

DOI: 10.5281/zenodo.20068268

GENE EXPRESSION AND CRIMINAL CULPABILITY: RETHINKING RESPONSIBILITY IN THE AGE OF EPIGENETICS

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*Received: 06/04/2026
Accepted: 29/04/2026*

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ABSTRACT

Recent advances in epigenetics, provide a new perspective on how life experiences, and context shape gene expression, and in so doing, challenge prior conceptualizations of criminal responsibility. This article explores whether epigenetic aspects related to impulse control and cognitive functions should play a role in deciding the legality of mens rea and imputability. Through a combination of philosophical accounts and contemporary biosocial science, the analysis considers doctrinal import for actus reus, defenses, and sentencing. The findings suggest that epigenetic states modulate criminal capacity, but do not deterministically cause conduct; thus, such evidence is evidence of responsibility, but does not remove it. The article will expand on this by developing a principled approach to introducing epigenetic analysis in court, setting up expert testimony guidelines, and establishing sentencing mechanisms that are responsive to life course influences without diminishing accountability. Through this, the aim is to bring together biosocial understanding with a fundamental understanding of justice – leading to more balanced and fair decisions in criminal cases.

KEYWORDS: Epigenetics, Criminal Responsibility, Mens Rea, Legal Admissibility, Biosocial Justice.

1. INTRODUCTION

Molecular biology research has prompted substantial questions regarding the traditional notions of criminal responsibility. Epigenetics includes mechanisms controlling gene expression without causing changes to the DNA, including DNA methylation, histone modifications, and non-coding RNAs. These processes are dynamic and function across the lifespan and can change according to environmental factors, including stress, trauma, nutrition, and social environments. They are biological mechanisms that connect life experiences to mental status and behavioral outcomes (McGowan & Roth, 2015; Dias et al., 2015; Varela et al., 2013; Lickliter & Honeycutt, 2015; Bohare, 2024). National new philosophies of criminal law also include, among others, the Pancasila Law Philosophy (Fajrin et al., 2023) and other cultural, moral, and social values and scientific knowledge, which emphasize the need to take such interweaving of cultural, social, and moral values into account to form an integrated perspective that leads to a fuller understanding of agency and responsibility in the legal framework. On a biophysiological level, epigenetic regulation redraws the neural circuits involved with emotional regulation, impulse, and decision-making so that it provides a biological foundation for the expression of life history conditions from the perspective of embodiment—without the risk of genetic determinism (Walsh & Yun, 2014; Dias et al., 2015; Maurel & Kanellopoulos-Langevin, 2008; Varela et al., 2013; Archer et al., 2012). Such a multidisciplinary approach is able to position behavior as residing between biology, psychology, and law, and it allows for a flexible understanding of human agency that is not reductive regarding life-course influences, free from determinism (Tammen et al., 2013; Cooney, 2007; Nishinakamura & Takasato, 2017). The task now before us is to explore how such epigenetic evidence can be integrated into criminal law assessment of responsibility—to say nothing of the fact that such epigenetic states actually modulate, not automatically restore, capacities for controlling behavior. Developing this insight, the research proposes a legally sensitive framework for considering the question of mens rea and imputability to help courts in assessing defendants. It ensures that basic principles inherent here are safeguarded through the application of state law as currently understood. The central question being studied is: How might criminal courts integrate epigenetic evidence, reflecting gene regulation by entrenched living conditions at a biological institution, into the assessment of whether something

is responsible but without destroying justice norms in the process? It focuses specifically on key epigenetic processes (such as DNA methylation, histone modification, and non-coding RNAs) that directly impact neural functions important for impulse control or decision-making (McGowan & Roth, 2015; Dias et al., 2015; Varela et al., 2013; Mustafin et al., 2019). This study has the deliberate aim of not indulging in detailed biomedical exposition but of bringing these insights into court (Brooks, 2014; Husak, 2010). Several limitations extend to this particular research: The focus is on legal analysis and philosophical theory instead of any biomedical details (Tiffany et al., 2022; Moore, 1990; Peiris, 1983); it does not include detailed empirical cases (Osiel, 2009; Canefe, 2017); it relies on Western legal frameworks; and it recognizes that epigenetic science is an ever-evolving field that still warrants future revision (Walsh & Yun, 2014; Wang & Allard, 2021). However, within this framework, the study contributes to a contemporary biosocial theory and justice approach supporting the scientific understanding of criminal law, as well as the integrity of the justice system (Robertson, 2017; Segate, 2024).

2. METHODS

This interdisciplinary study employed a critical conceptual analysis involving philosophical arguments, criminal law principles, and biosocial epigenetics. The methodology is based on (a) a normative-analytic formulation of imputability, answerability, and liability, and (b) a study of epigenetic science underlying important mental capabilities necessary for mens rea and actus reus.

A systematic review of the literature was performed in various academic databases such as PubMed, Scopus, Web of Science, HeinOnline, and Google Scholar. Keywords included 'epigenetics,' 'criminal responsibility,' 'mens rea,' 'legal admissibility,' and 'biosocial justice.' Peer-reviewed publications, doctrinal legal analyses, and philosophical discussions from 2000 and 2024 were included only. Non-academic and unrelated research was excluded.

Reference management software (Zotero) was employed to source files and remove duplicates. By gathering a variety of high-quality secondary sources from medical, legal, and philosophical fields, the reviewed texts provide comprehensive and multidisciplinary coverage. Given the nature of the study, only secondary sources were used and no primary empirical data were collected. The study acknowledges this limitation and reflects the current

state of epigenetic science and its ongoing development, concentrating on conceptual explication and normative guidance.

3. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

The integrated literature consists of biomedical studies, legal analyses, and normative perspectives, providing a fertile research ground to explore epigenetics and criminal responsibility.

Biomedical studies provide valuable empirical data explaining epigenetic pathways, including DNA methylation, histone modifications, and non-coding RNAs, which regulate critical neural processes involved in impulse control and decision-making (Varela and colleagues, 2013; McQuown and Wood, 2010; Walsh and Yun, 2014).

Legal doctrinal analyses forge paradigms for assessing the connection of such biological knowledge with *mens rea* and imputability. Philosophical and normative articles explore the deeper concepts of agency, duty, and justice. This study synthesizes these research streams to present a multidisciplinary case for the careful application of epigenetic evidence, emphasizing that scientific data must be embedded in a sound legal and ethical framework.

The evidence is assessed through four criteria: sufficiency of causal and descriptive research; epistemic reliability; linkage of causation to normative responsibility; and compatibility with legal doctrine. This conceptual framework aids courts in responsibly applying epigenetic findings while ensuring fairness.

Admissibility considerations emphasize the necessity of transparent methodologies, biological relevance (especially related to neural tissue specificity and developmental timing), clear articulation of scientific uncertainty, and expert testimony distinguishing correlation from causation.

Biosocial criminology demonstrates how environmental adversities biologically embed themselves via epigenetic processes influencing behavior without genetic determinism. Although biology modulates *mens rea* capacities, it does not nullify legal liability (Dias et al., 2015; Cooney, 2007), posing normative challenges in balancing biological influence, voluntary agency, and proportional liability.

The triad of imputability, answerability, and liability offers a legal framework to integrate biological factors without undermining legal foundations (Moore, 1990; Osiel, 2009; Brink, 2013; Canefe, 2017). Philosophical discussions (Sakr, 2024)

emphasize conscious intent as fundamental for culpability, augmenting biosocial approaches that respect legal autonomy alongside biological influence.

Protecting human dignity and preventing discrimination in legal contexts remain paramount when integrating scientific evidence (Sakr, 2025). Expanding accountability to include collective and systemic dimensions enriches discourse without detracting from individual responsibility (Osiel, 2009; Canefe, 2017).

Persistent gaps exist regarding tissue specificity, timing, replicability, and offense-specific translation, which require interdisciplinary collaboration and judicial safeguards (Moore, 1990; Brink, 2013).

Following this foundation, the next section examines epigenetic mechanisms relevant to criminal capacities, providing biosocial evidence essential for informed judicial decisions.

4. EPIGENETIC SCIENCE AND CRIME

The epigenetic basis of all of this is that it is a mechanism that controls the neural circuits controlling impulse control, decision making, and also stress responses, where dynamic plasticity is affected by developmental timing and context (Walsh & Yun, 2014; McQuown & Wood, 2010). The biosocial pathways connect adversity, the HPA/ANS regulatory axes, and antisocial behaviors, providing a non-deterministic account of the processes of plasticity and life-course shaped behavior.

These biological insights are consistent with behavioral genetics research that identifies interplay between genetic differences and environmental influences on behavior without assigning a level of determinism to causative agents (Gunter, 2015). Especially, Gunter highlights the forensic mental health profession's contribution in interpreting such biosocial data, making the argument that biological determinants—like epigenetic alterations—effectively shape behavior, yet do not themselves act as absolute determinants of criminal behavior.

The work of Leshem and Weisburd (2019) further complicates this view by exploring how epigenetic factors are implicated in crime “hot spots,” which highlight the interplay of biological predispositions and environmental settings affecting patterns of offending. This complex understanding supports a model in which genetic and epigenetic data inform clinical and legal judgments without supplanting individual responsibility.

Longstanding, sometimes transgenerational epigenetic signatures carry interesting implications;

however, methodological cautions and correlated findings complicate deterministic claims (Tammen et al., 2013; McGowan et al., 2011; Cooney, 2007). The evidence base is still more tentative and probabilistic: caution should be exercised in translating the claims of the law in order to avoid erroneous blame reallocation (Delisi & Vaughn, 2015; Amatullah et al., 2022).

Table 1 presents a focused overview of epigenetic

marks with an introduction, relevant neural functions, influences on the capacities with which the marks are understood to be associated with criminality and their implications for current research, as well as hypothetical scenarios involving these marks for individual forms of offense. This overview helps to connect the dots between complex biosocial science and its applications for forensic and criminal justice purposes.

Epigenetic Mechanism	Associated Neural Function	Relevance to Criminal Capacities	Strengths of Current Evidence	Limitations and Challenges	Hypothetical Related Offenses	Limitations of Case Application
DNA Methylation	Regulation of genes controlling impulse control and decision-making	Influences self-regulation and behavioral inhibition	- Measurable in peripheral tissues (e.g., blood) and brain samples - Linked to early-life adversity	- Tissue-specific variability - Difficulty establishing direct behavioral causation	Impulsive violent offenses (e.g., assault)	- Peripheral measures may not reflect brain status - Non-deterministic effects
Histone Modification	Modulates gene expression affecting memory and stress response	Impacts learning and adaptation to stress	- Evident effects on long-term memory consolidation	- Transient and reversible modifications - Sparse forensic-focused research	Repetitive offenses involving learned behaviors (e.g., theft)	- Temporal variability - Indirect measurement issues
Non-coding RNAs	Regulate neural gene expression and neurodevelopment	May affect emotional regulation and neural circuitry	- Broad gene regulatory functions across neural pathways	- Complex and not fully understood mechanisms	Impulsive or aggressive crimes	- Limited direct forensic evidence - Mostly lab-based studies
Early-Life Stress Epigenetic Effects	Modifies HPA axis and stress response systems	Heightened stress sensitivity linked to aggressive behavior	- Strong evidence linking early trauma to epigenetic changes	- Difficult to disentangle genetic vs. environmental causes	Domestic violence, assault	- Effects are probabilistic, not definitive

4.1. Discussion And Implications

Building on the findings here, this section discusses how epigenetic science might be well integrated into legal assessments of criminal responsibility. It will be interesting to see whether this will be fully integrated into our future criminal systems as epigenetic techniques are being developed elsewhere on the world stage, for example.

On one hand, living experiences in a given period of time are shown to bring about neural pathways for impulse and decisional regulation. But conversely, it also stresses the continuing truth of those core principles which underpin law: *mens rea*, the law's imputability, and responsibility.

Although such claims have come up often in law school, there is little discussion regarding how they are brought forth in practice, whether the truth is true or not. Epigenetic science is vital for making sure that a person is held accountable and will keep abrogating responsibility for crimes they have committed.

This section focuses on some of the important interpretive insights garnered from epigenetic research. It examines pragmatic and doctrinal obstacles to its admissibility and application in courts. It also offers ethical protections to prevent potential abuse or determinism.

It highlights potential gaps in knowledge and procedural norms, demonstrating avenues of future interdisciplinary and policy development. Positioning the biosocial perspectives in normative and legal contexts, this discourse also seeks to reconcile scientific comprehension with the necessity of providing equitable, proportionate, and transparent criminal trials.

4.2. Interpreting Findings

Epigenetic research provides a window into how our lives shape our experiences of life. It shows how they influence our decision-making ability to inhibit impulse control and determine how reactions occur without violating age-old doctrines of responsibility.

Epigenetic mechanisms — DNA methylation, histone alterations, and non-coding RNAs — provide

valid biological pathways for the recalibration of neural circuits associated with impulse control and foreseeability. Well-documented research in the developmental window has found the time course (Dias et al., 2015; Walsh & Yun, 2014; Palumbo et al., 2018).

Importantly, considerations of tissue specificity and forensic-epigenomic data translation considerations remain key when thinking about informed epistemic and policy processes (Dupont et al., 2009; Vidaki & Kayser, 2017). Biosocial framing embeds developmentally timed exposures, embodying adversity variably at the center of the complex and variable modulating offending propensity.

4.3. Hypothetical Case

The case is treated as an example of a hypothetical scenario. Take Alex, a defendant with an epigenetic profile related to increased impulsivity from chronic stress from a violent home.

The court considers epigenetic data as descriptive context for Alex's ability — he didn't lack intent or exculpation. The jury considers knowledge of consequences, voluntariness, along with capacity modulation. They decide that biology reflects capacity and does not negate mens rea as well as absolution.

Rehabilitation and life-course considerations in accordance with proportionality and preventive justice are integral aspects of the sentencing process. This is because many legal guidelines are applied in this regard.

Data from epigenetics show modulated self-

management abilities without violating the key legal constructs of imputability, answerability, and liability.

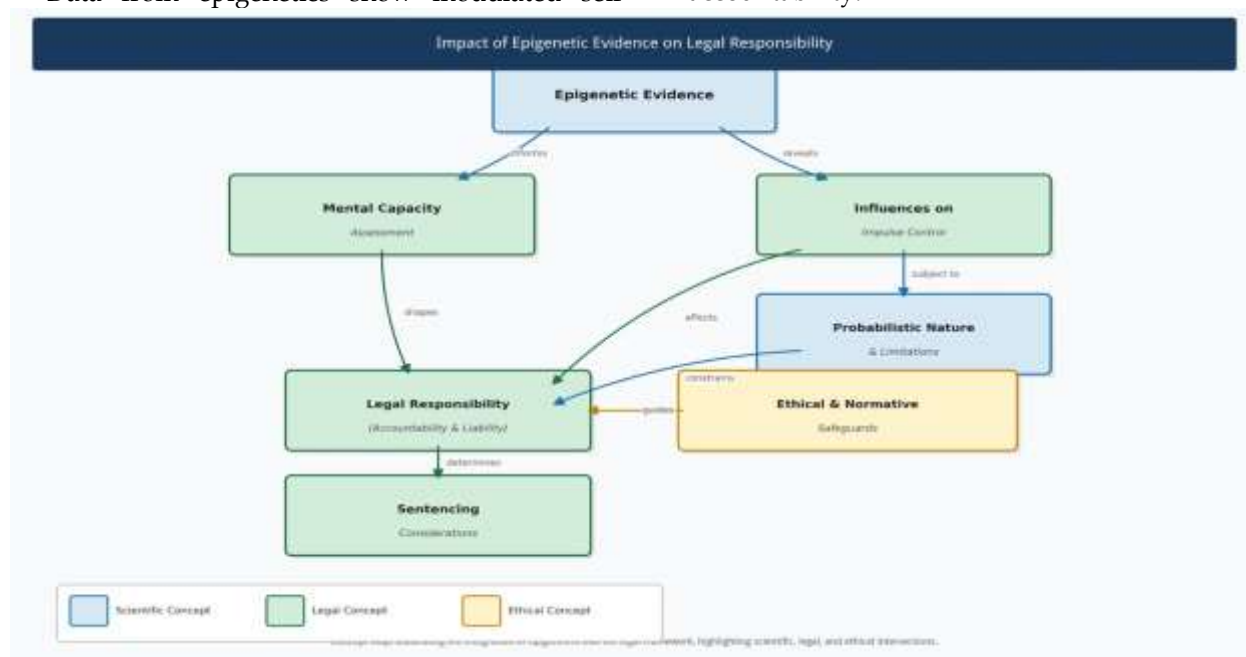
To protect against over-exaggerated causality, high epistemic standards must be established to properly evaluate the reliability of the outcomes. They must provide clear evidence of causation-to-normativity relationships, present the information openly and clearly while conveying that uncertainty, and consider doctrinal compatibility (Tiffany et al., 2022; Brink, 2013).

Specific tissues, timing of development, and other factors in developing tissues need attention to avoid overgeneralizing or misapplying findings (Vidaki & Kayser, 2017).

Epigenetic evidence should be read against an open and unbiased methodology to determine the rigidity of data admissibility. It should be accompanied by clear data-driven proof and expert evidence that clearly separates correlation from causation.

Crucially, caution should be taken so that biological determinism does not erode fundamental legal principles. Categorizing epigenetic data as direct causative evidence of behavior ("the brain did it") simplifies the complexity of human agency and undermines ideas of free will and criminal liability.

Legal discourse must steer clear of deterministic language. It must stress that epigenetic influences are probabilistic and contributory rather than causal. Suitable wording could be phrased like: "epigenetic factors may contribute to behavioral tendencies but do not preclude conscious control or legal accountability."



This graphical representation illustrates how epigenetic evidence interacts with core legal concepts while emphasizing scientific limitations and ethical safeguards vital to maintaining justice and fairness in the judicial process.

4.4. Normative Directions and Policy Recommendations

This section provides explicit normative guidance and policy recommendations for the incorporation of epigenetic evidence in criminal justice. This article has a cautious and balanced message. Emphasizing a cautious and well-defined approach, it provides a pragmatic process for making theoretical principles operational for courts and policymakers. The aim is to ensure accountability, coupled with safety; prevention and rehabilitation are promoted through strong evidence, ethical protections, and effective education to encourage prevention and rehabilitation.

4.4.1. Purpose and Scope

This section applies descriptive imputability and epistemic responsibility to normative guidance. This passage takes the theory of descriptive imputability and epistemic responsibility and formalizes the theoretical position for the courts to use to develop normative law for courts, policymakers, and actors. It calls for the judicious, non-deterministic use of epigenetic data in criminal adjudication, keeping agency descriptions focused on the types of offense(s) charged with a bias, but using biosocial insights to help sharpen capacity and control understandings (Tiffany et al., 2022; Brink, 2013).

4.5. Descriptive Imputability and Three-Level Descriptions

A differentiated framework is recommended based on a tiered approach in which epigenetic information provides information and guides capacity descriptions to a range of levels (e.g., not much, moderate, or significant modulations) without inducing automatic exoneration or increase of liability. This approach maintains mens rea and actus reus as normal points of reference.

Courts might write: "The degree of the defendant's regulatory capacity for impulse control expressed by epigenetic signs associated with impulse control and foreseeability in the charged description is moderate; this information informs (but does not determine) culpability."

This tiered formulation is consistent with central theory and supports proportional sentencing reflecting life-course determinants. You may use a

template that is prepared and applied in all of these scenarios.

4.6. Evidence Admissibility and Court Process

Admissibility of epigenetic evidence must take into account evidence of a causative chain that, by its underlying structure, relates the epigenetic state to the relevant activity, relevant to the offense; biological relevance, distinguishing the brain markers from peripheral proxies in considering developmental timing; replication; and methodological transparency; and qualified expert testimony in such evidence that signals uncertainty and does not overstate clarity.

This framework embodies our epistemic imperative to ensure scientific rigor and adherence to the law in alignment (Tiffany et al., 2022; Delisi & Vaughn, 2015; Vidaki & Kayser, 2017). Pre-trial competency tests standardized, and jury instructions can minimize misinterpretation and contextualize findings according to a prerequisite mental state for the offense (Williams, 2018).

This process is important, as due to the intricacies of epigenetic data, forensic pathology expectations govern testimony from experts in an application (Weedn, 2021). Weedn (2021) emphasizes a need for legal precedent and evidentiary regimes protecting the admissibility and persuasive force of forensic expert testimony, based on transparency in processes and appropriate distinction between correlation and causality.

Standards like this are necessary to prevent due process abuses and to avoid misuse of the new technology of epigenetic science in the criminal justice system.

5. POLICY RECOMMENDATIONS: PREVENTIVE AND CORRECTIVE JUSTICE

Recent findings advocate for trauma-informed care and early-life interventions to implement effective policy interventions to diminish biosocial risk factors affecting offender disposition and offending recidivism (Bohare, 2024; Palumbo et al., 2018). Such practices fit justice policy with larger public health goals, which are motivated by addressing the fundamental social determinants of health that underpin risk (Dias et al., 2015; Mustafin et al., 2019).

This biosocially informed policy framework complements individual responsibility, offering systemic interventions that echo the frameworks of mass harm and collective responsibility (Osiel, 2009; Canefe, 2017).

Epigenetics also underscores the social dynamics

of bioscience in justice policy and the need for a merging of ethical, legal, and social concerns for the prevention of naive biological determinism and policy appropriation (Wastell & White, 2017; Berryessa & Cho, 2013).

As a consequence, public health interventions guided by epigenetic understanding should work to reconcile harm minimization with the safeguarding of individual rights and social justice (Palumbo et al., 2018).

5.1. Ethical Protections and Human Rights

Ethical imperatives are critical to avoid any deterministic readings of epigenetic data with potential to stigmatize defendants or increase social injustice. Robust ethics oversight, with multidisciplinary review boards, guarantees responses to scientific developments to be both grounded and representative of societal norms (Segate, 2024; Osiel, 2009).

Due to the high sensitivity and possibly predictive nature of epigenomic data, privacy protection and informed consent must be secured to respect individual rights while applying epigenomic data in an ethical manner.

Wienroth et al. (2021) also foreground ethics as an embodied practice and underscore the idea that anticipatory capacity and in-the-moment ethical behavior in forensic genetics demand continuous contemplation and adjustment. The work supports the view that ethical consideration needs to be incorporated into the routine work of forensic scientists rather than as abstract concepts to counter the risk of misuse or misinterpretation of biosocial evidence.

This view is equally valid for epigenetic data, in which the ethical issue involves more than privacy, but also fairness, equity, and justice under the law.

Achieving educated and actively engaged judges, prosecutors, defense counsel, and experts is required to generate a balanced, accurate understanding and reduce misuse risk (Mustafin et al., 2019; Canefe, 2017). Ethical systems should be constant and must be responsive to the changing times and address the rights of persons throughout justice.

Sustained investment in training for legal and scientific professionals is necessary. Interdisciplinary workshops, joint seminars, and practitioner-specific guidelines all support the translation of sophisticated biosocial insights into fair adjudication. Public health objectives in balance with due process safeguards generate systemwide accountability and public trust (Bohare, 2024; Segate, 2024).

5.2. Roadmap and Evaluation of Implementation

Phase I: Formulate and issue court-facing admissibility guidelines, sample language, and jury instructions.

Phase II: Pilot (only in specific jurisdictions) monitoring of decisions, sentencing, and access.

Phase III: Regular checks, reviews (and revisions) in light of empirical results, feedback, and scientific advances.

Extending these normative perspectives and policy advice, the next section provides a critical reflection on the contemporary discussions surrounding these points, both in terms of apparent jurisprudential problems and ethical concerns resulting from the interlinked nature of epigenetics and criminal responsibility.

5.2.1. Nuances, Disagreements, and Open Questions

The introduction of epigenetic science in criminal responsibility also opens up exciting areas for sophisticated legal reflection. However, it is rife with complex debates and open questions requiring closer examination. This chapter deals with the unresolved controversy surrounding legal liability over biology and transgenerational effects, deficits in the available evidence, barriers (including those that exist in the forensic industry), and ethics. Through an articulation of these broad issues, matters in need of additional interdisciplinary inquiry are emphasized. Sober normative consideration is needed to inform responsible policy and practice. Recent research, including Albright and colleagues (2023), highlights the essential interface between knowledge dissemination in science, evidentiary standards, and justice-seeking in legal authorities. Their work sheds light on the difficulties courts encounter in deciding on experimental evidence. It shows that there may be both clear standards and procedural safeguards to ensure that experimental evidence is reviewed without breaking the basic tenets of law. For epigenetic data, as biosocial evidence emerging from the laboratory, these challenges are particularly pronounced and warrant careful interpretation to avoid misuse or overreliance.

5.2.2. Existing Arguments Over How Much Biology Must Govern Liability

One of the most controversial questions involves how much biological factors, such as epigenetic markers, should mediate accountability for liability. There is an active scholarly conflict between those

who support increased biological integration in liability evaluations and those who argue against such an approach, fearing extreme excusation or deterministic readings. Supporters of epigenetic data propose that bio-epigenetic data might change how capacity, intention, and foreseeability are weighted. This can help adjust mens rea under specification and sentencing determination (Tiffany et al., 2022; Moore, 1990). Nevertheless, opponents argue that flexibility in liability principles, depending on probabilistic or contextually specific biological findings, may dilute accountability (Brink, 2013; Williams, 2018). This drives current demands for a description-based approach that retains the basic triad of imputability, answerability, and liability while including a biosocial perspective (Delisi & Vaughn, 2015). Consider the situation of the accused who committed armed robbery with intent but also presents epigenetic information of early trauma negatively affecting impulse control. Courts could deploy epigenetic evidence to enable fuller characterizations of the defendant's ability to control actions without erasing conscious intent or absolving responsibility.

5.2.3. Transgenerational and Collective Statements

On both individual and collective levels, epigenetics brings considerations of developmental windows and transgenerational influences. This raises moral and normative considerations regarding collective and co-opted responsibilities and the need to design long-range policies. Some theorists recommend acknowledging the intergenerational effects of epigenetics in social science systems that promote preventive, socially based interventions but do not absolve individuals from responsibility (Dias et al., 2015; McGowan et al., 2009; Canefe, 2017). Some warn that it may be impracticable to separate individual responsibility from structural reasons by associating individual responsibility with intergenerational effects, especially given the immediacy of needing strong causal chains before determining responsibility in real-life cases (Osiel, 2009; Palumbo, 2018). Thus, scholarship is divided between: (a) applying epigenetic explanations to position risk factors and life-course disadvantages in sentencing and policy, and (b) retaining individual accountability for specific wrongful actions as charged.

5.3. Gaps of Evidence and Problems in Method

There is general agreement on substantial deficiencies in evidentiary and methodological rigor. Epigenetic evidence remains relatively correlational,

inter-tissue, and developmentally driven, problematic for direct litigation regarding mens rea or capacity. The literature calls for high standards of admissibility, such as clear causal chains, tissue-context awareness, replication, and unambiguous communication of uncertainty (Vidaki & Kayser, 2017; Dias et al., 2015; Tiffany et al., 2022; Delisi & Vaughn, 2015). Developing standardized language and juror-friendly explanations is doctrinally critical to provide sound legal reasoning that faithfully depicts scientific complexity without distortion (Williams, 2018).

5.3.1. The Forensic-Epigenetic Landscape and Policy Outcomes

Forensic epigenetics raises significant challenges and opportunities in investigations, identification, and age estimation. These have important implications for evidence admissibility and privacy rights. Though these forensic applications impact wider law reform debates, this article focuses on epigenetic evidence's role in determining capacity, mens rea, and sentencing proportionality. This raises novel ethical and policy issues, including protecting privacy, avoiding stigmatization, and pursuing anti-discrimination in biosocial risk monitoring (Vidaki & Kayser, 2017; Bohare, 2024; Segate & Weisburd, 2024).

5.3.2. Open Questions and Future-Oriented Research Agenda

Multiple important questions persist. These include mapping tissue-specific epigenetic markers to brain circuits implicated in offenses, adapting sentencing paradigms to life-course considerations, training legal actors to responsibly analyze epigenetic data, and establishing strong, empirically proven admissibility parameters. Developing robust guidelines and descriptive language for legal actors is crucial. A successful multidisciplinary cooperative research program is required. This program should integrate doctrinal simulations, empirical case studies, and public health education to systematically develop normative frameworks. These frameworks should be appropriate for emerging scientific developments (Palumbo, 2018; Vidaki & Kayser, 2017; Bohare, 2024).

5.3.4. Ethical and Normative Criteria for Protections

Ongoing ethical vigilance is key as epigenetic science evolves. New approaches are important. Key safeguards include privacy in information, proportionate sentencing, stigmatization prevention,

and transparent governance mechanisms for epigenetic evidence in law. Kristien Hens (2024) highlights the role of developmental bioethics to responsibly negotiate biologically determined forces with morality. Critics like Huang and King (2018) warn against interpretations that might reinforce determinism or injustice. Winkler (2024) identifies specific ethical issues related to epigenome editing compared to genome editing, showing how biomedical advances shape society. Inclusive engagement among judges, prosecutors, defense attorneys, scientists, and affected communities is crucial for rights, equity, and justice (Tiffany et al., 2022).

5.4. Summary of Nuanced Stance

Ultimately, the ongoing argument is ethically and legally nuanced. Though epigenetic factors substantially enhance understanding of criminal capacity and culpability, their use must be constrained by well-defined doctrinal borders. The goal is not to relativize accountability but to refine capacity descriptions, maintain evidentiary rigor, and promote preventive justice without sacrificing due process or proportional liability.

5.5. Conclusion: Key Findings, Limitations, and Policy Recommendations

The analysis highlights that epigenetic science provides a crucial biosocial viewpoint to better understand variability in human behavior driven by complex environmental and developmental conditions.

Epigenetic markers modulate capacities regarding mens rea and conduct but do not eliminate personal agency or legal responsibility.

Important limitations of this study include: it does not incorporate an original empirical study, restricting external application; epigenetic science is evolving and may require legal paradigm updates; the study is based on Western judicial systems, so generalizability across jurisdictions might be limited.

Awareness of these limitations underscores the

need for careful review and cross-disciplinary research.

A principled and descriptive legal framework is necessary. This framework includes tiered capacity assessments, admissibility protocols, transparent expert testimony, and prevention and rehabilitation policies. It reconciles state-of-the-art bioscientific knowledge with longstanding criminal justice laws and regulations.

Key findings include:

- Epigenetic evidence signals probabilistic influence on behavior but does not determine it, supporting fine-grained legal reviews that maintain liability.
- Strong epistemic and transparent articulation of scientific uncertainty is essential to prevent misinterpretations in legal proceedings.
- Ethical considerations including privacy protection and guarding against biological determinism must be incorporated into epigenetic data use.
- Multidisciplinary cooperation and sustained education of legal and scientific professionals promote better decision-making and fairness.

Actionable recommendations:

1. Standardize admissibility criteria with clear legal standards addressing evidence sourcing, scientific reliability, and uncertainty.
2. Enhance training for judges, lawyers, forensic experts, and regulators to build epigenetics competency and responsible application.
3. Strengthen privacy protections addressing the sensitive nature of epigenetic information.
4. Establish interdisciplinary ethics oversight bodies to monitor epigenetic evidence use and guide policy.
5. Promote collaborative research integrating law, biomedical, and social sciences to refine evidentiary and policy frameworks.

Sustained commitment to interdisciplinary dialogue, ethical governance, and empirical research is required. This approach balances justice's scientific basis with fair treatment of individuals, upholding accountability and human dignity.

Acknowledgements: The author would like to express sincere gratitude to Prince Sultan University, Riyadh, Saudi Arabia, for its invaluable support and resources. special thanks to the Governance and Policy Design Research Lab (GPDRL) of Prince Sultan University (PSU) for their financial and academic support to conduct this research and publish it in a reputable Journal.

Funding: This research was financially supported by the Governance and Policy Design Research Lab (GPDRL) at Prince Sultan University, Riyadh, Saudi Arabia.

Competing Interests: The author declares that there are no competing interests.

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