Best Practice Recommendations for Evaluative Forensic DNA Testimony

Human Forensic Biology Subcommittee
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Foreword

This document provides guidelines for best testimony practices in Forensic Biology. Its aim is to present recommendations based on a recognized framework for casework assessment and interpretation (CAI) [Cook et al., 1998 CAI], which ensures the following desired qualities [ENFSI Guidelines 2015, Assoc. For. Sci. Providers 2009]:

- Balance: The consideration of at least two propositions on the key issues and establishing the relevant background information as it relates to each proposition, as understood by the expert, avoids the evaluation to be one-sided (i.e., only taking into account one party's views) or biased.
- Logic: The assessment of the probability of the evidence given each proposition and the relevant background information prevents the expert from making statements about the probabilities of the propositions which would be usurping the role of the judge or jury.
- Robustness: The use of sound knowledge, accepted tests and examinations, verified databases, and applicable published studies increases the quality of the expert's testimony.
- Transparency: The application of a recognized framework in the expert's case notes will show the foundation and thought process used so that the expert will be able to demonstrate how the opinion was developed.

This framework promotes a logical approach for evaluating the forensic scientist's findings, and is based on the Four Principles of Evidence Evaluation [Evett and Weir, 1998, Evett 2015]:

1. To evaluate the uncertainty of any given proposition, it is necessary to also consider at least one alternate proposition (i.e., propositions are dealt with in pairs).
2. Scientific evaluation of the evidence is based on the question 'What is the probability of observing the evidence if the proposition were true?' for each of the competing propositions. In mathematical terms, this is written as Pr(E|H), where Pr is "probability", E is "evidence", | is "given", and H is the proposition.
3. Scientific evaluation of the evidence depends not only on each of the competing propositions, but also on the framework of case circumstances within which the evidence is to be evaluated. This expands the probabilities to Pr(E|H,I), where I is the relevant case-specific information.

It is logically meaningless to suggest that any evidence has value in itself as support for any particular proposition in isolation. Its value depends entirely upon its ability to discriminate between one proposition and an alternative proposition. This leads us to the fourth principle [Evett 2015]:

4. The value of the evidence is the ratio of two probabilities of the evidence given each of two alternate propositions within the case context. Mathematically, this will read:

$$\frac{Pr(E|H_1, I)}{Pr(E|H_2, I)}$$

and is termed the Likelihood Ratio or LR.

The scientist is the best person to help the jury understand the evidence by performing this task, given their insight into the issues at hand. Transferring these responsibilities to the jury or Court increases the risks of misunderstanding and for inappropriate conclusions to be made.

Application of the approach in the witness box requires a working knowledge of the four principles and a robust and educated response to questions so that the value of the evidence is conveyed in a balanced, fair and meaningful way, and inappropriate questions, such as "Is XX possible?", are effectively rebutted. Any comment on XX by the expert is a comment on the ultimate issue, and that is reserved for the jury.

This document is organized according to the Hierarchy of Propositions framework, which consists of the following levels: sub-sub-source, sub-source, source, activity, and crime or offence level [Cook et al., 1998 hierarchy, Evett et al., 2002, Gittelson et al., 2016]. As the expert's evaluation moves up the hierarchy of propositions (e.g., from sub-source to activity), the expert is communicating more expert knowledge of relevance to the court. In order to do this effectively, the scientist will incorporate data or personal knowledge, for example regarding body fluid attribution, DNA transfer and persistence and background levels of DNA as well as contamination—different levels in the hierarchy require considering separate factors and data. It is appropriate for the scientists to assist, where possible, in this way because the decision maker at court (jury or sometimes judge) does not have this specialized knowledge.

A high priority for this subcommittee was to include explicit guidance for testimony with regard to activity level propositions; that is, testimony that considers factors such as DNA transfer, persistence, and recovery. This is an area for which no real guidance currently exists in the United States. In cases where the activity is the issue, scientists will assess the value of the results (i.e., assign the probability of the results) given at least two competing propositions. We recognize that best practice would be to include the evaluation of DNA evidence given activity level propositions in the initial laboratory report. However, currently very few laboratories are doing this, yet questions regarding activity level propositions show up routinely in trials. The goal of this document is to address this immediate need for testimony guidance.

This document will not address offence level propositions in any fashion, as it is rare for forensic scientists to add value by the use of their specialized knowledge when considering this level of propositions.

The Recommendations (Section 4) are presented in four subsections:

4.1. Communication of results given sub-sub-source level propositions
4.2. Communication of results given sub-source level propositions
4.3. Communication of results given source level propositions
4.4. Communication of results given activity level propositions.

Each of these subsections was written to provide a complete, standalone list of recommendations for the given level, so that each one can be read by itself without reference to the other subsections.

The adherence to these guidelines will ensure that the forensic scientist's testimony is logically and scientifically sound without usurping the role of the judge or jury. Adopting them will improve the quality, accuracy and consistency of communicating results across practitioners, and lead to an increase in quality by providing added value to the Court. The document provides the theoretical background behind

the approach, real world guidelines for best testimony practices, and some working examples of how this might be applied. The practice could also be applied to statement writing.

All hyperlinks and web addresses shown in this document are current as of the publication date of this standard.

Keywords: *forensic DNA testimony, communication, likelihood ratio, activity level, hierarchy of propositions*

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1 Scope

This document describes best practices for the communication of biological results and opinions in the field of Forensic Biology. It addresses testimony given sub-sub-source, sub-source, source, and activity level propositions. This document will not consider the highest level of the Hierarchy of Propositions (crime level).

This document does not give guidance on how to obtain findings (DNA results/statistics) or form opinions (how or when to have an opinion that evidence supports a proposition or that the findings are neutral for a given pair of propositions). Rather, the purpose is to focus on best practices for the communication of findings and opinions in the role of an expert witness.

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3 Terms and Definitions

Bayesian/logical framework

A framework based on (the odds form of) Bayes' Theorem, which is a mathematical idealization of the belief about a set of propositions is updated based on the (value of the) evidence. This is a framework used to evaluate evidence or results given two different propositions summarizing the point of view of the parties as understood in the case. The value of the evidence is given by the expert in the form of a Likelihood Ratio (LR). The focus of the LR is always on the evidence, not on the proposition. The value of evidence (LR) presented by the expert can then be combined with the other non-expert evidence to update the decision maker's beliefs in the proposition. The odds form of Bayes' theorem is:

$$\underbrace{\frac{Pr(H_1|E,I)}{Pr(H_2|E,I)}}_{\text{Posterior odds}} = \underbrace{\frac{Pr(E|H_1,I)}{Pr(E|H_2,I)}}_{\text{Likelihood Ratio}} \times \underbrace{\frac{Pr(H_1|I)}{Pr(H_2|I)}}_{\text{Prior odds}}$$

Bayesian Networks

Bayesian Networks are a marriage between graph theory and probability theory. They provide a tool for describing (potentially complex) dependencies between variables whose value is uncertain; thus may be used to calculate an LR given activity level propositions.

Case Assessment and Interpretation (CAI) model

The CAI model is a framework for structuring forensic examinations and reporting results. It allows scientists to formulate examination strategies, record their expectations of the probability of various outcomes prior to analysis, and then compare the expected and observed results. The process of assigning probabilities given the activities before knowing the results ensures that scientists are not influenced by what they have obtained (i.e., avoiding post hoc rationalization).

Explanation
In the context of a forensic science evaluation, explanations are generated after the forensic findings have been obtained. While an explanation has the potential to account for particular observations, it does not qualify as a formal proposition because - often - it may be a statement of the obvious, speculative, or fanciful.

Hierarchy of propositions
The Hierarchy of propositions is a framework to help address different questions of relevance to the trier of fact. In the context of criminal proceedings, propositions can be classified into broad categories (or, hierarchical levels):

- 'sub-sub-source level'[1] for propositions about the source (i.e., person) of a part (i.e., major or minor contribution) of the DNA profile.
- 'sub-source level'[2] for propositions about the source (i.e., person) of the DNA
- 'source level' for propositions about the source (i.e., person or item) from which the trace material originated (e.g., propositions addressing who is the source of the body fluid)
- 'activity level' for propositions about an activity or a happening (e.g., propositions addressing how or when the DNA was transferred)
- 'offence level' for propositions that refer to the commission of a criminal offence

Likelihood ratio (LR)
In the context of evidence interpretation: The probability of the evidence under one proposition divided by the probability of the evidence under an alternative, mutually exclusive proposition. The magnitude of its value expresses the weight of the evidence.

Note: The likelihood ratio can be numerical or qualitative (especially for LR given activity level propositions). While the individual probabilities associated with the evidence given each proposition are useful, the full value of the LR comes from comparing the probabilities of the results given different propositions, because the value of the results depends entirely upon its ability to discriminate between one proposition and another.

Nature of the biological fluid
The question regarding the type of material (e.g., blood, semen, saliva) will be defined as questions about the nature of the material. Source questions will be defined as questions regarding from which person the body material/DNA came from.

Possible
Any non-zero probability. There is no distinction between high or low probability when using possible in relation to opinion testimony. The fact that something (i.e. the evidentiary result) is "possible" is not useful in determining whether or not the evidence supports one proposition or another. It is always desirable to put things in terms of probability, and best to compare probabilities of the findings given two competing propositions.

Posterior probability
In the Bayesian framework, this is the jury's probability of the propositions taking into account all the elements of the case, including the forensic results presented by the expert (e.g., the DNA evidence).

[1] sub-sub-source only has relevance or meaning in the interpretation of DNA mixture evidence.
[2] sub-source only has relevance or meaning in the interpretation of DNA evidence.

Prior probability
In the Bayesian framework, this is the jury's probability of the propositions taking into account all the elements of the case, excluding the forensic results presented by the expert (e.g., the DNA evidence).

Probability
Probability is a measurement device for uncertainty. In the Bayesian framework, it serves the purpose of expressing an individual's personal degree of beliefs about uncertain propositions conditional on the status of information of the subject who assesses it. Probability informed by relevant/appropriate data (e.g., scientific publications, in-house experiments, experience, or knowledge). Probability is governed by several axiomatic laws that constitute a fundamental framework for inductive logic. There are several schools of thought on the definition of probability; however, it is important to understand that the laws of probabilities hold, regardless of the definition.

Propositions
Propositions are statements that are either true or false, and that can be affirmed or denied. There is no requirement that any proposition must be "true" for assigning an LR. Propositions should be formulated in pairs (e.g., views put forward by the parties to the cases) given a background of task-relevant case information and assumptions. Propositions should be amenable to a reasoned assignment of credibility by a judicial body. A basic criterion for propositions is that they should be formulated in such a way that it is reasonable for the scientist to address a question of the form: 'what is the probability of the observations given this proposition within the framework of circumstances?'
Propositions should be distinguished from explanations that do not have the aforementioned properties. Propositions should be based on case information and the issue where forensic science can help, not on the biological results.

Transfer and persistence
Transfer is the mechanism that allows the movement of evidence (e.g. DNA) from its origin (source) to wherever it is recovered in the context of the case (e.g., primary, secondary).
Persistence pertains to the ability of the material to remain where it was deposited prior to its recovery by the forensic scientist. However, often the probability of recovery given the evidence was transferred and persisted is of more relevance. This is critical for any discussion in the context of activity level of propositions.

Transposed conditional
In forensic science this often refers to any statement from the scientist about the probability of the proposition given the evidence (incorrect) rather than the probability of the evidence given the proposition (correct). Formally, this is stating the probability of A given B (i.e., Pr(A|B)) as the probability of B given A (i.e., Pr(B|A)), or vice versa. This is commonly referred to as the "prosecutor's fallacy".

4. Recommendations

4.1 Communication of results given sub-sub-source level propositions

4.1.2. The expert should not communicate at this level if the person who is the source of this DNA is not the issue of interest to the court or/and if the issue is the activity that led to the DNA.

4.1.3 The use of the terms specific to this level, such as "major contributor" and "minor contributor", should be defined by laboratory protocols.

4.1.4 It is recommended to reserve the use of "major" and "minor" terms for cases where the issue of interest may move to the activity level.

4.1.5 The expert should follow the four principles of evidence evaluation [Evett and Weir 1998, Evett 2015]:

4.1.5.1 The expert should take into consideration at least one alternative proposition, so that the evaluation considers a pair of propositions.

4.1.5.2 The expert should only make statements about the probability of the evidence given a proposition [Thompson and Schumann, 1987]. The expert must avoid making any statement about the probability of a proposition given the evidence (i.e., transposing the conditional) [Aitken et al., 2010, ENFSI Guidelines 2015, Evett 1995, Robertson et al., 2016, Evett and Weir, 1998, Evett 2015, Assoc. For. Sci. Providers 2009]. Equally, the expert must avoid giving any statement on the probabilities of the propositions themselves.

4.1.5.2.1 The expert should be aware that most hypothetical questions are asking for an opinion about the proposition (or explanation), not about the evidence.

4.1.5.2.2 The expert must avoid transposing a conditional when answering direct questions from one of the parties as well as when considering both propositions.

4.1.5.3 The evaluation should take place in a framework of task-relevant case circumstances. This means that the probabilities are conditional upon the information and data specific to the specimen/case [ENFSI Guidelines 2015, Evett and Weir 1998, Evett 2015, Robertson et al., 2016, Gill et al., 2020].

4.1.5.3.1 Information should be directly task-relevant to the evaluation of the evidence [Evett and Weir, 1998, Evett 2015, National Commission on Forensic Science].

4.1.5.3.2 The information relied upon to form the opinion of the expert should be disclosed and clearly communicated.

4.1.5.4. Probabilities of the evidence given a proposition should be evaluated in pairs (i.e., the probability of the evidence given the main proposition and the probability of the evidence given the alternative proposition) in order to give a likelihood ratio (LR). This ratio is the value of the forensic results and expresses the strength of the evidence [ENFSI Guidelines 2015, Evett and Weir 1998, Gill et al., 2020, Evett 2015, Robertson et al., 2016, Aitken et al., 2010].

4.1.6 Probabilities and ratios of probabilities should be used when communicating the value of the evidence [ENFSI Guidelines 2015, Evett and Weir 1998, Assoc. For. Sci. Providers 2009, Aitken et al., 2010, Evett 2015, Robertson et al., 2016, Gill et al., 2020].

4.1.6.1 These probabilities may be explicitly calculated (e.g., published model for genotype probabilities) or they may be assigned notional (personal) probabilities based on published research data, data derived from internal laboratory studies and/or from casework experience (e.g., any published research data on transfer and persistence studies used to inform the expert opinion in a case) [Assoc. For. Sci. Providers 2009, ENFSI Guidelines 2015, Taroni 2018].

4.1.6.2 The LR may be communicated numerically (1 million times more likely) or using a qualitative verbal statement (much more likely, somewhat more likely) after assignment of the numerical LR [ENFSI Guidelines 2015, Assoc. For. Sci. Providers 2009, Gill et al., 2020].

4.2 Communication of results given sub-source level propositions

4.2.1 The expert should use caution when communicating at this level if the POI agrees it is their DNA, such as in a question of consent, or if the source of the DNA is not disputed (as there is only one proposition and not two). If the person from whom the DNA originated is not contested, then there is no uncertainty on who is the source of the DNA, thus the calculation given sub-source level propositions is not meaningful. A sub-source statistic could easily be misunderstood in the context of the activities [Gill et al., 2020, ENFSI Guidelines 2015, Robertson et al., 2016].

4.2.2 The expert should follow the four principles of evidence evaluation [Evett and Weir 1998, Evett 2015]:

4.2.2.1 The expert should take into consideration at least one alternative proposition, so that the evaluation considers a pair of propositions.

4.2.2.2 The expert should only make statements about the probability of the evidence given a proposition [Thompson and Schumann, 1987]. The expert must avoid making any statement about the probability of a proposition given the evidence (i.e., transposing the conditional) [Aitken et al., 2010, ENFSI Guidelines 2015, Evett 1995, Robertson et al., 2016, Evett and Weir, 1998, Evett 2015, Assoc. For. Sci. Providers 2009]. Equally, the expert must avoid giving any statement on the probabilities of the propositions themselves.

4.2.2.2.1 The expert should not make any statement about the POI being the source of the DNA unless or until the source of the DNA is no longer in dispute.

4.2.2.2.2 The expert should be aware that most hypothetical questions are asking for an opinion about the proposition (or explanation), not about the evidence.

4.2.2.2.3 The expert must avoid transposing a conditional when answering direct questions from one of the parties as well as when considering both propositions.

4.2.2.3 The evaluation should take place in a framework of task-relevant case circumstances. This means that the probabilities are conditional upon the information and data specific to the specimen/case [ENFSI Guidelines 2015, Evett and Weir 1998, Evett 2015, Robertson et al., 2016, Gill et al., 2020].

4.2.2.3.1 Information should be directly task-relevant to the evaluation of the evidence [Evett and Weir, 1998, Evett 2015, National Commission on Forensic Science].

4.2.2.3.2 The information relied upon to form the opinion of the expert should be disclosed and clearly communicated.

4.2.2.4. Probabilities of the evidence given a proposition should be evaluated in pairs (i.e., the probability of the evidence given the main proposition and the probability of the evidence given the alternative proposition) in order to give a likelihood ratio (LR). This ratio is the value of the forensic results and expresses the strength of the evidence [ENFSI Guidelines 2015, Evett and Weir 1998, Gill et al., 2020, Evett 2015, Robertson et al., 2016, Aitken et al., 2010].

4.2.3 Probabilities and ratios of probabilities should be used when communicating the value of the evidence [ENFSI Guidelines 2015, Evett and Weir 1998, Assoc. For. Sci. Providers 2009, Aitken et al., 2010, Evett 2015, Robertson et al., 2016, Gill et al., 2020].

4.2.3.1 These probabilities may be explicitly calculated (e.g., published model for genotype probabilities) or they may be assigned notional (personal) probabilities based on published research data, data derived from internal laboratory studies and/or from casework experience (e.g., any published research data on transfer and persistence studies used to inform the expert opinion in a case) [Assoc. For. Sci. Providers 2009, ENFSI Guidelines 2015, Taroni 2018].

4.2.3.2 An RMP should be expressed as a probability. In practical terms, this probability communicates the rarity of an event.

4.2.3.3 The LR may be communicated numerically (1 million times more likely) or using a qualitative verbal statement (much more likely, somewhat more likely) after assignment of the numerical LR [ENFSI Guidelines 2015, Assoc. For. Sci. Providers 2009, Gill et al., 2020].

4.3 Communication of results given source level propositions

4.3.1 These propositions are adequate if there is no issue about the nature of the biological material, (i.e., not disputed) or if the substrate is obvious (e.g., hair root, tooth, bone) [Evett et al., 2002, Gill et al., 2020].

4.3.2 The assumption that the nature of the material is either known or not in dispute (e.g., the DNA came from the blood) and its scientific basis need to be disclosed. This should be framed as an expert opinion given the presumptive nature of many body fluid tests (e.g., serology, mRNA, appearance, case information).

4.3.3 When there is uncertainty about the nature of the biological material, no definitive statements should be used. In these circumstances it would be inappropriate to use source level propositions. Depending on the issue, sub-source or activity level propositions should be used.

4.3.3.1 Probabilities or ratios of probabilities may be used to communicate the serology findings. This is an independent exercise and will not alter the LR given sub-source level propositions. It would be a process by which the expert is able to convey their confidence regarding the likely biological material tested given all of the laboratory tests available to them.

4.3.3.1.1 The expert should be transparent in this opinion. When the expert has an opinion based on that "testing, the expert should assertively state this opinion, as this opinion will most likely be required to move to higher levels of the hierarchy of propositions.

4.3.3.2 When uncertainty precludes the expert from an opinion that distinguishes among body (fluid) sources, the expert may still answer inquiries about other levels of the hierarchy but must be transparent with the limitations due to the uncertainty in body source identification.

4.3.4 Depending on the case, when a mixed DNA profile is obtained, assigning a person's DNA to a particular fluid may become difficult. Considerations must also be made for mixed biological material (e.g., semen and saliva).

4.3.5 If the nature of the biological material (i.e., specific biological fluid(s)) is of interest to the court, the expert should not communicate only the value of the DNA profile comparisons (sub-source level propositions). This avoids the translation of the LR given sub-source propositions to that of a higher level. It would be incorrect to apply an LR of 1 million given sub-source propositions to the LR consisting of the probability of the evidence if it is blood divided by the probability of the evidence if it is some other biological material.

4.3.6 If the issue of interest to the court regards the nature of the biological material, activity level propositions are generally more suited as they also account for presence of this material for reasons unconnected to the facts in dispute.

4.3.7 The expert should follow the four principles of evidence evaluation [Evett and Weir 1998, Evett 2015]:

4.3.7.1 The expert should take into consideration at least one alternative proposition, so that the evaluation considers a pair of propositions.

4.3.7.2 The expert should only make statements about the probability of the evidence given a proposition [Thompson and Schumann, 1987]. The expert must avoid making any statement about the probability of a proposition given the evidence (i.e., transposing the conditional) [Aitken et al., 2010, ENFSI Guidelines 2015, Evett 1995, Robertson et al., 2016, Evett and Weir, 1998, Evett 2015, Assoc. For. Sci. Providers 2009]. Equally, the expert must avoid giving any statement on the probabilities of the propositions themselves.

4.3.7.2.1 The expert should be aware that most hypothetical questions are asking for an opinion about the proposition (or explanation), not about the evidence.

4.3.7.2.2 The expert must avoid transposing a conditional when answering direct questions from one of the parties as well as when considering both propositions.

4.3.7.3 The evaluation should take place in a framework of task-relevant case circumstances. This means that the probabilities are conditional upon the information and data specific to the specimen/case [ENFSI Guidelines 2015, Evett and Weir 1998, Evett 2015, Robertson et al., 2016, Gill et al., 2020].

4.3.7.3.1 Information should be directly task-relevant to the evaluation of the evidence [Evett and Weir, 1998, Evett 2015, National Commission on Forensic Science].

4.3.7.3.2 The information relied upon to form the opinion of the expert should be disclosed and clearly communicated.

4.3.7.4. Probabilities of the evidence given a proposition should be evaluated in pairs (i.e., the probability of the evidence given the main proposition and the probability of the evidence given the alternative proposition) in order to give a likelihood ratio (LR). This ratio is the value of the forensic results and expresses the strength of the evidence [ENFSI Guidelines 2015, Evett and Weir 1998, Gill et al., 2020, Evett 2015, Robertson et al., 2016, Aitken et al., 2010].

4.3.8 Probabilities and ratios of probabilities should be used when communicating the value of the evidence [ENFSI Guidelines 2015, Evett and Weir 1998, Assoc. For. Sci. Providers 2009, Aitken et al., 2010, Evett 2015, Robertson et al., 2016, Gill et al., 2020].

4.3.8.1 These probabilities may be explicitly calculated (e.g., published model for genotype probabilities) or they may be assigned notional (personal) probabilities based on published research data, data derived from internal laboratory studies and/or from casework experience (e.g., any published research data on transfer and persistence studies used to inform the expert opinion in a case) [Assoc. For. Sci. Providers 2009, ENFSI Guidelines 2015, Taroni 2018].

4.3.8.2 The LR may be communicated numerically (1 million times more likely) or using a qualitative verbal statement (much more likely, somewhat more likely) after assignment of the numerical LR [ENFSI Guidelines 2015, Assoc. For. Sci. Providers 2009, Gill et al., 2020].

4.4 Communication of results given activity level propositions

4.4.1 Laboratories should establish policies regarding testimony given activity level propositions when this is of interest to the court. It is best to have previously reported any relevant opinions in writing as well, however guidance on the determination and reporting of these opinions is outside the scope of this document.

4.4.2 The expert should follow the four principles of evidence evaluation [Evett and Weir 1998, Evett 2015]:

4.4.2.1 The expert should take into consideration at least one alternative proposition, so that the evaluation considers a pair of propositions.

4.4.2.1.1 Propositions should be based on case information and the issue where forensic science can help, not on the biological results [Evett et al., 2000, Gill et al., 2020].

4.4.2.1.2 Propositions are best formulated prior to the start of examination based on the information available at that time [Evett et al., 2000, Gittelson et al., 2016, Gill et al., 2020].

4.4.2.1.2.1 At a minimum, the expert should record their expectations of results if each of the propositions were true based on the available relevant case information.

4.4.2.1.2.2 Tools such as the CAI framework [Cook et al. (1998) CAI paper] and/or Bayesian networks may be useful in communicating the thought process that leads to the expert's statement [Gill et al., 2020].

4.4.2.1.3 The expert needs to be aware of the various transfer steps that may occur as a part of an activity proposition (e.g., primary, secondary). However, transfer in and of itself is not an activity, and the term "transfer" should not be a part of the proposition.

4.4.2.1.4 One proposition should align with the prosecution's version of events.

4.4.2.1.5 The alternative proposition should represent an alternative version of events as understood by the expert.

4.4.2.1.5.1 In an adversarial judicial system, the defense is not required to offer any information or theory of the case. The expert should always keep this in mind, especially when the questions regard the activity that led to the presence of the DNA.

4.4.2.1.5.2 When no specific alternative is available from the defense, the expert should adopt a reasonable proxy proposition based on the case information in order to fully evaluate the evidence [Gittelson et al., 2016, ENFSI Guidelines 2015, Assoc. For. Sci. Providers 2009].

4.4.2.1.6 The expert should communicate that if a proposition(s) changes, the value of the evidence will change [ENFSI Guidelines 2015]. If the change of a proposition has a large effect on the LR, such as the evidence now has an LR of 1, it is crucial that the expert makes this known to the court.

4.4.2.2 The expert should only make statements about the probability of the evidence given a proposition [Thompson and Schumann, 1987]. The expert must avoid making any statement about the probability of a proposition given the evidence (i.e., transposing the conditional) [Aitken et al., 2010, ENFSI Guidelines 2015, Evett 1995, Robertson et al., 2016, Evett and Weir, 1998, Evett 2015, Assoc. For. Sci. Providers 2009]. Equally, the expert must avoid giving any statement on the probabilities of the propositions themselves.

4.4.2.2.1The expert should be aware that most hypothetical questions are asking for an opinion about the proposition (or explanation), not about the evidence.

4.4.2.2.2 The expert must avoid transposing a conditional when answering direct questions from one of the parties as well as when considering both propositions.

4.4.2.3 The evaluation should take place in a framework of task-relevant case circumstances. This means that the probabilities are conditional upon the information and data specific to the specimen/case [ENFSI Guidelines 2015, Evett and Weir 1998, Evett 2015, Robertson et al., 2016, Gill et al., 2020].

4.4.2.3.1 Information should be directly task-relevant to the evaluation of the evidence [Evett and Weir, 1998, Evett 2015, National Commission on Forensic Science]. In this case, this means that the expert should only consider information that is relevant to the evaluation of the evidence given activity level propositions.

4.4.2.3.2 The information relied upon to form the opinion of the expert should be disclosed and clearly communicated.

4.4.2.4. Probabilities of the evidence given a proposition should be evaluated in pairs (i.e., the probability of the evidence given the main proposition and the probability of the evidence given the alternative proposition) in order to give a likelihood ratio (LR). This ratio is the value of the forensic results and expresses the strength of the evidence [ENFSI Guidelines 2015, Evett and Weir 1998, Gill et al., 2020, Evett 2015, Robertson et al., 2016, Aitken et al., 2010].

4.4.3 Probabilities and ratios of probabilities should be used when communicating the value of the evidence [ENFSI Guidelines 2015, Evett and Weir 1998, Assoc. For. Sci. Providers 2009, Aitken et al., 2010, Evett 2015, Robertson et al., 2016, Gill et al., 2020].

4.4.3.1 These probabilities may be explicitly calculated (e.g., published model for genotype probabilities) or they may be assigned notional (personal) probabilities based on published research data, data derived from internal laboratory studies and/or from casework experience (e.g., any published research data on transfer and persistence studies used to inform the expert opinion in a case) [Assoc. For. Sci. Providers 2009, ENFSI Guidelines 2015, Taroni 2018].

4.4.3.2 The LR may be communicated numerically (1 million times more likely) or using a qualitative verbal statement (much more likely, somewhat more likely) after assignment of the numerical LR [ENFSI Guidelines 2015, Assoc. For. Sci. Providers 2009, Gill et al., 2020].

4.4.4 Hypothetical questions are often posed in court. The expert should consider/remember the following when choosing how to answer these questions.

4.4.4.1 A hypothetical question is often findings-based rather than case-information based. However, in the absence of any other proposition, it may be reasonable to adopt this scenario as one of the propositions for the likelihood ratio.

4.4.4.2 If a hypothetical question is posed in the form of "Is this possible?", the expert should communicate that the value of evidence is based on comparing probabilities of the results given competing propositions and not possibilities, and then give an answer in terms of relative probabilities. [Aitken et al., 2010, Evett 2015].

4.4.4.3 The expert should be cautious of hypothetical questions asking for the expert to provide an alternative explanation of the data (i.e., speculation) or making a comment on the probability of the hypothetical (proxy) proposition (i.e, transposing the conditional).

4.4.4.3.1 The expert must avoid giving any opinion on the probability of the activity. In this context, the term "activity" may include questions about direct/indirect transfer or about the same activities at different times [Gill et al., 2020].

4.4.4.4 If the hypothetical question is based on case information, the expert should try to give the value of the evidence given that new proposition. However, there may be propositions (hypothetical questions) where the expert has no information that informs an opinion about the value of the evidence. The expert should communicate that he/she is unable to form an opinion about the value of the evidence given that set of propositions or request additional time to properly consider it.

4.4.4.5 The expert should be prepared for multiple hypothetical questions.

Annex A
Recommendations – Supporting Information

4.1 Sub-sub-source level propositions address "Who is the major or minor contributor?". An example of a sub-sub-source proposition pair would be: "Mr. A is the major contributor to the DNA mixture" and "some unknown person is the major contributor to the DNA mixture".

4.1.4 The terms "major" and "minor" may translate into issues of activity rather than who contributed the most/least DNA. Consider a digital penetration case where a major female profile and a minor male profile is obtained from the male suspect finger swabs. The finding of a major female profile could be considered strong support if digital penetration occurred rather than casual contact. In this circumstance, the expert should keep in mind that this information is useful for discriminating activity level propositions rather than only for discriminating sub-sub-source level propositions. A sub-sub-source level evaluation leaves the jury the task of evaluating the evidence (i.e., the major profile) without proper guidance unless the expert also evaluates the evidence using activity level propositions.

4.1.5.1 It is logically meaningless to suggest that any evidence has value in itself as support for any particular proposition in isolation. The value of the evidence depends entirely upon the ability to discriminate between one proposition and another. Therefore, the expert should evaluate the evidence given at least two different mutually exclusive propositions that are exhaustive in the context of the case. The propositions should be based on task-relevant information such as timelines, alleged activities, and characteristics of the stain/targeted area. Task-relevant information does not include information such as prior convictions or allegations, and evidence from other forensic disciplines.

4.1.5.2 The transposed conditional is any statement by the expert about the probability of the proposition (disputed fact) given the evidence rather than the probability of the evidence, or findings, given the proposition. Other terms for this include the prosecutor's fallacy, source probability error, the ultimate issue fallacy, and the false positive fallacy. The transposed conditional can occur when considering one

probability or the ratio of two probabilities. Mathematically, the transposed conditional involves making statements about Pr(H | E) rather than Pr(E | H). Equally problematic are statements regarding the probability of the proposition. That is, statements about Pr(H) rather than statements about Pr(E|H).

Examples of the transposed conditional include:

A. "It is 800 billion times more likely that the DNA originated from Suspect than from an unknown individual."
B. "Given these results (suspect's matching the major DNA profile on the knife) my opinion is that shaking hands is unlikely."
C. "It is unlikely that shaking hands placed the suspect's DNA on the knife."
D. "There is only a 1 in 1 million chance that someone else is the source of the DNA profile."
E. "Based on the scientific results, the biological material is probably blood."
F. "Given the results of the presumptive test, it is unlikely that this DNA was deposited one year ago."

An example of an ambiguous statement would be:

G. "Shaking hands is unlikely to result in the suspect's DNA on the knife."

The corrected statements would be:

A. The **DNA profile** is 800 billion times more likely **if** the DNA originated from Suspect **than if** it originated from an unknown individual.
B. The **DNA profile** is less likely **if** the suspect had shaken hands with the true offender **than if** the suspect held the knife.
C. The presence of the DNA on the knife (that matches the profile of the suspect) is less likely **if** the suspect had shaken hands with the true offender **than if** the suspect held the knife.
D. The probability of the evidence is 1 in 1 million **if** someone unrelated to the suspect is the source of the DNA.
E. The scientific results are more likely **if** the biological material is blood **than if** the biological material originated from some other body fluid or tissue.
F. The results of the presumptive test are unlikely **if** the DNA was deposited one year ago.
G. The presence of the DNA on the knife (that matches the profile of the suspect) is less likely **if** the suspect had shaken hands with the true offender **than if** the suspect held the knife.

Another correct phrasing is: "The evidence strongly supports the hypothesis that the stain came from Smith", which is cited in [Evett 1995] and further explained: "The use of the word 'supports' in this context was proposed by an eminent statistician, H. Jeffreys, and this kind of formulation is, in the author's opinion, the best available. This is the method which is recommended to scientists within the Forensic Science Service. Although it successfully conveys the impression that the evidence favors one hypothesis over the other it is not a probability statement. The strength of the support is based on the likelihood ratio but the overall probability (or odds) in favor of the hypothesis depends also on the other evidence."

4.1.5.3 There is no standard general probability that applies to all cases alike. Each forensic case has unique surrounding circumstances (information) and data (analytical results). Therefore, probabilities will differ from one case/sample to another. This is an expected property of probability.

4.1.6 Few results in forensic DNA analysis can be communicated in absolute terms. For example, if a large number of sperm is observed microscopically, this might be considered an unambiguous result as to the presence of semen. However, there may be some level of uncertainty in forensic DNA casework, such as a presumptive test for blood, a low-level partial DNA profile (or component of a DNA mixture), or

questions about activity, transfer, and persistence of DNA. When uncertainty is present, the use of probabilities is the preferred way to evaluate evidence.

4.1.6.1 If sufficient relevant research exists, it is possible to assign numerical values for these probabilities based on these data and the expert's knowledge. However, in many situations the scientists will have to assign a range of notional (personal) probabilities, in the range of 0 to 1. These can also be expressed in a range of verbal terms such as: 'very low, low, medium, high, very high' to convey the probability. Notional probabilities can be based on expectations derived from data and/or from casework experience.

An example of a calculated LR given sub-source propositions is "the DNA profile is 1 million times more likely if it originated from the person of interest than if it originated from an unrelated individual." Here, the probability of the numerator ($Pr(E|H_p,I)$) is calculated separately from the probability of the denominator ($Pr(E|H_d,I)$), and the ratio of the two probabilities is presented as the LR. A desirable quality of this framework is that different models and allele probabilities produce different values, so this calculation can be specific to a particular case by choosing the most suitable model (e.g., accounting for subpopulations) and allele probabilities (e.g., representative of the population in the geographical location of interest) for that case.

An example of a notional LR given activity level propositions is "in my opinion, the evidence (i.e., full single DNA profile matching Mr. A that was obtained from the steering wheel) is more likely if Mr. A drove the car rather than if he shook hands with the car owner/driver two weeks ago." (Note that the choice of calculating a numerical value or presenting a verbal result is acceptable for this example.) At times, there may be studies (published or internal) available to inform the probability to some degree. However, each forensic case is unique, and laboratory studies that are repeated under controlled conditions may have little to do with the circumstances of a given case. In such cases, the probability of outcomes from studies (typically, frequencies) will need to be modified by the expert to fit the circumstances of the cases. As mentioned in the Supreme Court decision *Daubert v Dow Pharmaceuticals [509 U.S. 579 (1993)]*, the court is aware that sometimes there are no studies available for the expert to use when assigning probabilities:

> "Some propositions, moreover, *are too particular*, too new, or of too limited interest to be published. But submission to the scrutiny of the scientific community is a component of "good science," in part because it increases the likelihood that substantive flaws in methodology will be detected." (Emphasis added.)

Nevertheless, the expert should use probabilities in a robust, transparent, logical, and balanced approach when assigned probabilities are necessary, which is further alluded to in *Daubert*:

> "This entails a preliminary assessment of whether the reasoning or *methodology* underlying the testimony is scientifically valid and of whether that reasoning or *methodology* properly can be applied to the facts in issue." (Emphasis added.)"

It is for this reason that experts are encouraged to adopt an accepted methodology such as CAI or BNs when evaluating DNA evidence given activity level propositions.

4.2.1 If there is no dispute about whose DNA is present, then the LR given sub-source propositions should no longer be the focus of the expert testimony. Since the parties are now in agreement, it is no longer relevant. If an LR given sub-source propositions is calculated, then it should be made explicit that this figure does not relate in any way to questions regarding how or when the DNA was transferred. Not presenting an LR given sub-source propositions (or RMP) would simplify the task of the jury, since they

would not have to listen to testimony about an LR or RMP when there is no dispute as to who's DNA is present.

4.2.2.1 See supporting information for 4.1.5.1.

4.2.2.2 See supporting information for 4.1.5.2.

4.2.2.2.1 Making a statement about the POI being the source of the DNA is commonly known as transposing the conditional for an LR, and the prosecutor's fallacy (which is a form of the transposed conditional) for an RMP.

4.2.2.3 See supporting information for 4.1.5.3.

4.2.2.4 The LR is expressed in a manner that links the numerical value to the DNA profile and not the person of interest. "This DNA profile is 1 million times more likely if it originated from Suspect rather than from an unknown unrelated person."

There is an impression that the LR is more difficult to explain to a jury. The use of a verbal scale may be helpful in conveying the strength of the evidence.

A statement similar to "Whatever your belief about whose DNA is present in the sample without my testimony, based on other information that you have (but I don't), your belief should be X times greater with my evidence than it was without my evidence" may be helpful.

This statement introduces the concept of prior odds, and communicates that the value of the prior odds (other evidence) should be determined by the jury.

4.2.3 See supporting information for 4.1.6.

4.2.3.1 See supporting information for 4.1.6.1.

4.2.3.2 Usually the RMP is a very small number (e.g., 0.000001). However, it is most commonly expressed as a fraction, e.g., "1 in 1 million". It may be useful in explaining this to the jury by stating, "In a general population of 1 million unrelated persons (that we know does not include the offender) the profile obtained from the evidence is expected to occur one time on average. If multiple populations of 1 million persons are tested, sometimes it may not occur at all, and sometimes more than once, but on average, only one time." Care needs to be taken to avoid the defense attorney's fallacy or the uniqueness fallacy [Evett and Weir, 1998].

4.2.3.3 See supporting information for 4.1.6.2.

4.3 For DNA results, source level propositions relate to the attribution of the body fluid or tissue giving rise to the DNA profile result which matches the person of interest. An example of source level propositions might be: The bone has originated from Mr. X vs. the bone has originated from an unknown person unrelated to Mr. X. The results considered are those of the DNA comparison: their value is calculated given sub-source level propositions. By using source level propositions, the scientist is elevating the opinion regarding from whom the DNA has originated to from whom a specific body material has originated [Evett et al., 2002].

Note that source level propositions are not the same as the identification of the biological source (i.e., nature of the body fluid or tissue) of the recovered DNA (e.g., the DNA is from the bone). Both are important, but the distinction should be maintained by the expert.

4.3.1 There are times when there is little uncertainty about the nature of the biological material. Sometimes this is stated by saying "Semen was identified", such as when thousands of spermatozoa are observed on a microscope slide.

4.3.3 An example of uncertainty about the nature of the biological material is when semen/spermatozoa testing gives conflicting serological results. For example, this could occur as a negative acid phosphatase test, a positive immunological test (PSA/p30) and no spermatozoa were visualized microscopically.

In the example of only a positive PSA/p30 test, other information may be useful, such as where the sample came from (i.e., high vaginal sample or underwear) or that the sample ultimately revealed a male DNA profile in the fraction designed to give DNA results from sperm. In such cases, the use of probabilities may allow for an opinion on the nature of the biological material to be given in likelihood ratio form. "This evidence is more likely if the sample contained semen than if it contained some other form of biological material." The expert might consider additional information, such as reported injuries, when giving the overall opinion about the nature of the biological material. The expert should give serious consideration as to whether or not it is appropriate to give this opinion based on the available case information.

4.3.4 When more than one biological material may be present (i.e., blood and semen, saliva and skin cells) and a mixed DNA profile was obtained from the sample, the expert should be very careful when the line of inquiry by the parties is concerned about which donor is the source of which biological material.

If the source of each biological material is in dispute, or only a small amount of biological material resulted in a mixed profile, it may be more appropriate to discuss the evidence given activity level propositions. More value is added at the activity level, and if this activity is not specifically considered, the jury may make their own evaluation of activity level propositions without proper guidance.

4.3.5 When the nature of the biological material is in question, making a statement considering only the DNA profiling results could be mis-interpreted as a comment on the biological material.

Example: The sample has produced a positive result with Bluestar (a test that reacts with blood). The DNA profile produced from this trace shows a minor profile matching the suspect and a major profile matching the complainant. The LR statistic is more than 1 billion, meaning that the results are more than 1 billion times more likely if the complainant and suspect are the source of the DNA than if two unknown persons are. However, if the question of interest is "Whose blood is it?" this large LR for the DNA profile offers no information as to whose blood it is. The expert should be careful to either make an appropriate evaluation of the evidence if the blood was from one or both donors, or at the very least a caution that the LR of 1 billion given sub-source propositions cannot be transferred to the source (blood) level.

4.3.6 When the biological material is semen, there is usually an inference of sexual activity. If no evaluation of the evidence is given considering the alleged activities, the jury may be left with no alternate proposition to consider and assume that sexual activity is the only activity that could have occurred.

4.3.7.1 See supporting information for 4.1.5.1.

4.3.7.2 See supporting information for 4.1.5.2.

4.3.7.3 See supporting information for 4.1.5.3.

4.3.8 See supporting information for 4.1.6.

4.3.8.1 See supporting information for 4.1.6.1.

4.3.8.2 See supporting information for 4.1.6.2.

4.4.2.1 See supporting information for 4.1.5.1.

4.4.2.1.2 Questions of bias can be minimized when the expert records propositions and expected results given those propositions prior to testing. This also has an effect on the LR – the probabilities used in calculating the LR were determined independent of the data, and the results end up supporting one proposition compared to the other with little to no post results influence of the data. It should be noted that the propositions are not immutable, and that they may require refinement or alteration during the course of the case.

A simple statement such as "Per case information, one proposition will be that Suspect touched the item directly, and the alternative proposition will be that Suspect was interacting with a group of people, and someone else who had contact with Suspect touched the item" may be sufficient when there is information that Suspect was with a group of people that had some exposure to the evidence item.

4.4.2.1.2.1 An example of expected results may be "I would expect to see DNA only from Suspect if the first proposition is true; I would generally expect to recover DNA from Suspect and additional contributors if the alternative proposition is true."

The expert should be cautious of assigning any probability of 1 or 0 (zero) as that indicates no uncertainty and leaves no room for the other proposition to have any part in the evaluation of the evidence. These situations are rare in practice. (See the discussion on "possible" at Annex A 4.4.4.2 in this document.)

4.4.2.1.2.2 This process follows a recognized model for casework assessment and interpretation [ENFSI, Cook et al. (1998) CAI paper]. A number of steps are conducted:

1. The scientist will consider the expected outcomes of the test: for example, no DNA profile matching the person of interest, or DNA matching a person of interest.
2. (Notional) probabilities are then assigned to the expected outcomes given the truth of the proposition. This is repeated for each of the propositions in the case.
3. The relative weight of evidence (LR) that the findings provide is then derived through division of the probabilities.

The examples presented here are very simple and minimalistic. It is recommended that more formal approaches be adopted such as CAI using a table of probabilities or Bayesian network software. These approaches will require training and effort, but the tables or graphs that result are easily used to communicate the thought process to the decision maker. They also allow for transparency and ensure that conclusions are robust (i.e., sustain scrutiny by peers and cross-examination by counsel during the trial).

The use of CAI and BNs are strongly recommended, as these methods are recognized in published studies for the evaluation of DNA evidence given activity level propositions. Several are listed in Annex C as a starting point. Because it is expected that different experts may present different likelihood ratios for DNA evidence given activity level propositions (as is the case for likelihood ratios given sub-source level

propositions when using different models), the courts have recognized that using a rigorous framework is imperative for the evaluation of the testimony of the expert by the court. In *Kumho Tire Co. v Carmichael [526 U.S. 137 (1999)]*, the Supreme Court has emphasized that the method applied by the expert must stand up to scrutiny, whether from published studies and data or notional probabilities based on personal observations and experience gained through evidence testing:

> "It is to make certain that an expert, whether basing testimony upon professional studies or personal experience, employs in the courtroom the same level of intellectual rigor that characterizes the practice of an expert in the relevant field." (*Kumho Tire Co. v Carmichael, 526 U.S. 137 (1999))*

4.4.2.1.3 "Transfer" is not a part of the actual actions alleged in the proposition. Anytime DNA moves from point A to point B, transfer has occurred, but it is not descriptive of the actions that may have been taken by the parties. The mode of transfer is implicit in the activities considered in the propositions.

Propositions are addressed by the court. If the term "transfer" is woven into the propositions, then it would mean that the court has to assess transfer. However, as forensic scientists have knowledge on that topic, it should be part of the assessment, not of the propositions.

An incorrect example of using "transfer" in the propositions is:

> "The presence of the DNA on the knife is more likely if direct transfer occurred than if indirect transfer occurred."

This is incorrect because the term "transfer" is a part of the propositions. "Transfer" is not a proposition; it is a mechanism.

Another incorrect example is:

> "It is more likely that direct transfer occurred than indirect transfer."

This statement is incorrect for two reasons: 1) it transposes the conditional, and 2) the term "transfer" is a part of the propositions.

The correct statement would be:

> "The presence of the DNA on the knife is more likely if the suspect held the knife rather than if the suspect had shaken hands with the true offender."

It would be incorrect to say, "This evidence is more likely if primary transfer occurred than if secondary transfer occurred." It would be correct to say "This evidence is more likely if Mr. A handled the gun than if Mr. A didn't handle[3] the gun." While there is a 'primary' transfer for the first proposition, and a 'secondary' transfer in the alternative proposition, the actual propositions are based on the allegations of the parties and communicate more to the finder of fact.

4.4.2.1.4 Typically, the expert is aware of the prosecution's version of events at the time of evidence testing. The proposition is formulated for the purpose of assigning the probability of the evidence if this proposition were true.

[3] In the case information, one will describe what is meant by 'not' (e.g, The gun was touched by the police with the same gloves that were worn to arrest Mr. A).

There may be times where the prosecution proposition is not supported by the evidence and the evidence is more probable given the defense proposition. For example, when the sexual activity in question occurred 72 hours ago according to the prosecution, yet many sperm heads are seen from a vaginal swab. This does not mean the proposition is or is not true. Rather, the defense may have an alternative time frame (e.g., 24 hours rather than 72 hours) for the sexual activity that is better supported by the evidence. If this is the situation, then the expert should explain that the evidence is more likely if the sexual activity occurred one day prior to collection than if it occurred three days before collection.

4.4.2.1.5 The alternative proposition must be different and mutually exclusive from the prosecution's proposition or version of events. That is, if a proposition is "true," then the alternative proposition cannot be "true" and vice versa. The alternative proposition must either benefit the defense, *as understood by the expert based on the available information*, or if provided, reflect the position of the defense.

4.4.2.1.5.1 It is crucial to be aware that in the United States (as well as in other countries) there is no requirement for the defense to make a statement of any sort. This does not relieve the expert from the responsibility of evaluating the evidence using a proper Bayesian framework with competing propositions.

4.4.2.1.5.2 When there is no specific information, the expert has no choice but to adopt a proposition for the defense. This is necessary to give a balanced evaluation of the evidence.

Examples of proxy propositions for the defense may sometimes be found in surrounding activities that are not in dispute. Examples in a sexual assault case may include having dinner together, social contact, having previous intercourse, holding hands prior to touching an item, and so on. On occasion, the expert may have little choice but to choose a proxy of "not sex" or "not touching the knife" if there is little to no information available. Be aware that these "not X" proxy propositions can be problematic both for the expert (difficult to assign a probability of the findings given this proposition) and the defense (may lead to relatively large LRs which favor the prosecution proposition.)

4.4.2.2 See supporting information for 4.1.5.2.

4.4.2.3 See supporting information for 4.1.5.3.

4.4.2.3.1 There is always a concern about bias when the expert needs case information to evaluate the evidence. Only task-relevant information should be considered (e.g., relationships of the individuals, the alleged activities, the time between the alleged events and evidence collection). Information such as prior convictions, whether the suspect was recognized or not, and the presence of other evidence are examples of information that is not useful and potentially harmful. Some laboratories will filter the information given to the analysts, so that the person(s) assessing the findings will only be given task relevant information.

The so-called "black box" expert where the expert testifies only to analytical results with no conditioning information has its own dangers and could be misleading to the decision maker. In the following examples, the expert needs information about the circumstances of the case and the propositions of the parties in order to give any value to the evidence that was examined.

One example would be where the expert testifies only to "the major semen DNA profile" and doesn't evaluate the evidence given activity level propositions. If the question of interest to the court is the timeline of activity (e.g., 12 hours or 72 hours) and no comment is made beyond "major semen DNA profile" the jury does not have the information necessary to evaluate the real issue before the court.

Another example might be "Complainant is included as a DNA contributor on the item." If there is no dispute that the DNA profile came from the Complainant, because the question of interest is whether direct or indirect contact occurred between the complainant and the object, this statement by the expert adds no value to the case.

4.4.2.4 The principles used to assign a likelihood ratio provide a recognized framework to communicate the value of the evidence given activity level propositions [Gill et al., 2020, ENFSI Guidelines 2015]. It is common to consider propositions at the activity level in forensic DNA testimony. Activity levels can be implied at the sub-sub-source level (e.g. complainant corresponds to major profile on Suspect fingernails in a digital penetration case) or the source level (e.g. Suspect matches the semen profile). It can also be direct testimony given activities of interest from one or both of the parties in the case. There is a high level of uncertainty in most cases involving activity. The likelihood ratio using probabilities of the evidence given competing propositions is the preferred way of evaluating evidence. It is important to use the Bayesian framework where the expert focuses on the likelihood ratio and lets the decision maker (jury/judge) consider the other evidence (prior odds). The decision maker – and not the expert – is responsible for the final evaluation of the propositions (posterior odds). Oftentimes the judge instructs the jury on this issue, even if these exact terms are not used.

4.4.3 See supporting information for 4.1.6.

4.4.3.1 See supporting information for 4.1.6.1.

4.4.3.2 See supporting information for 4.1.6.2.

4.4.4 Oftentimes, whether or not there is any statement made prior to court regarding the activities, counsel will ask the expert a hypothetical question about DNA transfer and persistence (e.g., "Is it possible for one person to handle an item, and then a second person handle that same item and transfer the DNA of person 1 to a second item?").

'Whose DNA is it?' is an entirely different question from addressing *'How and when did the DNA get there?*' This means that any sub-source statistics quoted have no bearing on the issues regarding how or when the DNA was transferred. In a scientific context, it might not be known for certain 'how' or 'when' DNA was transferred to an object.

The 'how' and 'when' questions involve issues affecting the transfer of DNA from one place to another and a consideration of how long the DNA might have persisted on the item once transfer has taken place. In addition, the attribution of the DNA to a particular body fluid will also form an important part of these considerations as well as background levels of DNA and possible contamination.

Any DNA transfer event requires four factors to be considered and fulfilled:

i) there needs to be a source of DNA.

ii) there needs to be a mechanism by which the DNA is transferred.

iii) there needs to be an opportunity for the DNA to be transferred by the proposed mechanism.

iv) the DNA must be in sufficient quantity and quality to persist and be recovered from the item.

Consideration of these points needs to be undertaken within the context of the case information.

4.4.4.1 Most often, a hypothetical question is asked at court in an attempt to explain the evidence after the evidence (results) are known. The expert should understand that an explanation is not a proposition. However, a hypothetical question on activity/transfer/persistence issues by the defense is an engagement about the activity and should be considered in the same manner as a more formal proposition. When this happens, the best answer the expert can give is to evaluate the evidence if the prosecution's proposition occurred compared to if the hypothetical situation just asked about occurred. (See the discussion on "possible" at Annex A 4.4.4.2 in this document.)

The expert needs to be aware that such "after the fact" hypothetical questions (explanations) will often lead to an LR of 1. That is to say, after the results are obtained, there may be multiple explanations that can be put forward that could yield results similar to the observed results. For example, if the prosecution proposition involved non-consensual sex and the defense proposition involves consensual sex, the probabilities of the result given either of those propositions would be equal. This assessment of the DNA evidence offers no value to the proceedings.

4.4.4.2 The forensic scientist should not deal with "possibilities" as this is a mathematically meaningless term. In the context of a hypothetical case, "possible" typically means any non-zero probability. However, probabilities are discrete values between 0 and 1, and if there are several outcomes to consider, the sum of all probabilities must equal 1. The opposite term for "possible" is usually "not possible" or "impossible". In mathematical terms, this can be expressed as (1 – possible = impossible) where impossible has a probability of zero. Therefore "possible" cannot be dealt with mathematically by the scientist when evaluating evidence.

When a question is asked if something is "possible" one or more of the following may be useful:

> "As a scientist, I can only deal with probabilities as all things may be possible."
>
> "Possible is any non-zero probability, yet what is relevant when evaluating evidence is to consider the relative probability assigned to that evidence given each of two different propositions."
>
> "I can only answer your question if I consider relative probabilities of the evidence considering two options, not by stating some unknown intrinsic value of a single proposition in isolation."
>
> "The only way to put "possible" into context is to compare the relative probabilities of the evidence given each of two different propositions. We can never be certain about the probability of the evidence for a given event, but we can provide context by comparing the probabilities given each of two different and mutually exclusive propositions."
>
> "There may be a lot of ways to explain how DNA was deposited somewhere. I can't properly assess every possibility on its own. My job is to compare the probabilities of getting this type of DNA profile under two different scenarios that are useful and reasonable to the case. The outcome may change when different scenarios are compared, but there is not much value in considering only one scenario by itself."

4.4.4.3 This may be the biggest challenge when considering activity level propositions. Often hypothetical questions are directly asked in reference to the activity, or the expert is asked to provide activities that could result in the type of testing results found in the case. The expert needs to recognize these questions as the transposed conditional (See 4.1.5.2) and attempt to answer appropriately by referring to the evidentiary findings if that activity has occurred. Answering these questions directly is not the role of the expert. We list some examples and possible responses below:

Q1 "What are some other explanations for this data?" – Requires the expert to know the other evidence in the case in order for the explanation to have a prior. This is outside the scope of the expert.

"You are asking me to provide explanations after I know the data. This is outside my role. If you have additional explanations that interest you, I can give you an opinion on whether or not the evidence supports what you are interested in."

"I'm not aware of any case information that would allow me to make any speculations like that."

Q2 "Is it possible that the DNA got there by secondary transfer?" – Any simple answer (yes/no/maybe) is a comment on the probability of the proposition, not the probability of the evidence if the proposition were true. Therefore any "simple" answer is a transposed conditional. Also, see the problems with "possible" addressed in 4.4.4.2.

"I'm certain that if we were able to run some trials, we could determine how often and under what circumstances DNA is detected from a secondary transfer event. However, what is relevant is whether the observed DNA profile is more likely if an object was handled by the person of interest or if he did not handle it but had contact with an unknown person who did."

"When you ask if that's possible, the answer is yes. However, if we do not attach any value to the results then this is of little assistance. Is it possible to win the lottery 6 times, yes it is possible. Is it possible that if I flip a coin it will land on heads, yes it is possible. But as you see the probabilities are very much different. Here, in this specific case, in order to be of assistance to the court, I would need to give the value of the DNA results considering the two competing views of the parties."

4.4.4.4 When answering a hypothetical question, the expert should be clear as to whether or not he/she has relevant case information related to the question. While the expert should never give an opinion about the other evidence (which represents prior odds in the Bayesian approach), it is prudent to consider the case information that has been presented to the expert. The expert needs to be aware that giving an opinion on the weight of evidence for a given pair of propositions may imply some activity has occurred when there is no other evidence supporting that particular proposition.

The use of a likelihood ratio does not generally imply that one of the two propositions considered must be true. Though the considered propositions are those deemed most relevant, they do not need to be exhaustive, so both propositions could be false. The likelihood ratio says nothing about propositions other than the two that were considered.

If the hypothetical seems "reasonable" such as 'dancing together', the expert may not have specific case information about dancing but is aware that V and S were on a date. In this case, the expert may feel that he/she has an opinion that could add value.

"I'm unaware of any specific information about dancing, but I'm aware that V and S were together on a date for the evening. Therefore, I am comfortable giving an opinion that the evidence is more/less likely if they danced together than if X were true," where X is some other proposition.

If the hypothetical seems "unreasonable" such as multiple steps of transfer that require specific conditions for which no information is available to the expert to consider, the expert may or may not be able to

answer directly. Consider an apparent outlandish scenario of semen on a vaginal swab with a hypothetical question of V using contaminated toilet paper because the holder was empty [Gittelson 2016]:

> "I am unaware of any information in the case where it was claimed the toilet paper roll was empty so V used discarded tissue from the bathroom trash. However, in my opinion, recovering a DNA profile from sperm cells is more likely if sexual activity occurred than if contaminated tissue was the source of the sperm cells."
>
> "I have not been presented with this specific alternative in this case. I would need some more information and some time to prepare an answer if this is relevant."

The expert should remember that any transfer mechanism of DNA could have a non-zero probability given the right circumstances. Because the specific case information matters, the expert should discuss the limits of any opinion with the decision maker and be clear that hypothetical questions should fit within the overall case information.

4.4.4.5 Often an expert is asked a series of hypothetical questions. The expert should attempt to make the court understand that the best way to answer these questions is to consider the probability of the results obtained given each of two different options. When one hypothetical question involves a significant question (such as "touch DNA" moving to a body fluid), the expert may need to ask for a moment to consider the answer. Finally, if the answer were to involve much effort, perhaps it is best to ask for a recess. It is also possible that the expert should answer by saying he/she has no ability to offer an opinion on the probability of the evidence given that scenario.

Annex B
(informative)
Examples

The following examples have been included in an attempt to give guidance on how one might testify at trial when the court has interest in the evaluation of the evidence given activity level propositions. In the examples presented, both parties have described activities that could have legitimately led to the transfer of DNA. These examples have been simplified and may exclude issues such as lab-derived contamination, background DNA, or underlying issues with the testing methodology. The reader must be aware that in real life cases these issues might need to be considered.

It is beyond the scope of this best practices recommendation to give detailed instructions and strategies for specific cases examples. For more information, consult the references cited throughout this document.

It is recommended that the expert include the following information as general background before addressing his or her opinion about the evidence given propositions at the activity level of the Hierarchy of Propositions:

- "In order to assist the court, I have followed a recognized framework for evidence evaluation by considering the probability of observing the results in this case given two alternative propositions. These reflect the prosecution and defense standpoints as understood by me."

- *(This statement may be needed as well:)* "I have no specific information that would allow me to infer what alternative activities would have taken place. To assess the biological results, I have adopted a proposition that incorporated case information that is not disputed between the parties, to the best of my knowledge."

- "The approach to the examination and interpretation of the findings in a case is crucially dependent on the information made available to me and the propositions considered. If any of the information I used in the evaluation were to change, is incorrect, or incomplete, then I will reconsider the evaluation of the evidence and this may result in a different overall opinion."

The examples are intended to model the thought processes and the proper presentation of the opinion using a Bayesian framework. The process used in the examples follow the recognized framework for casework assessment and interpretation (CAI) [Cook et al., 1998 CAI] as described in the introduction of this document.

Both qualitative and quantitative approaches are acceptable. It is recommended that if a purely qualitative approach is used consisting of verbal qualifiers (such as more likely/very much more likely, high/low), the expert should give context by at least discussing the word choices, and some indication as to the relative scale of each. Because words may mean different things to different people, it is recommended that a quantitative evaluation be used whenever possible. However, there may be situations where this is not possible as there is no available research that is directly related to the case activities of interest. In addition, there may be jurisdictional preferences between qualitative and quantitative evaluations that must be considered. Much more information may be gained by consulting the references cited in this best practices recommendation.

The examples are intended to move through a progression from entirely qualitative in the first example to a fully quantitative example at the end. The examples between the first and last are intended to show a progression that incorporates published literature, and some form of numerical quantification of the strength of the evidence – even if that is merely an acknowledgement that a numerical evaluation cannot be calculated. While a qualitative evaluation is acceptable, and sometimes the only available option, it is recommended that all efforts be made to offer a quantitative assessment whenever possible.

- Example 1 is purely qualitative and makes no mention of research.
- Example 2 is qualitative, although there is mention that a numerical evaluation cannot be performed. Some relevant research is mentioned, but it is unbalanced and only related to one proposition. Therefore, a numerical evaluation is not presented.
- Example 3 is a continuation of Example 2 and serves to show how new/additional information may have a significant effect on the expert's opinion.
- Example 4 presents a quantitative number, but it is based on a qualitative scale. This is one way to bridge the gap between qualitative and quantitative evidence evaluation, and further serves to enforce the criteria of transparency, balance, logic, and robustness.
- Example 5 is an attempt to show a quantitative approach using relevant literature. However, the numerical LR presented in #5 has been simplified for clarity and an example of the craft:
    - Simplified propositions were considered.
    - No attempt was made to find current literature that may exist, the citations are fictitious.
    - A Bayesian network was not used.
    - Sensitivity analysis was not done.

Case scenario 1.

Information:

Ms. Y alleges that she awoke to find Mr. X masturbating over her, and that he ejaculated on her clothing. Mr. X denies the allegation, but stated he argued with Ms. Y, and did at one point spit at her. A night

shirt with a stain has been provided as evidence and was collected within a few hours of the event. Mr. X is not vasectomized.

Question: Did Mr. X ejaculate onto Ms. Y's clothing?
Propositions considered:

- Mr. X ejaculated on Ms. Y.
- Mr. X spat on Ms. Y.

Laboratory testing:
a) Visible stained area on shirt, this area also shows fluorescence using a forensic light source.
b) Positive result for the presence of amylase.
c) P30 test returned a negative result.
d) No sperm were found via microscopic analysis of the stain.
e) After quantification, the DNA extract required a 10-fold dilution before amplification.
f) A DNA profile was recovered from the stain on her nightshirt.
g) The DNA typing results showed a major profile matching Mr. X, and Ms. Y accounts for the minor.

Assumptions:
Any DNA matching Mr. X on the nightshirt has originated from him.

Oral Testimony:
I have evaluated the evidence with respect to two propositions: either Mr. X ejaculated on Ms. Y, or Mr. X spat on Ms. Y. If ejaculation had occurred, then I would expect the P30 test to be positive, and perhaps there to be sperm cells present. If spitting had occurred, then I would expect the amylase test to be positive. The second proposition would give rise to the results obtained in this case, whereas the first would not. Therefore, I consider that the results would be very much more likely to be observed if Mr. X spat on Ms. Y rather than if Mr. X ejaculated on Ms. Y.

Evaluation:
a) Based on case information, the analysis was limited to semen and saliva testing. Laboratory validation shows that when semen is present (with similar timing as in this case), one expects to have a P30 positive test and to observe sperm heads using microscopy. (Case information exists that Mr. X has not been vasectomized). When saliva is present (again within the same timing), we expect a positive amylase test. However, amylase testing is not a specific or confirmatory test. I do not expect DNA recovered from an item of evidence to require a 10-fold dilution prior to amplification as a result of normal social contact (or background level DNA). Generally, only body fluids and tissue samples require dilution.

b) Considering the first proposition. I do not expect to observe negative semen testing results if ejaculation occurred. Based on a timely collection of the evidence and proper handling to preserve biological material, I would expect positive semen testing results if semen were present on the shirt. I do not expect such quantities of DNA as recovered here to be present as background. The probability of these results if Mr. X ejaculated on the shirt are considered to be extremely low.

c) Considering the alternative proposition. The results in this case (large quantity of DNA; saliva positive test, negative semen test) are what I would expect if spitting took place. I do not expect such quantities of DNA as recovered here to be present as background. The probability of these results if Mr. X spat on the shirt are considered to be extremely high.

d) In summary, only one of these activities would be expected to give rise to the findings in this case. Therefore, in my opinion, the results are very much more probable if spitting took place rather than if ejaculation took place.

Case scenario 2:

Information:

Mr. X and Ms. Y were socializing in a public bar. They were part of a group who drank and danced together. Ms. Y has accused Mr. X of forcibly penetrating her with his fingers while dancing. Mr. X has not washed his hands, and he has invoked his right to remain silent.

Question: Did Mr. X digitally penetrate Ms. Y?

Propositions considered:

- Mr. X digitally penetrated Ms. Y and also socialized (danced) with Ms. Y.
- Mr. X simply socialized (danced) with Ms. Y.

Laboratory testing:

a) Right- and left-hand fingers/fingernails of Mr. X swabbed ~5 hours after the alleged incident.

b) DNA Right hand fingers/fingernails of Mr. X give a mixed DNA profile. The major component profile matches Ms. Y; the minor component profile matches Mr. X.

c) The left-hand fingers/fingernails gave a DNA profile matching Mr. X only.

d) No laboratory testing has been performed to establish the body fluid or cell type.

Assumptions:

The source of the DNA is not disputed (i.e., the DNA is from Mr. X and Ms. Y).

Oral Testimony:

I have evaluated the evidence in this case with respect to two propositions: either Mr. X digitally penetrated Ms. Y during an evening spent socializing/dancing, or Mr. X simply socialized/danced with Ms. Y. My opinion, considering the probability of observing the results under the different propositions, is that the results would be considered much more likely to be observed if the first proposition were true rather than the second. I am unable to provide a quantitative measure of the relative strength of support that the findings provide.

Evaluation:

a) Considering the first proposition. The vaginal environment contains an abundance of DNA rich cells. Insertion of a finger would require some force and, in conjunction with the wet nature of the cells, would promote DNA transfer to a finger. This would likely result in a good quality DNA profile matching Ms. Y, as were the findings in this case. The absence of a similar result on the other hand is also considered significant under this proposition. This is because there is an expectation of similar results on both hands if Mr. X and Ms. Y only had typical social contact. The expectation of these results if digital penetration occurred is so high that for simplicity's sake, one can ignore the “social contact” portion of this first proposition. If the first proposition is true, then the probability of obtaining the results in this case would be considered ‘high’.

b) Considering the alternative proposition. Social situations will provide opportunities for direct and indirect DNA transfer through successive contacts with common objects and individuals. In this situation, it would be my expectation that these activities would generate complex mixed DNA profile results from many contributors, since Mr. X and Ms. Y were part of a larger social group. Additionally, these results would be expected on both hands. The probability of obtaining the results found in this case (all DNA accounted for by Mr. X and Ms. Y, and only on one hand) if this proposition were true would therefore be considered ‘low,’ and against expectations.

c) Additionally, research indicates that the chances of finding a high-quality foreign DNA profile on a person’s fingernails, other than from someone with whom they have an intimate relationship, is low.

d) In summary, both activities would give rise to the findings in this case, but with different expected probabilities. When considering the probability of observing the results under the different propositions, the results would be considered much more likely to be observed if the first proposition were true rather than the second.

Case Scenario 3:

This is a continuation of Case Scenario 2. However, after the initial expert testimony by the DNA expert, defense later presented a witness that testified during the evening he saw Ms.Y lick the index finger of Mr. X's right hand after he dipped it into her drink.

Note: The expert was not incorrect in Case Scenario 2, but rather the information provided was incomplete with respect to the alternative proposition. In light of the new information introduced by the defense, it is imperative (and logical) that the expert re-assess the results given the new information. Although Mr. X has made no statement, the defense is entitled to introduce evidence as fits their case strategy, and this may—or may not—affect the evaluation of the evidence by the DNA expert.

Question: Did Mr. X digitally penetrate Ms. Y?

Propositions considered:

- Mr. X digitally penetrated Ms. Y.
- Ms. Y licked the index finger of Mr. X and no digital penetration took place.

Laboratory testing:

See Case Scenario 2; there are no additional testing results.

Assumptions:

All previous assumptions apply.

Oral Testimony:

I have evaluated the DNA results in this case with respect to two propositions: either Mr. X digitally penetrated Ms. Y, or Ms. Y licked the index finger of Mr. X and no digital penetration occurred. The fact that Ms. Y and Mr. X danced together and spent the evening together in a social setting is taken into consideration under both propositions, as this is not contested. The probability of observing the DNA results under the different propositions would be generally considered the same when considering the nature of the body fluids and cell types (vaginal cells/fluids versus buccal cells or saliva). I would expect the same findings for either proposition. Therefore, the results are uninformative or neutral and do not help address the issue.

Evaluation:

a) Considering the first proposition. The probability of obtaining the result remains 'high' as stated in Scenario 2 for the proposition that Mr. X digitally penetrated Ms. Y's vagina.

b) Considering the alternative proposition. The new information changes the probability of the results under the alternative proposition. Insertion of a finger into the oral cavity, as with the vagina, is expected to provide a good opportunity for the transfer of cells/DNA. The probability of obtaining the results under this proposition, with conditions of retention and persistence being the same as that of the first proposition, is considered 'high' and equal to the probability of the results if there were digital penetration.

c) In summary, I would expect the same findings under both propositions. Notwithstanding that the nature of the body fluid cannot be determined, the probability of observing the DNA results under the different

propositions would be generally considered the same. Therefore, the results are uninformative or neutral and do not help address the issue.

Case scenario 4

Information:

Motor vehicle collision – airbag deployed. One person (driver) is seen leaving the scene. Mr. X is charged with the offence. He states that:

- he owns the car, and therefore, his DNA will be on surfaces within the car
- a cup was present in the central console of the car which he has drunk from
- someone stole the car prior to the collision.

Question: Who was driving the car at the time of the collision?

Propositions considered:

- Mr. X was driving the car at the time of the collision.
- An unknown person was driving the car at the time of the collision, not Mr. X.

Laboratory testing:

a) Airbag tested for saliva and DNA.
b) Central front region contained an area of staining that yielded a strong amylase positive result.
c) The area of assumed saliva gives a good quality single source profile matching Mr. X.
d) The LR is 1 billion. That is, it is 1 billion times more likely to observe the DNA evidence if it originated from Mr. X rather than if it originated from someone else unrelated to Mr. X.

Assumptions:

a) The determination of saliva is not under dispute.
b) The DNA has originated from the saliva tested.
c) Saliva has originated from Mr. X.

Oral testimony:

I must first point out that the stated likelihood ratio for the DNA profile (i.e., 1 billion) cannot be applied to the evaluation of the evidence given the propositions about who was driving the car. I have considered this evidence with respect to two possible propositions: Mr. X was driving the car at the time of the collision, or an unknown person was driving the car at the time of the collision. It is my understanding that Mr. X is the normal driver. It is my opinion that both scenarios could give rise to the findings in this case. However, when considering the probability of observing the results under the different propositions, the results would be considered much more likely to be observed if the first proposition were true rather than the second. This is because I have a high expectation of these results given one proposition, and a low expectation given the other.

I can illustrate my opinion by assigning a numerical value, for example, of 0.9, or 90% to the term 'high' and 0.01, or 1%, to the term 'low.' So another way to express my opinion is to say that the evidence recovered from the airbag is in the order of 90 times more likely if Mr. X were driving the car at the time of the collision than if someone else were driving, and Mr. X's DNA was present due to car ownership. I have simplified this mathematical example by not considering that the cup Mr. X had in the car was an alternative source of the DNA on the airbag. In my opinion, this possibility is so remote as to have no influence on my calculation.

Evaluation information:

a) The two probabilities assigned for the observed results given each proposition allow the calculation of a likelihood ratio. This likelihood ratio represents the relative strength of support that the findings provide given the stated propositions. I am giving a qualitative opinion, as I am unaware of any published studies

related to DNA profiles recovered from airbags and car owners. However, I am aware of numerous studies involving the comparison of DNA transferred by saliva and other body fluids compared to skin cells, and also of studies involving general background levels of DNA.

b) Considering the first proposition. If Mr. X were driving, then it is reasonable to consider that the driver's airbag has deployed into his face with some force. There is an expectation that this would have resulted in the transfer of his saliva, and therefore his DNA, to the central part as a single source DNA profile as were the findings in this case. The probability of the evidence given this proposition is considered very high (i.e., close to 1), because these results are expected if this proposition is true. I have assigned a probability value of 0.9 to this proposition as an illustration of 'high.'

c) Considering the alternative proposition. If some other person were seated in the driver's seat, then:

- saliva is present in the area tested as a result of the airbag being deployed into the unknown driver's face and
- the DNA profile of the 'true' driver (i.e., the driver at the time of the collision) could, by some very remote possibility, match that of Mr. X. This is not expected to be the case; therefore, I have to accommodate for the profile of the 'true' driver not being detected.
- Since the airbag is entirely enclosed within the steering column before deployment, there would be no reasonable opportunity for DNA from Mr. X to be transferred to it as a result of him sneezing over it or being in his car on a previous occasion. Therefore, we may consider the DNA/saliva was transferred through contact with areas of the car where his DNA is expected to be present when the airbag was inflating or deflating. Additionally, in my opinion, it would be difficult to conclude that the saliva detected on the airbag could be explained from transfer of saliva from the rim of a cup in the cup holder. This saliva would have to be wet to facilitate transfer and would have to be present over a similarly shaped and equivalent area as detected on the airbag (i.e., not commensurate with the rim of a cup).
- In this situation the chances of observing the DNA profiling results would be considered 'low.' This is because the second alternative requires a number of assumptions and conditional events to come together in an unlikely manner for the results to be observed. I have assigned a probability value of 0.01 to the results given this proposition to illustrate 'low'.

d) In summary, both activities might be expected to give rise to the findings in this case. However, when considering the probability of observing the results under the different propositions, the results would be considered much more likely to be observed if the first proposition were true rather than the second. Using the numerical example to express this outcome is to say that the evidence is in the order of 90 times more likely given that Mr. X was driving the car rather than an unknown person.

Case Scenario 5

Information:

A female, Ms. Y, is assaulted by a man as she exits a bar. She puts up a fight and scratches his face with her dominant hand. The incident was observed by other customers. Mr. X states he was in the bar on the night in question but did not assault the complainant.

Question: Did Ms. Y scratch Mr. X or some unknown person?

Propositions considered:

- Ms. Y scratched Mr. X outside the bar they both visited during the evening.
- Ms. Y scratched an unknown person but was present in the same public space as Mr. X

Laboratory testing:

Samples are recovered from underneath Ms. Y's fingernails, an hour after the incident. DNA from her dominant hand yielded a mixed DNA profile exhibiting one major male component profile (Contributor

1: mixture proportion 90%) and a minor profile (Contributor 2: mixture proportion 10%). The minor profile contribution is concordant with the profile of Ms. Y.
A statistical evaluation, a determines that the DNA profile result is on the order of 1 billion times more likely if it originated from Ms. Y and Mr. X rather than Ms. Y and an unknown person who is unrelated to Mr. X.

Assumptions:
a) Ms. Y is the minor contributor on the sample from her fingernails.
b) There is a reasonable basis for concluding that Mr. X (rather than someone else) and Ms. Y contributed to the DNA mixture.
-Mr. X has given a statement that he was at the same bar at the same time as Ms. Y.
-Mr. X matches the major contributor to the DNA profile from the fingernails of Ms. Y.
-There is a large LR for the DNA profile that supports the inclusion of Mr. X.
c) The evaluation considering activity level propositions is based upon the DNA from the fingernails of Ms. Y coming from both Ms. Y and Mr. X.
d) It is not in dispute that Ms. Y was involved in an incident where she scratched someone.

Oral Testimony:
I have evaluated the DNA results in this case with respect to two propositions: either Ms. Y scratched Mr. X during a scuffle, or she scratched some unknown person and Ms. Y and Mr. X just happened to be in the same bar at the same time, which might have resulted in casual social interaction.

There is data from research that discusses the occurrence of foreign DNA under one's fingernails after casual social contact. These studies show that recovering even a partial foreign profile from casual contact is remote, and if it is, then it is expected to be at a very low level. Generally, foreign profiles can be attributed to the person's partner, which means it is very unusual to recover a major profile of a non-partner from someone's fingernails, which is the data in this case.

In contrast, scratching during a fight often leads to skin cells, and sometimes even blood and tissue, under one's nails. We can typically expect to recover good quality DNA profiles in this situation, often with the foreign profile being the major donor. Studies done where volunteers have participated in vigorous scratching experiments show foreign profiles in about 60% of the samples collected. Therefore, I have assigned a probability to this evidence of 0.6 if the proposition that Ms. Y scratched Mr. X during a scuffle was true. I would describe this probability as reasonable, because it is unlikely that the volunteers in the scratching experiments I have described scratched as aggressively as what might happen during a fight.

I have also assigned a probability to the evidence given the alternative proposition. If Ms. Y scratched an unknown person instead of Mr. X, yet she was present in the same public space as Mr. X, then this means we did not detect the DNA of the person she scratched. Based in part on the timely collection of the sample, it is very unlikely to not detect DNA from the person Ms. Y scratched and to detect the DNA of a single random person that happened to be at the same bar. Therefore, my probability of the DNA result is very small, in the order of 0.0004 if this alternate proposition were true.

When I consider the two propositions, the DNA results are 1500 times more likely if Ms. Y scratched Mr. X rather than if Ms. Y scratched an unknown person but was present in the same public space as Mr. X.

It is important to note that the LR of 1 billion is for the evaluation of the DNA evidence if Mr. X were a contributor or if some other unrelated person were a contributor of the material from under the fingernails of Ms. Y. This LR of 1500 only relates to my interpretation of the evidence given scratching occurred rather than if only social interaction took place. These numbers are not interchangeable and have very

different magnitudes. We do not ever expect such large LRs for the evaluation of DNA results given activity level propositions.

Evaluation:

a) Background information:

- The scientific literature provides some useful information which allows a quantitative evaluation of obtaining the results if DNA had been transferred by scratching or by social contact. Given that the data represents the state of knowledge in this area at the moment, it can be used to inform my expert opinion.
- Research and data demonstrate that:
  - the incidence of foreign DNA beneath the fingernails in the general population as a result of casual social contact is low;
  - even if foreign DNA is detected, then invariably it is attributable to a person's partner rather than to a random individual and is generally attributed to more intimate contact;
  - foreign DNA profiles from casual social contact tend to be at a low/trace level;
  - scratching promotes the transfer of foreign DNA to fingernails resulting in good quality foreign DNA profiles.
- Experience shows that transfer events of DNA in a social environment are typically complex and involve direct and indirect DNA transfer involving many individuals. This situation is expected to generate low level DNA profile results most likely from multiple foreign contributors.

b) Considering the first proposition:

- If Ms. Y had scratched Mr. X, then I expect a good quality DNA profile a little more than half of the time when sampled in a timely fashion. This is based on a study where volunteers scratched one another for time intervals from 5 to 30 seconds. In that study, 52% of the samples yielded a complete (but minor) foreign DNA profile [Meandhim, 2040].
- More vigorous scratching, such as that which might occur during a fight, would be expected to promote DNA transfer through the transfer of cellular material/skin tissue (and possibly blood) to the fingernail area. The transferred cellular material would produce a good quality DNA profile from the scratched person. The presence of Ms. Y's own DNA would also be expected to form part of the result. These expectations match the DNA findings in this case.
- However, I am adjusting the probability of these results slightly upward given the scratching proposition, since this real-life situation resulted in a major foreign DNA profile. The study by Meandhim only found minor profiles. This is support for more transfer in a real-life fight than that found in the study. Therefore, in my opinion the probability of observing the results if she scratched him would be in the order of 60%.

c) Considering the alternative proposition:

- If no scratching has occurred between Ms. Y and Mr. X, then any DNA matching Mr. X has arisen through social activity.
- Therefore, the scratching has occurred between some unknown person and Ms. Y. This unknown person's DNA profile would be expected to be observed in the result, but this was not the case. Literature shows the absence of a DNA profile of a person who has been scratched is in the order of 20% [Soandso, 2050]. This value is favorable to the alternative proposition, as it is understandable that volunteers would not agree to be scratched in an overly aggressive fashion. The actual probability of not finding DNA from someone scratched in an aggressive fashion, and collected in a timely fashion, is assumed to be less than 20%.
- Research data indicates that finding a foreign DNA profile, following social activities, associated with someone's fingernails is remote, in the order of 2% [Thisandthat, 2060].
- Additionally, my expectation is that any DNA profile resulting from social interaction would be a complex low-level mixture of multiple foreign contributors. Mr. X's DNA would be at the same

level as others whose DNA might have been transferred in a social environment. However, these were not the findings in this case. Because a mixture with a major component was recovered instead of a mixture with multiple trace contributors, the probability is adjusted downward by a factor of 10 for transfer only via social interaction at the same bar.

- I have considered that the events are independent. Therefore, in my opinion, the probability of observing the results if this proposition was true would be 'very low' on the order of 0.0004 (0.2 x 0.02 x 0.1 = 0.0004).

d) In summary, both scenarios might give rise to the findings in this case. However, when considering the probability of observing the results under the different propositions, the results would be considered 1500 times (0.6 / 0.0004) more likely to be observed if the first proposition were true rather than the second.

Possible follow-up questions based on Scenario 5:

Note: The previous examples conclude with the expert opinion. In practice, a series of follow-up questions is common by both parties. The following are examples of questions that might arise after the expert gives his or her opinion.

Q1) So you are saying that it is a billion times more likely that Ms. Y scratched Mr. X?
A) No. The statistical evaluation of a DNA profile result, which addresses the question regarding 'whose DNA is it?' is an entirely different question from addressing 'how and when did the DNA get there?' This means that the statistic of '1 billion' has no bearing on the issues regarding how or when the DNA was transferred. With respect to this question of scratching I have conducted a qualitative evaluation and given a verbal likelihood ratio.

(Notes: This question crosses levels of the hierarchy of propositions and additionally, it contains a transposed conditional.)

Q2) So what you are saying is that Ms. Y scratched Mr. X?
A) No, this is a statement on what has happened, which I do not know. But, I can help with this issue by assessing how likely the results are given the propositions. What I can say is, given that they were in the same bar, I am offering my opinion on the probability of observing the mixed DNA profile result with respect to two propositions:

either Ms. Y scratched Mr. X
or, Ms. Y scratched some unknown person.

In my opinion the DNA result is more likely if Ms. Y scratched Mr. X than if Ms. Y scratched some unknown person. This is a piece of the puzzle that must fit with the other puzzle pieces as the jury tries to decide what happened. I do not have those other pieces.

(Notes: This question is asking for a direct comment on the activity that is alleged to have occurred. This is sometimes referred to as "the ultimate issue". It is not the role of the expert to comment on this. The expert is to comment on the evidence, not the activity.)

Q3) So, it is possible the result can be explained by DNA transfer through social contact?
A) Yes, and I have indeed considered this explicitly in the evaluation of my results. But my evaluation considers the probability of the DNA results (quantity, major corresponding to Mr. X) given one proposition (here, scratching during a scuffle) compared to the alternative (here, social contact in the bar). The evidence I evaluated shows a foreign male profile matching Mr. X from the nails of Ms. Y. I do not expect this result from social contact. I do have some level of expectation of finding these results if someone was scratched during a fight. Therefore, in my opinion the evidence is more likely if Ms. Y scratched Mr. X than if Ms. Y scratched some unknown person. What is important is that my evaluation does not eliminate the possibility that the results were obtained by social contact; however, given that

alternative scenario to scratching during a fight, I consider these results less likely to be observed if the social transfer scenario were true rather than if scratching had occurred as alleged.

(Notes: An LR which says the evidence is more likely if A than if B does not mean that B cannot be "possible". But the term possible has no meaning in a probabilistic assessment of the evidence. In this example, the evidence is "possible" if either option occurred, but the expert analysis clearly favors the evidence as being more likely if Mr. X were scratched by Ms. Y.)

Q4) Are there any other explanations for the findings?

A) I do not have any additional information as a DNA scientist that would help me say what could have happened in this case. I can give you my opinion on the results when given activities of interest to the court, but not on the (alleged) activities themselves. It is not my role. In addition, discussing the probability of these results given only a single explanation offers no real value, as it needs to be put into contrast using alternate propositions. Only then may I offer an opinion that the evidence is more likely under proposition A than proposition B, and those propositions must have some reasonable relation to the case.

(Notes: The expert needs to be aware of the difference between an explanation after the results are known compared to a proposition based on case information. The expert should not be the source of new propositions, and any evaluation of a single proposition by itself has no real meaning in the context of the activities alleged by the parties. For example, the probability of the evidence given explanation A is Pr(E | A) = 0.001 (one in one thousand). Numerically, that is a low number. However if the probability of the evidence given another explanation (B) is Pr(E | B) = 0.0001 (one in ten thousand), then comparatively, Pr(E | A) is a high probability.)

Q5) Your opinion is subjective in that it is based on personal beliefs. Why should the court rely on this?
A) I have considered my results in the light of two propositions. For this I have used my personal knowledge and in that sense, it is my opinion, so it is subjective. But it is not arbitrary nor biased. My opinion is based on my experience, my expertise, and the relevant data and literature that addresses these questions. I am qualified, by virtue of my training, to address the questions put forward to me by the court following a recognized framework, which accommodates both the prosecution and defense alternatives. My opinion is presented in a transparent manner which allows scrutiny and discussion.

(Notes: All expert opinion is subjective to one degree or another, or else there would be no expertise. Even evaluation of evidence given the sub-source level propositions is subjective, as a choice was made about which allele frequency database to use, artifact labeling, statistical models or software, and other issues.)

Q6) The LR reported for the activity level propositions is very much lower than that reported when considering whose DNA might be present (1 billion). Doesn't this mean that the LR of 1500 has less probative value?
A) First of all, the two LRs relate to two very different questions. The LR of "1 billion" is helping to answer the question of "Whose DNA is present?" and the LR of 1500 is helping to answer the question "How did the DNA get there?" The factors that go into the calculation of these two different numbers consider very different things with different magnitudes. The results are also very different. In the first LR, the results pertain to the comparison of two DNA profiles. In the second, as there is no dispute on the source of the DNA for the activity propositions, the results are only the quantity of DNA from which donors - or lack of donors. The two numbers are therefore not comparable as they are addressing different things.

Annex C
(informative)
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