the range of expert views. So this is we're now going to enter the second stage. And in this stage, we will try and rank these as a group. Since some of you haven't had the opportunity to talk to one another, then we can all share our views again, about the new ranking. So shall we start From the beginning? How do you see the top five then with the data sources in position one and two, specifically, volume and quality? I think in my group, these appeared quite strongly. I was that something that appeared in with E2 as well?

E2 51:54
I'm sorry, do you do you repeat the question

Nicola Georgiou 51:58
saying that I'm not surprised with a one and a two being the top two because they were in the top priorities in my group. Was that something you saw in your group as well? And would that be something that you agree?

E2 52:12
Or a one on a two? We put it in, in positions two and three.

Nicola Georgiou 52:19
Okay, so you're not that far off. I think the only person that seems to disagree a little bit with this is E3, and maybe we would, perhaps me to see how to either you manage or you want to get your ranking higher up E3, or whether we can all agree to bit of a lower ranking for those. And how do you see the rest of the sources of uncertainty? Anyone wants to say anything about the new list? And

E4 53:05
I think the ranking as it looks now, sort of agreed with what we had discussed as a group.

53:12
And

E4 53:14

probably from my point of view, the introductions are more to do with the C section. f1 to do with analytical instruments precision. Yeah. And the precision validity of the probabilities as well.

Nicola Georgiou 53:32
Yeah. So you your f1 being in the, in the new sort of rankings. I think we hadn't actually discussed that very much in our group, but it seems to have been a quite important aspect for the other group. I see that g three, which was one of the points of debate that we had in our group Facilitator B with the bias and the judgement of forensic science experts, does, must have been a quite important source in your group because it came up to position 11 and E2? Is that something that you agree? Do you find position 11 to be a good position to place G3?

E2 54:18
Now, for G three. We put it in in 14 position. But I think it's in the group of 15 but not upper than 10 Yeah, from 10 to 15. One, one position of them.

Nicola Georgiou 54:37
So you wouldn't place it in the top 10

E2 54:41
in the top 10 No.

54:42
Okay. And since we are in g3, we might as well see if we would like to have it in the final top 10th and so according to E2, it would not be in top 10 How about the rest of you? Would you see it in top 10

E5 54:59
Nicola Can I? Yeah, it the way it looks at the minute, I mean, I would put in the top 10, about half of the ones that are in there. But it looks tracks to me as being a fairly reasonable compromise between what everybody has said. And although there are items at 11 to 15, that I could make an argument for being in the top 10. For my part, I'm fairly certain that the top 10 of that list is a fair reflection of what we all think, is important. And a lot of the ones that I would want to see in the top 10 are in there. And so I'm not going to make a powerful play for the inclusion of anything else above and beyond what's already in there, I suspect.

55:38
Okay, that's great. How about E4 and E3? Would you think that there is anything in the 11-15 that you disagree with and you feel quite strongly about and you would like to see in the top 10

E4 55:54
so I would, I would tend to agree with you know, what, E5 just said, and perhaps the only issue is whether a couple of the areas have a bit of overlap. C one and C Two. So whether different methods used by different examiners are different views offered by different examiners sort of overlapping away, and maybe they don't. Whether that was one of those which

Nicola Georgiou 56:28

which one, C two and

E4 56:30
G one, C two and C two and G one yeah seems to be quite similar sort of thing that conflicts between experts essentially. And whether,

56:45
okay, so g g one is in place 15. So could be merged with C two, actually, and it would make it into the top 10. Yeah, that's a very good point. Anything else? E3 was there is there anything in the bottom 5 that you would like to see in the top 10

E3 57:06
other other points I quite agree with with others. And I am my opinion on some points that are similar and can be grouped under the same type. For example, if you intend volume the data similar to complexity, complexity of data for a sample the point would be two or another one that in this moment I can try. I can find sorry yeah. Yeah, for example, D1 or D2 for me are similar in my field with the concept descriptor from A2, so if you can group this point,so my level go up, and yeah,yes.

Nicola Georgiou 58:34
Like a two, you feel like the quality could be represented by the points that are made in D one and D two. So you would sort of agree with the new ranking.

E3 58:43
Yeah,

58:44
yeah. Okay, that's a very good idea. Thank you. And so we could add here, then a two, D one, D two, and then we said c two that can be grouped with G one and And then we would have D1 leaves from place 15 and we have only four that are out is everyone fine with the four that are at to be left out of the top 15 out of the top 10 So, that is

E3 59:17
Sorry Nicola. Also if you if you advise you to group c one and C two for me are similar also this for example, in my opinion, if I intend two different instruments, like software instruments, you can think also are two different algorithmics or methods for me are a similar similar concept.

59:53
Okay, is that something that everyone else would agree with? Or do you think they should be on different different categories and different rankings

E2 60:03
well in my opinion c one is how to how to how to be the alone I disagree with e3 sorry, but in my opinion the question of the uncertainty that the equipment could offer in the in the method has the big weight than the uncertainty that different methods could suggest? You yeah In my opinion, C1 is the the first uncertainty point. I agree with more or less this, this sort of view you have and but C2 I think, C2 of course have to be in the top 10 meaning that in the top five Of course, in another level than C1.

61:05
Okay, so the way that it is captured right now does capture your opinion. So C one being higher than C two and C two being in the top five, perhaps you would put c one a little bit higher from what I've gathered. Yeah. And would anyone else want to contribute on that?

E3 61:26
Do you do

E4 61:26
I would agree with what was just said.

Nicola Georgiou 61:29
Okay. So see one just being a little bit higher than

E4 61:34
that's in the top five.

61:38
Okay, so it looks like we're pretty much in agreement. I don't think my E3, we're going to go ahead with putting c one c two together, because it looks like people do perceive them differently. And as if they give rise to different sources of uncertainty. And so then, is there any other Do you agree with the way they have been prioritised? And if we are going to focus on the top 10, is there anything that you would like to see higher or lower in this list?

E4 62:12
I the way it is now i i think it looks good. Just looking at the ones that would fall out of the top 10. Yeah. And I do wonder whether like, again, some of those themes could be merged with other themes. And if you wanted to expand them slightly, so I think when we talked about e one and E two, we were sort of talking about the same issue just about understanding and communication. And so maybe those could sort of be put in together. And I think for B three was about really whether it's a junk science or not, And to me, that's quite a black or white question, and it doesn't matter as much as some of the other issues. Perhaps

Nicola Georgiou 62:57
that's be b2 or b

E4 63:01
B 3 for me, it doesn't really matter that it's going away.

Nicola Georgiou 63:06
Okay, that's good. So, we could potentially group e one and E two together. E one just to remind everyone is how the topic of uncertainty is understood and E two is differences and understanding and with regards to descriptions or definitions that are being used, a would that be a good compromise for everyone to sort of bring a two along with IE one to capture this in the top 10.

E2 63:34
Yeah, if you can consider before I saw all these numbers in this table, I thought what could be for me in my experience, what could be the the main problem when I have to, to go against the uncertainty company And personally, I must say, the display of content for the

importance of uncertainty is maybe sometimes laziness when I because because it's very hard to think about the source of uncertainty. And I asked the my colleagues and all of them more and most of them say, well, the calculation of uncertainty is very boring, pretty hard. And please, what it really needs to do, do you really need it? Yes, of course, we are. Forensic science experts. We cannot explain a result without an uncertainty value. What is not a, you can say a measure without the uncertainty even in quality analysis. So I think E, E, E1 is more or less the point that expressed this? How is the uncertainty define it or proceeded for the, for the scientists and for the clients? Ya know our work. So maybe is the hips problems we consider? Yeah, C1 and E1 are or the top one I think is my opinion.

65:36
Okay. How about you Mr. Jarvis, would you say? Do you agree with the ranking of E one and would you like to see it merged with E two

Nicola Georgiou 65:52
I think it's muted and we can't hear you.

E5 65:56
Alright, I'll repeat all of that and I'm happy with where it is, I mean, I think has been some really good input to get the list in the form that it is I, I'd certainly leave a one and a two where they are I think that's where they deserve to be with the others that are there in the top 10. I think there's credible arguments for moving them up and down, but fundamentally, it seems like a pretty decent list at the moment to me.

Nicola Georgiou 66:19
Okay. And I think e two is equally important. And I think there is a case to be made for perhaps putting it with E one, so it makes its way into top 10. E3, I think that's part of what you were also discussing when in our group where you were saying that a lot of the times you have a hard time sort of expressing that uncertainty from a scientific point of view, but in a way that translates well, with lay stakeholders. Correct?

E3 66:52
Yeah, I agree with the other participants that E1 can is Can grouped with the e2. In fact, in my my classification, they are in the top five.

Nicola Georgiou 67:09
Okay. Okay, great. So then I think we are also moving E2 from the ones that were left behind. And I think the only three that if everyone can agree or not as important, then we do have our top 10. And we've got the judgement of experts G3 not making the top 10. We've got H2 which is the practical uncertainties about giving evidence and reporting, also not making the top 10. And we have B3, which is limited underpinning science. Also not making its way into the top 10. Is everyone alright with that?

E2 67:54
Yeah.

Nicola Georgiou 67:55
Okay, so then I suppose we do have our top 10 And any other comments on the top 10 would you like to see them in a different order? Are you okay with the order that it is now? Ah, E2 are you also good with the how it looks top 10?

E2 68:52
Yeah, yeah, no comments.

Nicola Georgiou 68:53
Okay, E5?

E5 68:56
Yeah, no, that seems that seems

Nicola Georgiou 68:59
Okay, perfect. I think I missed you there. Sorry. Could you repeat that? Is it E5 is probably not working E3 Are you? Okay with the top 10?

E3 69:31
Yes, yes, it's okay.

Nicola Georgiou 69:33
Perfect. And let's see, I think I don't know if anyone heard E5 that you say that he was also fine with the top 10. I think we've got some connection issues. But I think we do have our top 10 then. And let's just wait for E5 to reconnect. Yes. Hi.

E5 69:58
Oh, yeah, no, I said Yeah, fine. I'm happy with that.

Nicola Georgiou 70:01
Okay, perfect. Great. So I think we actually have reached a consensus. And I'd like to thank you all for joining. And I'm just going to tell you a little bit about how, what we're going to do with this results. First of all, I'm going to disseminate this to all the participants. Of course, you who have played the most important role, but also the ones that have expressed an interest in the results. And we are also aiming for a journal publication so that we can make these results available to the academic world and inform the kind of research that can be done on how to evaluate and communicate these, and then hopefully treach, the more practitioners as well. We are hoping to publish an article in different format in a magazine to make this more publicly available. And do you have any other questions or anything else you'd like to comment on? Oh, good. Well, thank you all very much for joining. I was pretty nice to meet you all. Thank you so much for your time and input. And I will be in touch soon with a summary of what we discussed. And the

E2 71:18
Thank you. Thank you very much Nicola for invited us back to me through the survey, but to participate in this season, and look forward, looking forward for the conclusions and results.

Nicola Georgiou 71:33
Perfect. Thank you so much. I really appreciate your opinions and your time. Okay, good rest of your day everyone. And bye.

Appendix F: Comment Report from open-ended questions of survey

The following link provides access to the comment report that collates all the responses of participants to the open-ended questions of the interim priority setting exercise (Opinio survey): https://drive.google.com/drive/folders/1cEQ_w7pMssKGMYaeuTPhcIZhR4L9d7I9?usp=sharing

Appendix G: Publication

Chapter 5 of this thesis was published in April 2020 in the journal of Science & Justice. The following link provides access to the publication:
https://www.sciencedirect.com/science/article/abs/pii/S1355030620300046