EXAMINING THE ROLE OF SCIENCE IN THE COURTROOM: ADMISSIBILITY AND RELIABILITY OF FORENSIC SCIENCE IN THE COURTROOM

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ABSTRACT

There has been an increase in the recognition of the role of human cognition within the field of forensic science. This has entailed a growing understanding of the limitations and vulnerabilities of human decision-making when making decisions under conditions of uncertainty, and how these may impact the admissibility and reliability of forensic science. These often occur as a result of motivational or cognitive biases, and this paper will discuss how they may influence every stage of the investigation. The lack of a scientific foundation behind many of the methods used to analyze and communicate the value of evidence is also reviewed. It is important to address these issues as forensic science plays a much wider role within society.

The capabilities of forensic science have expanded and evolved over the years, facing a number of significant challenges. A main weakness is its susceptibility to cognitive bias.[1] Today, despite remaining a powerful element within the justice system, and playing a key role in establishing and reconstructing events, forensic science

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[1] Itiel E. Dror, *Biases in Forensic Experts*, SCI. MAG., Apr. 20, 2018, at 243, http://science.sciencemag.org/content/360/6386/243

much like any scientific domain, faces weaknesses and limitations. These issues can arise throughout an investigation; from when the forensic evidence is first collected at the scene of the crime, until the evidence is presented at court. While recognizing the cognitive and scientific challenges forensic science faces, this paper also demonstrates that the value of forensic science extends beyond the courtroom.

I. WHEN IT GOES WRONG

Forensic science is often assumed to be scientific and impartial. Yet, examining wrongful convictions in the United States reveals that sixty percent of the cases involved flawed forensic testimony.[2] The United States' National Academy of Sciences ("NAS") released a report in 2009, calling into question the scientific validity of many forensic domains, stating that, "[w]ith the exception of nuclear DNA analysis, however, no forensic method has been rigorously shown to have the capacity to consistently, and with a high degree of certainty, demonstrate a connection between evidence and a specific individual or source."[3] Despite this, studies have demonstrated that DNA evidence is hardly incontrovertible.

In 2016, a report by the President's Council of Advisors on Science and Technology ("PCAST") stated that irrelevant contextual information can bias the interpretation of DNA evidence.[4] In one particular study supporting this, seventeen expert DNA examiners were asked for their interpretation of a DNA mixture previously examined in an adjudicated criminal case.[5] They were only provided with relevant contextual information, but their interpretations were still found to be inconsistent with each other.[6] If mixed DNA interpretation was truly objective, all the expert DNA examiners would have come to the same conclusions. Furthermore, the majority of the examiners that were context-free (unaware of the details of the case), disagreed with the laboratory's pre-trial conclusions.[7] Hence,

[2] *See* Brandon L. Garrett & Peter J. Neufeld, *Invalid Forensic Science Testimony and Wrongful Convictions*, 95 VA. L. REV. 1, 9, 13–14 (2009).

[3] NAT'L RESEARCH COUNCIL, STRENGTHENING FORENSIC SCIENCE IN THE UNITED STATES: A PATH FORWARD 7 (2009) [hereinafter NAS].

[4] *See* PRESIDENT'S COUNCIL OF ADVISORS ON SCI. & TECH., FORENSIC SCIENCE IN CRIMINAL COURTS: ENSURING SCIENTIFIC VALIDITY OF FEATURE-COMPARISON METHODS 76 (2016), https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/PCAST/pcast_forensic_science_report_final.pdf [hereinafter PCAST].

[5] *See id.* at 76, 77.

[6] *See id.* at 77.

[7] *Id.* at 76, 77; Itiel E. Dror & Greg Hampikian, *Subjectivity and Bias in Forensic DNA*

the irrelevant contextual information surrounding the original DNA evidence may have influenced the interpretation of that evidence, thereby showing a biasing effect of contextual information in DNA mixture interpretation.[8]

The PCAST report also stated that several forensic techniques should no longer be used in court until sufficient scientific research is done to validate their accuracy and reliability.[9] It was stated that some of the forensic methods used have been assumed rather than established to be foundationally valid based on appropriate empirical evidence.[10] Firearm, fingerprint, bite-mark, and hair analysis are just a few of the methods found to fall short.[11] The assumption that within each of these fields one can rely on the uniqueness of a source has been continuously challenged by studies of variability in proficiency testing and in actual cases.[12]

Hence, various inquiries into forensic science, empirical research, and actual casework have revealed two major issues with forensic science: first, the lack of an empirical foundation, and second, the susceptibility of forensic decision-making to context and potentially bias.[13] It is important to distinguish the two issues, as these have different roles to play in the forensic science process. This paper examines the whole arc of the process, starting from the crime scene, continuing to the analysis and interpretation of the evidence, and ending with the presentation of the findings. These issues will be discussed to determine how and where they arise in the field of forensic science, and how such problems can impact the fair administration of justice.

II. WHY DOES FORENSIC SCIENCE GO WRONG?

The majority of forensic science still relies on the human examiner to be the instrument of analysis.[14] Therefore, a deeper comprehension of the processes involved in judgment and decision-making, and how they relate to forensic science has to be considered.

Mixture Interpretation, 51 SCI. & JUST. 204, 204 (2011).

[8] Dror & Hampikian, *supra* note 7, at 205.

[9] PCAST, *supra* note 4, at 122.

[10] *See id.*

[11] *See id.* at 87, 101, 102, 112–13, 120, 121 (noting that while latent fingerprint analysis is foundationally valid the false positive rate is large and higher than expected by jurors).

[12] Michael J. Saks & Jonathan J. Koehler, *The Coming Paradigm Shift in Forensic Identification Science*, 309 SCI. 892, 892 (2005).

[13] *See* Itiel E. Dror, *Cognitive Neuroscience in Forensic Science: Understanding and Utilizing the Human Element*, 370 PHIL. TRANSACTIONS ROYAL SOC'Y B. 1, 1 (2015).

[14] *See id*.

A practical example of how decision-making processes are vulnerable to cognitive limitations can be seen by examining the lack of inter-rater reliability across experts and intra-rater reliability over time within the same expert.[15] These terms refer to how consistent conclusions are between forensic experts, as well as within themselves respectively. Many studies on fingerprint analysis have found that examiners' decisions are not always in agreement,[16] and in particular, a study in 2011 found that only sixteen percent of participating experts observed the exact same number of fingerprint minutiae when analyzing the same latent fingerprint mark a few months later.[17]

The lack of reliability within and between examiners indicates that the identification process can be subjective and that judgments are susceptible to bias from other sources.[18] Often, forensic analysis conclusions are drawn from observations on whether two patterns are "sufficiently similar."[19] These methods often have no quantification, and thus, these judgments lead to subjective observations. Especially problematic are cases containing complex or ambiguous forensic evidence—which crime scene evidence often is.[20]

III. BIASES LEADING TO FLAWED DECISION-MAKING AND JUDGMENT

The literature in behavioral research has demonstrated that judgments and decisions are subject to numerous influencing variables.[21] The term most often used to describe these in the

[15] *See* Itiel E. Dror et al., *Cognitive Issues in Fingerprint Analysis: Inter- and Intra-expert Consistency and the Effect of a 'Target' Comparison*, 208 FORENSIC SCI. INT'L 10, 11 (2011); I.W. Evett & R.L. Williams, *A Review of the Sixteen Points Fingerprint Standard in England and Wales*, 65 J. FORENSIC IDENTIFICATION 557, 566, 578 (2015); Glenn Langenburg, *A Performance Study of the ACE-V Process: A Pilot Study to Measure the Accuracy, Precision, Reproducibility, Repeatability, and Biasability of Conclusions Resulting from the ACE-V Process*, 59 J. FORENSIC IDENTIFICATION 219, 224, 238 (2009).

[16] *See, e.g.*, Dror et al., *supra* note 15, at 13; Evett & Williams, *supra* note 15, at 569, 572; Langenburg, *supra* note 15, 239, 243; Bradford T. Ulery et al., *Accuracy and Reliability of Forensic Latent Fingerprint Decisions*, 108 PROC. NAT'L ACAD. SCI. 7733, 7738 (2011).

[17] Dror et al., *supra* note 15, at 14.

[18] *See* Dror, *supra* note 1.

[19] Saul M. Kassin et al., *The Forensic Confirmation Bias: Problems, Perspectives, and Proposed Solutions*, 2 J. APPLIED RES. MEMORY & COGNITION 42, 43 (2013).

[20] *See* Itiel E. Dror et al., *When Emotions Get the Better of Us: The Effect of Contextual Top-down Processing on Matching Fingerprints*, 19 APPLIED COGNITIVE PSYCHOL. 799, 800 (2005); Lisa J. Hall & Emma Player, *Will the Introduction of an Emotional Context Affect Fingerprint Analysis and Decision-Making?*, 181 FORENSIC SCI. INT'L 36, 36 (2008).

[21] *See, e.g.*, Hans Ditrich, *Cognitive Fallacies and Criminal Investigations*, 55 SCI. & JUST. 155, 155, 156 (2015).

literature is biases.[22] The two main categories of the biases that will be discussed in this paper are cognitive and motivational.[23] Cognitive biases are the result of unwarranted and illogical inferences.[24] These inferences are a result of mental shortcuts to logical reasoning that individuals develop unconsciously, as a consequence of their experiences.[25] In forensic science, the most common types of cognitive biases that have been studied in the literature are confirmation bias[26] and contextual bias.[27] Motivational biases, on the other hand, include conscious or subconscious judgments, and decisions that are influenced by self-interest, social pressures, or organizational context.[28]

Research has found that there are seven potential sources by which these cognitive and motivational biases influence the judgments and decisions that forensic experts have to make.[29] A taxonomy developed by Dror illustrates how these sources interact with each other, and can be seen in Figure 1, below.[30] The structure of the taxonomy begins with the foundational level, which relates to basic human nature and the architecture of the brain.[31] The mere fact of

[22] *See, e.g.*, Gilberto Montibeller & Detlof von Winterfeldt, *Cognitive and Motivational Biases in Decision and Risk Analysis*, 35 RISK ANALYSIS 1230, 1230 (2015).

[23] *See id.* at 1230, 1231.

[24] *See* Ziva Kunda, *The Case for Motivated Reasoning*, 108 PSYCHOL. BULL. 480, 480 (1990).

[25] *See* BERNARD ROBERTSON ET AL., INTERPRETING EVIDENCE: EVALUATING FORENSIC SCIENCE IN THE COURTROOM 64, 102 (2nd ed. 2016).

[26] *See* Jon S. Byrd, *Confirmation Bias, Ethics, and Mistakes in Forensics*, 56 J. FORENSIC IDENTIFICATION 511, 511 (2006); Paul C. Giannelli, *Confirmation Bias*, 22 CRIM. JUST. 60, 60–61 (2007); Kassin et al, *supra* note 19, at 44; Jose Kerstholt et al., *Does Suggestive Information Cause a Confirmation Bias in Bullet Comparisons?*, 198 FORENSIC SCI. INT'L 138, 138 (2010); Sherry Nakhaeizadeh et al., *Cognitive Bias in Forensic Anthropology: Visual Assessment of Skeletal Remains is Susceptible to Confirmation Bias*, 54 SCI. & JUST. 208, 208 (2014).

[27] *See* Dror et al., *supra* note 20, at 801, 806; Itiel E Dror et al., *Contextual Information Renders Experts Vulnerable to Making Erroneous Identifications*, 156 FORENSIC SCI. INT'L 74, 76 (2006); Bryan Found & John Ganas, *The Management of Domain Irrelevant Context Information in Forensic Handwriting Examination Casework*, 53 SCI. & JUST. 154, 154 (2013); Hall & Player, *supra* note 20, at 38; Mark Page et al., *Context Effects and Observer Bias—Implications for Forensic Odontology*, 57 J. FORENSIC SCI. 108, 108 (2012).

[28] *See* Montibeller & von Winterfeldt, *supra* note 22, at 1230.

[29] *See, e.g.*, Itiel E. Dror, *Human Expert Performance in Forensic Decision Making: Seven Different Sources of Bias*, 49 AUSTL. J. FORENSIC SCI. 541, 542, 543 fig. 1 (2017).

[30] *See Id.*

[31] *See id.* at 543 fig. 1; *see, e.g.*, Bin Mai et al., *Neuroscience Foundations for Human Decision Making in Information Security: A General Framework and Experiment Design*, *in* INFO. SYS. & NEUROSCIENCE 91, 94 (F.D. Davis et al. eds., 2017); Maël Arnaud et al., *The Role of Cognitive Biases in Reactions to Bushfires*, PROC. OF 14TH ISCRAM CONF. 87 (Tina Comes et al. eds., 2017), http://idl.iscram.org/files/maelarnaud/2017/1448_MaelArnaud_etal2017.pdf); Patrick Haggard, *Sense of Agency in the Human Brain*, 18 NATURE REV. NEUROSCIENCE 197, 206 (2017); Dominic D.P. Johnson et al., *The Evolution of Error: Error Management, Cognitive Constraints, and Adaptive Decision-Making Biases*, 28 TRENDS ECOLOGY & EVOLUTION 474, 476 (2013); Geoffrey R. Norman et al., *The Causes of Errors in Clinical Reasoning: Cognitive*

human vulnerability to limitations of the brain underpins the subsequent levels of the taxonomy. As we progress up the taxonomy, the sources of bias become more conditional on the specific environmental circumstances and individuals involved.[32] Examples of these are: training[33], motivation[34], organizational culture[35], as well as base-rate expectations.[36] The highest level of the taxonomy presents sources of bias that are specific to the case at hand, such as irrelevant contextual case information, as well as the reference materials and actual evidence from the crime scene and the suspect.[37]

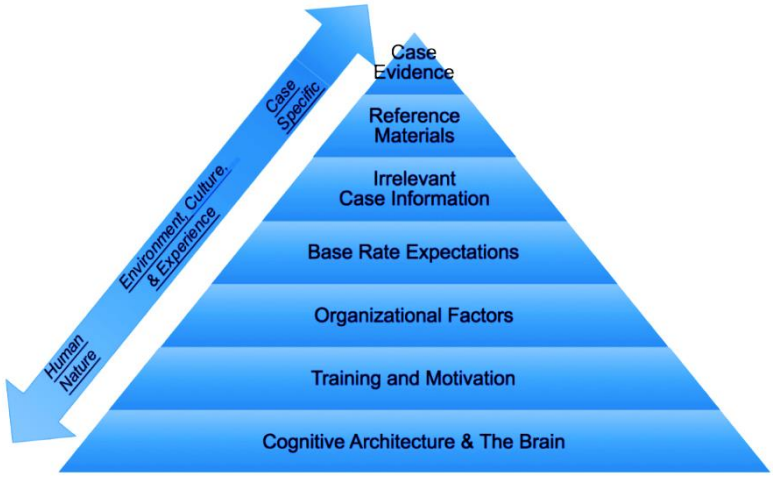

Figure 1. Dror's taxonomy of different sources of bias that may cognitively impact forensic observations and conclusions.[38]

The concern is that any bias can create flawed decision-making at any stage of an investigation and, consequently, affect the following

Biases, Knowledge Deficits, and Dual Process Thinking, 92 ACAD. MED. 23, 24 (2017).

[32] *See* Dror, *supra* note 29, at 542.

[33] *See* Dror & Hampikian, *supra* note 7, at 205; Larry S. Miller, *Procedural Bias in Forensic Science Examinations of Human Hair.*, 11 L. & HUM. BEHAV. 157, 161, 162 (1987).

[34] *See* Paul C. Giannelli, *Independent Crime Laboratories: The Problem of Motivational and Cognitive Bias*, 2 UTAH L. REV 247, 251 (2010); Montibeller & von Winterfeldt, *supra* note 22, at 1231; Daniel C. Murrie et al., *Are Forensic Experts Biased by the Side that Retained Them?*, 24 PSYCHOL. SCI. 1889, 1895 (2013).

[35] *See* Dror et al., *supra* note 15, at 10; D. Michael Risinger et al., *The Daubert/Kumho Implications of Observer Effects in Forensic Science: Hidden Problems of Expectation and Suggestion*, 90 CALIF. 1, 39 (2002).

[36] *See* Michael J. Saks & D. Michael Risinger, *Baserates, the Presumption of Guilt, Admissibility Rulings, and Erroneous Convictions*, 4 MICH. ST. DCL L. REV. 1051, 1057 (2003).

[37] Dror, *supra* note 29, at 542, 543.

[38] *See id.* at 543 fig. 1.

stages as that investigation progresses. Bias cascade and bias snowball effects are terms that refer to this phenomenon.[39] The bias cascade effect is when bias arises by cascading from one stage to another, e.g., from the initial evidence collection at the crime scene, to the evaluation and interpretation of the evidence at the forensic laboratory.[40] The bias snowball effect increases as a variety of sources are integrated and influence each other.[41] The following section of this paper will discuss each stage of an investigation and what some of the current literature has found in terms of the potential impacts on decision making at each stage of a forensic reconstruction.

IV. THE INVESTIGATION

These seven sources of bias have the potential to occur and influence every stage of the investigation, even before the evidence is submitted to the forensic laboratory. At the crime scene, a specialist advisor or a crime scene examiner must initially determine where to look for evidence, and then decide whether what they find is relevant to the case.[42] It then must be determined if sufficient information can be gained from submitting the evidence in to be analyzed, to justify sending it to the laboratory.[43] These decisions often depend on the environment and context at the crime scene; however, the same contextual information has the potential to have an impact upon what is looked for, where it is looked for, and how it is collected.[44] This can be particularly concerning, as these are vital decisions that impact the future 'success' of the investigation, for instance, material that is not collected at the time often cannot be retrieved later.

The next stage in the investigative process occurs when the evidence arrives at the forensic laboratory. Before it is interpreted and used for identification, it first must be perceived. At this stage, in some environments, experts are potentially surrounded by unnecessary contextual information about the case. This may

[39] *See* Itiel E. Dror et al., Letter to the Editor, *The Bias Snowball and the Bias Cascade Effects: Two Distinct Biases that May Impact Forensic Decision Making*, 62 J. FORENSIC SCI. 832, 832 (2017).

[40] *Id.*

[41] *See* Dror, *supra* note 29, at 542.

[42] *See* HANDBOOK OF FORENSIC SCIENCE 257, 374 (Jim Fraser & Robin Williams eds., 2013)

[43] *Id.* at 257, 532.

[44] *See* Howard Atkin & Jason Roach, *Spot the Difference: Comparing Current and Historic Homicide Investigations in the UK*, 1 J. COLD CASE REV. 5, 8 (2015).

include knowing the nature and the details of the crime, knowing information about the suspects (e.g., their past criminal convictions), as well as potentially experiencing pressure from other actors within the justice system.[45] In some environments, forensic experts can receive direct communications from these other actors in the justice system, either electronically, on the phone, or in person, as well as receiving information from different examiners involved in the same case.[46] While there are documented benefits in some circumstances to a collaborative approach, communication between forensic scientists and outside parties can potentially lead to motivational bias. Two illustrative examples are Fred Zain and Joyce Gilchrist: two experts who became infamous for routinely reporting results that favored the prosecution.[47]

The information that is passed from other members of the justice system to forensic scientists may also result in irrelevant contextual influences. Consequentially, these can impinge on forensic examiners' ability to be objective because of cognitive and motivational biases, as in the Madrid Bomber case.[48] In this case, the latent fingerprint was collected and examined against a pre-existing "target."[49] The fingerprint was *not* first analyzed in isolation.[50] As a result, the examiners were primed with contextual information, leading them to examine the evidence with a target in mind.[51] Furthermore, the case was high-profile and time-sensitive, increasing the pressure for closure.[52] It has been asserted that these factors influenced the motivation of the examiners and created a

[45] *See* Kassin et al., *supra* note 19, at 48.

[46] *See id.* at 43.

[47] *See* Elisa Bergslien, *Teaching to Avoid the "CSI Effect": Keeping the Science in Forensic Science*, 83 J. CHEMICAL EDUC. 690, 691 (2006); Giannelli, *supra* note 34, at 251; Paul C. Giannelli, *Wrongful Convictions and Forensic Science: The Need to Regulate Crime Labs*, 86 N.C.L. REV. 163, 172, 173, 174 (2006).

[48] *See* Itiel E. Dror & Simon A. Cole, *The Vision in "Blind" Justice: Expert Perception, Judgment, and Visual Cognition in Forensic Pattern Recognition*, 17 PSYCHONOMIC BULL. & REV. 161, 162 (2010); Dror et al., *supra* note 27, at 74; Robert B. Stacey, *Report on the Erroneous Fingerprint Individualization in the Madrid Train Bombing Case*, 7 FORENSIC SCIENCE COMM., no. 1, Jan. 2005, https://archives.fbi.gov/archives/about-us/lab/forensic-science-communications/fsc/jan2005/special_report/2005_special_report.htm; Giannelli, *supra* note 26, at 61; Giannelli, *supra* note 47, at 203, 204.

[49] OFFICE OF THE INSPECTOR GEN.: U.S. DEP'T OF JUSTICE, A REVIEW OF THE FBI'S HANDLING OF THE BRANDON MAYFIELD CASE 1, 7 (2006), https://oig.justice.gov/special/s0601/final.pdf.

[50] *See id.* at 1.

[51] *See id.* at 12.

[52] David Charlton et al., *Emotional Experiences and Motivating Factors Associated with Fingerprint Analysis*, 55 J. FORENSIC SCI. 385, 391 (2010).

bias.[53] Furthermore, two additional FBI examiners corroborated and verified the erroneous identification.[54] It is possible that confirmation bias was the cause for the verification of the erroneous identification of the fingerprint mark.[55]

For these reasons, it has been suggested that the forensic examiners need to work from the evidence to the suspect, and not backwards, from the suspect to the evidence. There is, therefore, a strong argument for incorporating procedures such as Linear Sequential Unmasking ("LSU"), which aims to minimize the influence of context on decision making, such as confirmation bias.[56] Such procedures ensure that the case evidence and reference material are examined in isolation in order to minimize the context (and influence) of the "target" suspect. It is only after it has been examined in isolation that the examiner is then exposed to information regarding the suspect.

There are instances, however, where the biasing information is so inherent and integrated into the evidence that it is almost impossible to separate them. For instance, a shoe print, on its own, may not provide much contextual information about the case, but semen on an item of clothing might. It may be that unconscious judgments are made based on the appearance of the clothing worn by the parties involved.[57] Thus, it can be very difficult to carry out a "blind" interpretation, as some suggest, without access to the conditioning information (framework of information surrounding the case).[58] This same issue arises when a case is particularly emotional—for example, there is a debate among scholars arguing that higher emotional intensity leads to more "matches" being identified with ambiguous fingerprint marks.[59]

The next stage of the investigation is the comparative stage, where evidence is compared to a potential source. Any effect of irrelevant contextual information, which may have occurred at an earlier stage, has the potential to impact the comparative stage (bias cascade). An

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[53] *See* Giannelli, *supra* note 47, at 204–05.

[54] Dror & Cole, *supra* note 48, at 162.

[55] *See, e.g.*, Giannelli, *supra* note 26, at 61.

[56] *See* Itiel E Dror et al., *Context Management Toolbox: A Linear Sequential Unmasking (LSU) Approach for Minimizing Cognitive Bias in Forensic Decision Making*, 60 J. FORENSIC SCI. 1111, 1112 (2015).

[57] *See* Mark D. Everson & Jose Miguel Sandoval, *Forensic Child Sexual Abuse Evaluations: Assessing Subjectivity and Bias in Professional Judgements*, 35 CHILD ABUSE & NEGLECT 287, 296, 297 (2011).

[58] *See* Dror & Cole, *supra* note 48, at 161, 165; Hall & Player, *supra* note 20, at 39.

[59] *See* Dror et al., *supra* note 20, at 806; Hall & Player, *supra* note 20, at 37.

example can be found in a study within the field of Forensic Anthropology.[60] The study found that in an assessment of the sex of a human skeleton, 31 percent of the control group concluded that the remains were male. "However, in the group that received extraneous contextual information that the remains were male, 72% indicated the remains were male . . . [and in] the group that was given the context that the remains were of a female, 100% of the participants concluded the remains to be female."[61] This suggests that, prior to the analysis of the remains, the participants exposed to the contextual information were affected and it influenced the conclusions drawn from their subsequent analysis. Even with the assistance of statistical tools to assist with this stage of the investigations, results have been shown to be inconsistent and potentially influenced by context.[62]

The influence of cognitive factors has also been observed when examining variability of conclusions not across different forensic examiners, but with the same examiner at different times.[63] This issue can arise due to inherent uncertainty in science and in forensic reconstruction approaches. For example, there are often only partial samples from a crime scene to be compared against a comparator sample from particular suspect.[64] Another issue is that given that no two patterns are identical, an examiner must determine whether they are "sufficiently similar" and come to a conclusion as to the likelihood of whether or not they originate from the same source.[65]

In one published study, the Madrid Bomber case was used to construct a context that suggested that two similar prints were not from the same source.[66] Five expert latent print examiners, who had not seen the original prints from the Madrid Bomber or Brandon Mayfield (the individual who was wrongly identified as the bomber by the FBI), were involved in data collection.[67] The experts were presented with a pair of prints and were told that they were from the

[60] *See, e.g.*, Nakhaeizadeh et al., *supra* note 26, at 208.

[61] *Id.*

[62] *See, e.g.*, MICHAEL COBLE, INTERPRETATION ERRORS DETECTED IN A NIST INTERLABORATORY STUDY ON DNA MIXTURE INTERPRETATION IN THE U.S. (MIX 13) (2015); Dror & Hampikian, *supra* note 7, at 205; Itiel Dror & Robert Rosenthal, *Meta-Analytically Quantifying the Reliability and Biasability of Forensic Experts*, 53 J. FORENSIC SCI. 900, 903 (2008); Bradford T. Ulery et al., *Repeatability and Reproducibility of Decisions by Latent Fingerprint Examiners*, 7 PLOS ONE 1, 1 (2012).

[63] *See* Dror & Rosenthal, *supra* note 62, at 902.

[64] *See id.* at 901.

[65] Kassin et al., *supra* note 19, at 43. *See, e.g.*, Ulery et al., *supra* note 62, at 8.

[66] *See* Dror et al., *supra* note 27, at 74.

[67] *See, e.g.*, *id.* at 75.

Madrid Bomber case, but they were in fact presented with a pair of prints that they had previously concluded to be a match in a real criminal case. Four of the five examiners contradicted their original conclusions. Three of them changed their identification to exclusion, one from identification to inconclusive, and only one stuck with the original response.

During the verification stage, further cognitive and motivational biases may also arise.[68] Issues around verification can be impacted by base-rate biases.[69] Identifications are most often verified, thus causing an a priori expectation to verify.[70] The use of databases may also cause a bias when the experts verify the data that is suggested to them. For example, the Automated Fingerprint Identification System ("AFI") is a computer assisted system which is used for automatically, opposed to manually, comparing and searching for fingerprints and determining when there are associations between multiple friction ridge impressions of known or unknown sources.[71] It has been argued that when fingerprint marks are ranked by the closest match, this may result in the forensic expert examining the data in a top-down fashion.[72] This top-down fashion means the forensic expert has arguably already been influenced by prior knowledge, which may influence the examination and potentially give rise to a conclusion of a match because AFIS has ranked a particular print "first."[73]

Another issue which affects the reliability of the verification process is that forensic examiners' conclusions are not blind—it is often the case that examiners know who made the initial decision and what they based their decision on.[74] When, as in many forensic laboratories, the examiners choose who will verify their work,[75] interpersonal issues arise. The human element highlights the importance of considering the protocols and standard operating procedures that are employed.[76]

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[68] *See* Dror, *supra* note 13, at 4.

[69] *See* Saks & Koehler, *supra* note 12, at 895; Saks & Risinger, *supra* note 36, at 1051.

[70] *See* Dror, *supra* note 13, at 4.

[71] Cedric Neumann et al., *Determination of AFIS "Sufficiency" in Friction Ridge Examination*, 263 FORENSIC SCI. INT'L 114, 114, 115 (2016).

[72] *See* Itiel E. Dror & Jennifer L. Mnookin, *The Use of Technology in Human Expert Domains: Challenges and Risks Arising from the Use of Automated Fingerprint Identification Systems in Forensic Science*, 9 LAW. PROBABILITY & RISK 47, 59–60 (2010).

[73] *Id.*

[74] *See* Dror & Cole, *supra* note 48, at 162.

[75] *See* Dror, *supra* note 13, at 4.

[76] *See* Itiel E. Dror, *Practical Solutions to Cognitive and Human Factor Challenges in Forensic Science*, 4 FORENSIC SCI. POL'Y & MGMT. 1, 3 (2013); Kassin et al., *supra* note 19, at

V. THE COURTROOM

The popularity of TV programs, such as CSI, has provided the public with an arguably idealized and in some cases unrealistic perspective of forensic science.[77] These programs portray evidence as if it is black or white, and they often minimize the importance of the interpretation of the evidence within a specific case context, and the inherent uncertainty that is present in all science, including forensic science. This is known as the CSI effect, and there is some concern that it may influence jurors into having higher expectations of evidence presented at court.[78] However, the literature has come to mixed conclusions. It has been argued that although the CSI effect does occur and effects perceptions of evidence,[79] there is little to indicate that these perceptions significantly impact the judgment and decisions the jury makes regarding the final outcome of each case.[80] Still, research on forensic investigators and prosecutors suggests that the majority of these individuals believe juries are much more heavily influenced by the CSI effect than they are.[81]

The main concern is the possibility that juries may be mislead by the science.[82] Even the confidence with which the expert witnesses present their evidence has a significant impact on their perceived credibility.[83] This can be especially problematic within adversarial legal systems, as expert witnesses are often brought into the legal proceedings to strengthen a case (for, or against a suspect). Hence, experts are arguably often recruited to play a role that is beyond that of scientific expertise. The defense and prosecutors may have less interest in the evidence itself, and more for what that evidence might mean for each side of the case. Consequently, juries become

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[77] *See* Donald E. Shelton, *The 'CSI Effect': Does It Really Exist?*, 259 NAT'L INST. JUST. J. 1, 2 (2008).

[78] *See id.*

[79] *See, e.g.*, Kit R. Roane & Dan Morrison, *The CSI Effect*, 138 U.S. NEWS & WORLD REP. 48, 49 (2005); Jeffrey Toobin, *The CSI Effect: The Truth About Forensic Science*, NEW YORKER (May 7, 2007), https://www.newyorker.com/magazine/2007/05/07/the-csi-effect.

[80] *See* Shelton, *supra* note 77, at 5.

[81] *See* Dante E. Mancini, *The CSI Effect Reconsidered: Is It Moderated by Need for Cognition?*, 13.1 N. AM. J. PSYCHOL. 155, 156 (2011).

[82] *See* Monica L. P. Robbers, *Blinded by Science: The Social Construction of Reality in Forensic Television Shows and Its Effect on Criminal Jury Trials*, 19 CRIM. JUST. POL'Y REV. 84, 86 (2008).

[83] *See* Robert J. Cramer et al., *Expert Witness Confidence and Juror Personality: Their Impact on Credibility and Persuasion in the Courtroom*, 37 J. AM. ACAD. PSYCHIATRY L. 63, 65 (2009).

particularly vulnerable to being misinformed.[84]

It has been reasoned that this should not be a concern when two experts have two "strongly opposed" opinions, as it is thought to improve the quality of information that is presented to the juries.[85] For instance, if two expert witnesses hold strongly opposing opinions on a specific piece of evidence, it is argued that an expert witness can have an "incentive to provide additional information" in support of their side.[86] Therefore, even if the two sides are biased, it allows the jury to objectively put one bias against the other and produce an unbiased conclusion.[87]

These arguments, however, are only as good as the forensic evidence itself, its interpretation, and its presentation. Problems can occur when the courtroom does not have the time or expertise to follow the two different opinions.[88] Instead of two sides "balancing each other out," the science can often be misunderstood, misused, and abused in the courtroom, all within the motivation of the different sides of the adversarial system. This can happen when there is a failure to effectively communicate some of the uncertainties that are associated with the evaluation of hypotheses, which can result in an inaccurate understanding of the evidential value of the evidence.[89] Consequentially, this can support an incorrect hypothesis, while reporting opposition against the correct hypothesis.[90]

Evidence of this comes from a recent study, which investigated 10,859 cases heard in the Court of Appeal of England and Wales between the years 2010 and 2016.[91] Notably, "[o]f the 996 cases

[84] *See, e.g.*, Erica Beecher-Monas, *Blinded by Science: How Judges Avoid the Science in Scientific Evidence*, 71 TEMP. L. REV. 55, 66–67, 83–84 (1998).

[85] Roger Koppl & E. James Cowan, *A Battle of Forensic Experts Is Not A Race to the Bottom*, 22 REV. POL. ECON. 235, 254 (2010); Roger Koppl & Dan Krane, *Minimizing and Leveraging Bias in Forensic Science, in* BLINDING AS A SOLUTION TO BIAS: STRENGTHENING BIOMEDICAL SCIENCE, FORENSIC SCIENCE, AND LAW 151, 159 (Christopher T. Robertson & Aaron S. Kesselheim eds., 2016); Glen Whitman & Roger Koppl, *Rational Bias in Forensic Science*, 9 L. PROBABILITY & RISK 69, 86 (2010).

[86] Koppl & Krane, *supra* note 85, at 159.

[87] Éadaoin O'Brien et al., *Science in the Court: Pitfalls, Challenges and Solutions*, 370 PHIL. TRANSACTIONS R. SOC. B. 1, 2 (2015).

[88] *See* Jennifer L. Mnookin et al., *The Need for A Research Culture in the Forensic Sciences*, 58 UCLA L. REV. 725, 743–44 (2011).

[89] *See* Nadine M. Smit et al., *A Systematic Analysis of Misleading Evidence in Unsafe Rulings in England and Wales*, 58 SCI. & JUST. 128, 131 (2018).

[90] *See* W. Kerkhoff et al., *Design and Results of an Exploratory Double Blind Testing Program in Firearms Examination*, 55 SCI. & JUST. 514, 515 (2015); William C. Thompson, *The Potential for Error in Forensic DNA Testing (And How That Complicates the Use of DNA Databases for Criminal Identification)*, GENE-WATCH 17, 18 (Aug. 12, 2008), http://www.councilforresponsiblegenetics.org/pageDocuments/H4T5EOYUZI.pdf.

[91] Smit et al., *supra* note 89, at 131.

which involved criminal *evidence*, rulings in 218 cases (22%) were argued unsafe because they contained *misleading evidence*."[92] "[T]he relevance, probative value, and validity of evidence [were] often misunderstood and miscommunicated within a criminal trial when expressing beliefs in (competing) hypotheses."[93] Since most of these rulings were overturned without the introduction of new evidence in the appeal, it indicates that they could have been avoided if the interpretations more accurate to begin with."[94]

Another study revealed that in 60 percent of the 137 trials of exonerees that were analyzed, forensic scientists working for the prosecution provided invalid testimony.[95] The invalid testimony which occurred in these cases could be divided in two groups: (1) the misuse of empirical population data, and (2) conclusions regarding the probative value of evidence that were unsupported by empirical data.[96] This study in particular used the Dotson case as an example of the first type of invalid testimony.[97] The forensic scientists included Dotson within the 11 percent of the population that could have been the semen donor, when in fact 100 percent of the population could have been the donor. An example of the second type of invalid testimony was in Timothy Durham's case, where, despite the lack of empirical data available on the frequency of hair characteristics, it was said that the "particular reddish-yellow hue" of his hair and the crime scene hair could only be found in "about 5 percent of the population."[98] Achieving a robust and reproducible forensic reconstruction of events depends on an empirical base for understanding the significance of forensic evidence.[99]

This issue of overstating conclusions and confidence in the interpretation of forensic science evidence is especially apparent and problematic within the adversarial legal system. It has also been observed that there have been occasions where there has been a failure to point out the limits and universalities of conclusions.[100] In fact, "[m]any forensic disciplines have been overwhelmed with high-

[92] *Id.*
[93] *Id.* at 135.
[94] *Id.*
[95] Garrett & Neufeld, *supra* note 2, at 9.
[96] *Id.*
[97] *See id.*
[98] *Id.*
[99] *See* Ruth M. Morgan, *Conceptualising Forensic Science and Forensic Reconstruction. Part I: A Conceptual Model*, 57 SCI. & JUST. 455, 456 (2017).
[100] *See* Andrea O. Baumann et al., *Overconfidence Among Physicians and Nurses: The 'Micro-Certainty, Macro-Uncertainty' Phenomenon*, 32 SOC. SCI. & MED. 167, 167 (1991).

profile errors."[101] One example comes from the ongoing review of the FBI's microscopic hair comparisons. The forensic experts were looking for distinguishing features such as the "thickness, texture, and pigment in a hair strand." It was revealed, however, that erroneous statements occurred in more than 90 percent of cases in which FBI examiners gave testimony.[102] Interestingly, it was often stated by analysts that hair could be individually linked with a specific individual, which we now know hair analysis cannot prove.[103]

These issues can be exacerbated if forensic examiners present the evidence as objective and unaffected by irrelevant case and contextual information to which they have been exposed.[104] This is sometimes referred to as the bias blind spot,[105] which has been confirmed by a recent study which found that out of 403 forensic examiners, nearly all regarded their judgments as nearly infallible.[106] Furthermore, courts are often found to accept unsubstantiated and unsupported claims provided in forensic science testimony.[107]

VI. PRESENTATION

If a case has gone through the entire investigative and court process with transparency and mitigation of any influences of context, and has been robustly communicated to members of the court, it may still be problematic to assess the significance and weight of the evidence. This is because judicial case decisions, whether they are made by judges or juries, are determined by humans and so are governed and limited by the workings of the brain and cognitive architecture.[108]

Behavioral and cognitive neuroscience research has presented some of the issues within the field of forensic science, but also the bias that can occur when it is communicated to the judges and jury. For instance, the primacy and recency effects demonstrate how order and sequencing of information influences what is most

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[101] *See* Kelly Servick, *Sizing Up the Evidence*, 351 SCI. 1130, 1131 (2016)

[102] *Id.*

[103] *Id.*

[104] *See* Emily Pronin et al., *Objectivity in the Eye of the Beholder: Divergent Perceptions of Bias in Self Versus Others.*, 111 PSYCHOL. REV. 781, 783 (2004).

[105] *See id.* at 785, 788.

[106] *See* Jeff Kukucka et al., *Cognitive Bias and Blindness: A Global Survey of Forensic Science Examiners*, 6 J. APPLIED RES. MEMORY & COGNITION 452, 452, 453 (2017).

[107] *See* Mnookin et al., *supra* note 88, at 747, 748–49, 758.

[108] Dror & Hampikian, *supra* note 7, at 204, 207.

remembered,[109] as do anchoring effects.[110] Other examples include how judicial case decisions on length of sentencing can be affected by whether crime photos are in black and white, or in color,[111] or how attractive the suspect is.[112]

Therefore, how forensic science evidence is presented is of vital importance, as there is potential for misinterpretation by a lay audience. Most forensic experts and agencies agree that likelihood ratios can be valuable in helping members of the court to establish the weight that should be assigned to specific pieces of evidence.[113] It is argued, however, that it is only the scientist's role to provide an expert opinion on the probability of the observations given, and it is the role of the jury to assign a *value* to that probability.[114] Therefore it is up to the jury to consider how the probability compares to all the other evidence that is presented at court.[115]

One caveat is that there is a growing amount of evidence which demonstrates that verbal formulations of evidence are less effective than equivalent forms of evidence communicated numerically.[116] This is of concern when considering the issues which arise when there is a lack of an empirical evidence base underpinning forensic evidence. For example, likelihood ratios can be communicated in verbal rather than numerical estimates when there is a lack of appropriate databases for that particular piece of evidence.[117]

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[109] *See* Hyatt Browning Shirkey, *Last Attorney to the Jury Box Is a Rotten Egg: Overcoming Psychological Hurdles in the Order of Presentation at Trial*, 8 OHIO ST. J. CRIM. L. 581, 582–83 (2011).

[110] *See* Birte Englich et. al., *Playing Dice with Criminal Sentences: The Influence of Irrelevant Anchors on Experts' Judicial Decision Making*, 32 PERSONALITY & SOC. PSYCHOL. BULL. 188, 188, 189, 194 (2006).

[111] *See, e.g.*, Edward Oliver & William Griffitt, *Emotional Arousal and "Objective" Judgment*, 8 BULL. PSYCHONOMIC SOC'Y 399, 399 (1976).

[112] *See, e.g.*, John E. Stewart II, *Appearance and Punishment: The Attraction-Leniency Effect in the Courtroom*, 125 J. SOC. PSYCHOL. 373, 377 (1985) [hereinafter *Appearance and Punishment*]; John E. Stewart II, *Defendant's Attractiveness as a Factor in the Outcome of Criminal Trials: An Observational Study*, 10 J. APPLIED SOC. PSYCHOL. 348, 348, 353 (1980) [hereinafter *Defendant's Attractiveness*].

[113] *See* Charles E.H. Berger et al., *Expressing Evaluative Opinions: A Position Statement*, 51 SCI. & JUST. 1, 1–2 (2011).

[114] *See id.* at 1; Roger Cook et al., *A Model for Case Assessment and Interpretation*, 38 SCI. & JUST. 151, 152, 153, 154 (1998); I.W. Evett et al., *Finding the Way Forward for Forensic Science in the US—A commentary on the PCAST Report*, 278 FORENSIC SCI. INT'L 16, 17, 18 (2017).

[115] Evett et al., *supra* note 114, at 17, 18, 19.

[116] K.A. Martire et al., *On the Interpretation of Likelihood Ratios in Forensic Science Evidence: Presentation Formats and the Weak Evidence Effect*, 240 FORENSIC SCI. INT'L 61, 61, 67 (2014).

[117] *See id.* at 61.

VII. WHY WE NEED FORENSIC SCIENCE

A. The Changing Role of and Greater Dependence on Forensic Science

As the field progresses, it is clear from this discussion that forensic science faces challenges it must address. However, the work of a forensic scientist must not be diminished. It is important to determine the full contribution of forensic science to determine what role it plays in the courtroom. Recent evaluative research generally focuses on forensic science being used to produce evidence for court and its subsequent costs.[118] At the same time, this research does not acknowledge the fact that forensic science has the potential to provide a useful contribution at different levels and for several dimensions within investigation and security issues.[119]

For example, forensic science can provide actionable intelligence that may reveal repetitive offenses by prolific offenders based on traditional methods of analyzing recurring trace patterns, as well as determining signature digital behavior in the online world.[120] The forensic scientist may also interpret criminal trends. An example of which could be the analysis of illicit drugs. Here, not only will the forensic scientist determine the relative purity and other components of the seized substance,[121] but may also identify patterns in trafficking. Hypotheses are drawn for explaining these changes and this may provide a dynamic picture of certain dimensions of the illicit drug market.[122] Such forensic interventions are not limited to criminal activity. The scenes of recent fires may be scrutinized by forensic scientists, where discovery of a recurrent technical issue may be determined as the cause, and help in the implementation of preventive measures.[123]

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[118] Anika Ludwig, *E 'value' ating Forensic Science*, 7 FORENSIC SCI. POL'Y & MGMT. 69, 77 (2016); Joseph L. Peterson et al., *Effect of Forensic Evidence on Criminal Justice Case Processing*, 58 J. FORENSIC SCI. S78, S79, S80 (2013).

[119] *See* Sonja Bitzer et al., *Is Forensic Science Worth It?*, POLICING, 1, 1, 2, 8 (2017).

[120] *See* Anika Ludwig & Jim Fraser, *Effective Use of Forensic Science in Volume Crime Investigations: Identifying Recurring Themes in the Literature*, 54 SCI. & JUST. 81, 84 (2014).

[121] *See* Pierrre Esseiva et al., *Forensic Drug Intelligence: An Important Tool in Law Enforcement*, 167 FORENSIC SCI. INT'L 247, 248, 254 (2007).

[122] *See, e.g.*, Julian Broséus et al., *Chemical Profiling: A Tool to Decipher the Structure and Organisation of Illicit Drug Markets: An 8-Year Study in Western Switzerland*, 266 FORENSIC SCI. INT'L 18, 26 (2016); Marie Morelato et al., *The Use of Organic and Inorganic Impurities Found in MDMA Police Seizures in a Drug Intelligence Perspective*, 54 SCI. & JUST. 32, 36 (2014).

[123] *See* NAS, *supra* note 3, at 172.

B. Impact

> To measure the impact of forensic science, it is helpful to determine what the optimal potential is of the evidence itself. This can lead to a deeper comprehension of the limitations of such evidence. In particular, the literature has highlighted six major roles forensic evidence may have on a criminal investigation:
>
> [(1) Demonstrate] a crime has been committed or establish key elements of a crime[, (2) Place or exclude] the suspect in contact with the victim or with the crime science[, (3)] Establish the identity of persons associated with a crime [, (4)] Exonerate the innocent[, (5)] Corroborate a victim's testimony[, and (6)] Assist in establishing the facts of what occurred.[124]

However, although police and crime scene investigators may appreciate the importance of such evidence at various stages of the investigation, not all stakeholders do. For instance, prosecutors will often seek out evidence which proves guilt beyond reasonable doubt.[125] Additionally, there is an expectation from many jurors that forensic evidence must be presented in order to 'prove' guilt or innocence. The failure to present such forensic evidence will often plant doubt in their minds.[126] Indeed, a study found that the conviction rate for cases with linking forensic evidence was significantly higher than cases without such evidence.[127] Therefore it could be argued that the impact of forensic science cannot be measured on its own, but by how it is viewed from various members of the justice system.

In a more detailed study conducted in 1984, Peterson and colleagues found that at the police investigation level, clearance rates of offences with evidence that had been sent to be forensically examined, were three times greater than cases where such evidence was not forensically examined.[128] A more recent study by Peterson

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[124] *See* JOSEPH PETERSON ET AL., THE ROLE AND IMPACT OF FORENSIC EVIDENCE IN THE CRIMINAL JUSTICE PROCESS, NAT'L INST. JUST. 22–23 (2010); ROBERTSON ET AL., *supra* note 25, at 1; Frank Horvath & Robert Meesig, *The Criminal Investigation Process and the Role of Forensic Evidence: A Review of Empirical Findings*, 41 J. FORENSIC SCI. 963, 968 (1996); Tom McEwen, *The Role and Impact of Forensic Evidence in the Criminal Justice System*, INST. L. & JUST. 3 (2010).

[125] McEwen, *supra* note 124, at 3.

[126] *Id.*

[127] *See, e.g.*, PETERSON ET AL., *supra* note 124, at 9.

[128] *See, e.g.*, *id.* at 15–16; JOSEPH L. PETERSON ET AL., FORENSIC EVIDENCE AND THE POLICE: THE EFFECTS OF SCIENTIFIC EVIDENCE ON CRIMINAL INVESTIGATIONS 194 (1984).

et al., in 2013 found that forensic evidence still had a similar influence on case-processing decisions across all crimes.[129] Interestingly, the study also found that with or without subsequent analysis, the collection of evidence alone predicted arrest and case referral, as well as prosecutors' decisions. And the *examination* of evidence predicted 'case referral, charging, trial conviction, and the severity of sentences.'.[130] For example, when evidence is collected from the scene of a robbery, the likelihood of an arrest increases. When evidence has been examined, and linked a suspect to a victim in homicides, it was a predictor of sentence length.[131] The research suggests that the impact of forensic evidence can be significant whether or not it is examined. And once it is examined, may influence the decisions of judges and juries in unexpected ways.

C. Value

The value of forensic science goes beyond simple cost measurement.[132] It has been argued that too many studies restrict the measurement of cost to the following; property stolen; associated medical costs for injuries of victims; as well as intangible costs which may be associated with the stress caused and lowered quality of life due to the crime.[133] They often neglect to take into consideration the very important benefits of the exoneration of innocent suspects and the value placed on their lives,[134] as well as the compensation payouts to people who are exonerated.[135]

Despite the influence that forensic science has been found to have on the criminal justice system, very little is known of its true value, since value and effectiveness are very difficult to define and measure. In 2017, Doleac determined that the cost of collection and analysis of DNA samples was between $20 and $40 per sample in the United

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[129] Peterson et al., *supra* note 118, at S88.

[130] *See, e.g.*, PETERSON ET AL., *supra* note 124, at 3–7.

[131] *See id.* at 6–7.

[132] *See* AMBROSE LEUNG, THE COST OF PAIN AND SUFFERING FROM CRIME IN CANADA 1 (2004).

[133] Ludwig, *supra* note 118, at 80.

[134] *See* Jennifer J. Raymond, A Criminalistic Approach to Biological Evidence: Trace DNA and Volume Crime Offences 172, 176–77 (June 9, 2010) (unpublished Ph.D. thesis, Univ. of Technology, Sydney) (on file with author).

[135] *See, e.g.*, Shawn Armbrust, *When Money Isn't Enough: The Case for Holistic Compensation of the Wrongfully Convicted*, 41 AM. CRIM. L. REV. 157, 166, 169 (2004); Newton N. Knowles, *Exonerated, but Not Free: The Prolonged Struggle for a Second Chance at a Stolen Life*, 12 HASTINGS RACE & POVERTY L.J. 235, 236 (2015); Kevin Davis, *After Years, Even Decades, the Exonerated Leave Prison Walls Behind Only to Find New Barriers*, ABA J. (Jan. 2011), http://www.abajournal.com/magazine/article/after_years_even_decades_the_exonerated_leave_prison_walls_behind/.

States (however, it was noted that marginal costs would continue to fall as technology improves).[136] The social cost of crime also must be considered when determining the value of forensic science, as McCollister and colleagues demonstrated in their study in 2010, which identified a possible social cost saving of between $1,566 and $19,945 per profile.[137] When considering the 761,609 profile uploads of the CODIS database in the United States in 2010, it was estimated that the cost was approximately $30.5 million, but when including the social cost, the crimes prevented by the profile uploads could be estimated as a social cost saving of at least $21 billion.[138]

Despite this, if a study were to find that the financial cost of using forensic science outweighs the resulting benefits, it does not necessarily reduce its contribution to the investigation. For instance, the Innocence Project demonstrates that post-conviction DNA testing has proven over 354 cases of wrongful conviction, including twenty death sentences.[139]

VIII. CONCLUSION

The purpose of this paper was to review and consider the recent literature in forensic science, and to highlight the challenges within the criminal justice system from a cognitive perspective, as well as recognizing the important role forensic scientists play in the courtroom and in society as a whole. The issues extend from the very start of the forensic investigation and continue throughout the process to the presentation of findings to members of the court.[140] It is clear that a significant amount of research is still necessary to address these challenges. Yet, because published research is often conducted within universities, it is important that research be casework-informed and designed with the implementation of the findings in mind. Research that has the practice of forensic science integrated into research questions and design has the potential to be able to offer valuable findings that could be adopted into practice[141].

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[136] *See* Jennifer L. Doleac, *The Effects of DNA Databases on Crime* 24 (Stanford Inst. for Econ. Pol'y Research, Working Paper No. 12-002, 2011).

[137] *See* Jennifer L. Doleac, *The Effects of DNA Databases on Crime*, 9 AM. ECON. J.: APPLIED ECON. 165, 200 (2017).

[138] Doleac, *supra* note 136, at 24.

[139] *All Cases Exonerated by DNA*, INNOCENCE PROJECT, https://www.innocenceproject.org/all-cases/ (last visited Apr. 11, 2018).

[140] *See* Morgan, *supra* note 99, at 456.

[141] *See* Ruth M. Morgan, *Conceptualising Forensic Science and Forensic Reconstruction. Part II: The Critical Interaction Between Research, Policy/Law and Practice*, 57 SCI. & JUST. 455, 456 (2017).