I Got My Attitude From My Mom: Behavioral Inheritance

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Author Note

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Abstract

The evolutionary principles of Mendelian inheritance and Darwinist natural selection are not exclusive to morphological expression. On a baseline level, evolution can be most observable and understood through physical features. With recent studies, evolution has been applied to psychiatric disorders and natural behaviors. Through the peer review of different academic literature, evolution has expanded beyond the physical sciences and into the frontier of the social sciences. The biological characteristics of inheritance and natural selection still apply to inherited mental illnesses and behaviors because individuals are more likely to inherit mental illnesses or behaviors from their parents. The transgenerational inheritance of adaptations to environmental stimuli is a result of epigenetics. This adds a nuanced layer to the nature versus nurture debate. The novelties presented in the field of behavioral epigenetics broaden the perspective of evolution and create potential diagnostics, preventions, and treatments for psychiatric and behavioral disorders.

Keywords: *Inheritance, transgenerational epigenetics, behavioral evolution, memory retention*

Glossary Box

Term/Concept	Definition
Modern Synthesis	the most contemporary understanding of evolution that combines the principles of Mendelian inheritance and Darwinist natural selection.
Mendelian Inheritance	the principles of passing down features from parent to offspring based on Mendel’s Law of Segregation and Law of Independent Assortment.
Law of Segregation	inheritance is based on one of two laws that states that genetic material in the form of alleles separate during the formation of gametes and randomly combine during fertilization.
Law of Independent Assortment	inheritance is based on one of two laws that states that allele pairs separate independently during the formation of gametes.
Darwinist Natural Selection	the fitness of a species is based on the most advantageous survival traits for the

	environment inhabited.
Epigenetics	the study of inherited gene function changes without the change of the DNA sequence.
Stability of Traits (SoTs)	the phenomenon by which a phenotypic trait persists throughout generations in a population.
Holobionts	the ecological entities composed of a macrobial host and the set of associated microorganisms that compose its microbiome
Transgenerational Epigenetic Inheritance	the transmission of epigenetic information through the germline.
Drosophila melanogaster (D. melanogaster)	known as the common fruit fly or vinegar fly, is the model organism for biological research involving molecular genetics and animal development.
BX2 Cluster	a sequence made of repeated P-lacZ-white transgenes
PIWI-Interacting RNA (piRNAs)	a class of small RNAs involved in the maintenance of the germline genome.

B-Galactosidase (beta-gal or β-gal)	a family of enzymes that catalyze the hydrolysis of β-galactosides into monosaccharides through the breakdown of glycosidic bonds.
Caenorhabditis elegans (C. elegans)	known as a nematode worm, is a model organism for genetic developmental studies.
Plasticity	the quality of being malleable enough to be changed into a new form.
Argonaute Proteins	a protein family responsible for RNA silencing processes.
Behavioral Epigenetics	the study of how epigenetic changes affected by experience and environmental stress may affect animal behavior
Saccharomyce cerevisiae (*S. cerevisiae*)	known as brewer’s yeast, is the model organism for biological research for eukaryotic cell biology.

The Modern Synthesis: The Derivation of Evolution

The main principles of the Modern Synthesis in evolution are based on the advanced concepts of Darwinist natural selection with Mendelian inheritance, molecular genetics, and population genetics (UC Museum of Paleontology, 2021). Gregor Mendel's idea of inheritance involves the process of parents passing down their traits to their offspring, while Charles Darwin's idea of natural selection involves the process of survival of the fittest. In short, these principles along with other works from other renowned scientists have laid a widely accepted foundation for the causes and mechanisms of evolutionary changes (UC Museum of Paleontology, 2021). As seen in many specimens, each generation of a species is exposed to new environmental stimuli at some point in evolutionary time. Then, the stimulus becomes a latent variable of the characteristics they get to better adapt to their environment.

People can easily find the adaptability of living organisms over time based on their observed characteristics. A classic demonstration of physical evolution in the form of adaptive radiation, the speciation of different organisms based on specific ecological niches, is in Darwin's Galapagos finches (Burrows, 2021). The finches, despite having a variety of beak shapes, seem to come from the same common ancestor because their overall body structure is like each other. The most reasonable explanation for the finches to have distinct beaks is that they have evolved to better adapt to their different respectable environments given the development of land resources and diet. As a result, the principle of inheriting the most advantageous traits has become a staple in understanding evolution.

As time moves forward, recent discoveries show that behavior can also change over time with the principles of Mendelian inheritance and Darwinist natural selection. Some may be skeptical as to quantifying transgenerational epigenetic inheritance through experimental and observational studies (Horsthemke, 2018). This skepticism has been disproven through recent findings of different specimens and different mechanisms. Through learned behavior, a specimen may inherit a change in their individual epigenetics and may pass down the learned behavior to their offspring. The intangible phenomena of inherited behavior play an immense role in behavioral evolutionary endeavors and understanding inheritance from a new perspective.

Epigenetics: The Reevaluation to Evolution's Definition

Epigenetics is the study of inherited gene function alterations that support the integrity of the DNA sequence. This means that the original genetic makeup of a species will remain the same with added changes layered upon the DNA sequence. To put in perspective of a home, the foundation of the house is the same with different exterior renovations. The renovated house results in a changed house set-up for the grandchildren to play in. Similarly, the function of the changed gene can be inherited by future offspring and potentially more generations after. Gametes transmit epigenetic inheritance through extracellular RNA to transfer phenotypic information during embryonic gene regulation and development (Sharma, 2017). Sharma's study supports that offspring inherit physical characteristics such as health, disease, and aging from their parents and mentions the environmental effects of the parents transmitting into the germline and becoming transgenerational.

With a focus on an individual's biological systems, there are different gene regulation mechanisms that enable epigenetics to be passed down from the parents to the offspring. Some mechanisms include histone modifications, tRNA fragments, microRNAs, etc. (Skvortsova et al. 2018). The many forms of the modifications can be induced by different external stimuli experienced by the parent's soma into the germline. Figure 1 below depicts an example of environmental stressors affecting parents and offspring in animals (Casier et al. 2019). Studied in *D. melanogaster*, the BX2 cluster, represented by the dark blue regions on the rod-shaped chromosome, contributes to the production of piRNAs after the first generation's exposure to a higher temperature. The production of piRNAs in the experimental group is then repressed by the homologous P-lacZ sequence, represented by the light blue regions on the chromosomes, that would traditionally produce β-galactosidase seen in the control group. From the second generation to the fiftieth generation, the piRNA production was inherited in the experimental group after the first generation's first exposure to a higher temperature. This external stimulus kept a silencing trait to be expressed without the need for the higher temperature to be present (Casier et al. 2019).

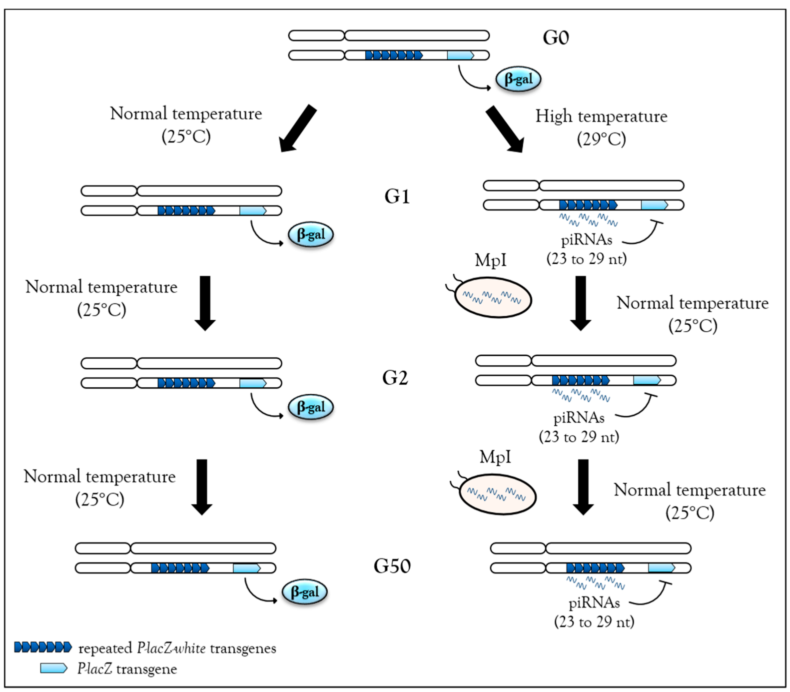

Figure 1: Environmentally-Induced Transgenerational Epigenetic Inheritance with piRNA (Casier et al. 2019)

The development of epigenetic-induced plasticity in *C. elegans* solidify the influence of trans-representative inheritance (Serobyan and Sommer, 2017). Affected by many external stressors in a controlled environment, the nematode undergoes an epigenetic transmission of small RNAs mediated by Argonaute proteins. The Argonaute proteins inhibit developmental switch genes, which are essential in expression. The nematode's response to environmental influences on their developmental systems is innate to its genome after undergoing several types of natural selection in their environment (Serobyan and Sommer, 2017). Therefore, the idea of an organism's external stimuli enhancing its body's adaptation to the environment is crucial in epigenetic research.

To rethink the understanding of phenotypic inheritance, the mechanisms of inheritance must be reevaluated. Inheritance must be redefined and viewed as having many forms. This includes epigenetic, behavioral, and symbolic/linguistic as they contribute to the Stability of Traits (SoTs) passed on to generations in a population (Veigl et al. 2019). The exploration of new sources and processes that impact inherited variation includes microRNAs, holobionts, and ecological exposure. All these sources have expanded the definition of inheritance as they correlate with elongating a population's lifespan to then have the chance to reproduce and further evolve.

Starting with microRNAs, they are small RNAs. MicroRNAs have recently been accepted to become a more common source of preserving and passing on genetic information to offspring (Veigl et al. 2019). Before, it was presumed that DNA was an exclusive source of inheritance through the ideas of Central Dogma. Central Dogma states that DNA holds all the instructions to transcribe messenger RNA that is translated by ribosomes to produce proteins throughout an organism (Genome Research Limited, 2021). MicroRNAs challenge the notion that DNA is the only source of genetic material that can pass on to future generations by diving deeper into the other components of Central Dogma.

Next, holobionts are microbiomes that coexist within a macrobe and contribute to the symbiotic co-evolutionary adaptations related to the specimens in their coevolutionary relationship (Veigl et al. 2019). Holobiont relations would be best described in a study where the microbial inheritance occurs between the seed and root formed from the first generation of plants to the next (Choong‐Min et al. 2019). The recruitment and accumulation of microbiota through biotic and abiotic stresses enhance the current plant immunity and is transferred in the next generation. The plant-soil feedback and soil memory improve the microbiota with a better fit to the environment (Choong‐Min et al. 2019). Thus, this symbiotic relationship between different organisms contributes to the formation of beneficial inheritance in a non-parental to offspring trajectory.

Lastly, ecological exposure refers to the accessibility to resources that aid one's survival. The discovery of resources that were not previously accessible in one region compared to another furthered the survival of a population. Their once major disadvantageous trait became tolerable to live with and sustain their life (Veigl et al. 2019). To create a clearer picture, people with inherited heart conditions may move to areas with more resources to deal with their heart disease. The individual would then live long enough to bear a child of their own and the child may also inherit the parent's heart disease. Fortunately, the child has a significantly lower chance of mortality because they were born in a region with the medical supplies needed to treat his conditions for them to live (Veigl et al. 2019).

Psychiatric Disorder and Behavioral Inheritance

Epigenetics has reached its attention beyond morphology and into the mind. Recently, studies have shown that the inheritance of psychiatric disorders follows the same epigenetic mechanism that physical phenotypes do. In humans, some individuals are more predisposed to psychiatric disorders than others due to their parental generation's predisposition to the disorder. The spread of depression and anxiety-related behaviors can affect multiple generations, where the developmental time point and the father's source of stress will affect the complex transmission trend to the offspring (Cunningham et al. 2019). The understanding of the psychiatric and genetic risk factors involved can help predict, prevent, and treat the offspring of vulnerable populations. This discovery and similar findings show that heredity is not limited to observable physical characteristics.

Transitioning from a psychiatric inheritance, behavioral inheritance touches upon the same principles of inheriting intangible traits. Through recent studies, there has been a higher prevalence of more nuanced evidence of behavior-based epigenetic consequences rather than physical. Consequently, epigenetics is redefined to fit both physical and behavioral scenarios. A single trait can be inherited by cultural and genetic methods (Aguilar and Akçay, 2018). The evolutionary dynamics allow the cultural transmission of a non-physical trait to change the genetic selection and to create a higher quantity of genetic frequencies to increase genetic variance (Aguilar and Akçay, 2018). This study was used to explain altruism as a desirable trait that found its way to shift genetic variance.

Behavioral epigenetics follow the same biological mechanisms and are applied and seen in a more subtle manner. Through the same gene regulation process, the environment is still a key role in somatic cell interactions with epigenetically inherited germline cells (Pang et al. 2019). This understanding of behavioral adaptation may increase parental awareness of their environment on their children and the potential impact for generations on their great-grandchildren. Beyond immediate blood lineage, the behavioral adaptation sets a tone for future generations on a population scale. For example, the transgenerational effects of harassment on seed beetle females over a period of three generations show that the second generation of seed beetles had poorer fertility compared to their paternal generation of female beetles that were more harassed (Lind and Spagopoulou, 2018). The interpretation of this data was that the second generation of seed beetles was born into an unsafe environment that was not fit for their future offspring to be born and survive. Therefore, the fertility of the second-generation seed beetle was dependent on past generational experiences their harrassed parents faced. The violent environment set up in the first generation of seed beetles served as an indicator of low fertility for the second generation of seed beetles. Interestingly, the second generation of seed beetles was not exposed to the multiple mating and harassment environment and caused the third generation of seed beetles to reverse the infertility effects on the second generation. This study brings light to transgenerational effects and their dynamics (Lind and Spagopoulou, 2018). As a result, behavioral evolution must be viewed with the same amount of importance as physical evolution to understand the development of a population.

The behavior presented in the seed beetles can also be seen in humans and their chosen lifestyles. Like a psychiatric disorder previously mentioned, the environmental stimuli induced by an individual can have a long-term effect on their future children and grandchildren. Behavioral epigenetics can be exemplified in exercising as it can influence the behavioral, affective, and cognitive characteristics of their progeny (Yeshurun and Hannan, 2019). The parent's behavioral impact on a child's predisposition to life can be a precursor in the child's lifestyle. The concept of inherited behavior is strengthened by Figure 2 below (Szyf, 2014). Figure 2 shows the first male rat in the parental generation being exposed to a smell and getting shocked. As this smell is being imprinted with the shocks, then the conditioned fear of the smell became an inheritable trait through sperm demethylation. As diagramed in the first and second generations after the parental generation, these rats would become startled when they hear the sound that is linked to the smell. The exposed smell is the same smell the parental rat got shocked for and the first and second-generation rats are startled by the smell without experiencing the shock themselves (Szyf, 2014).

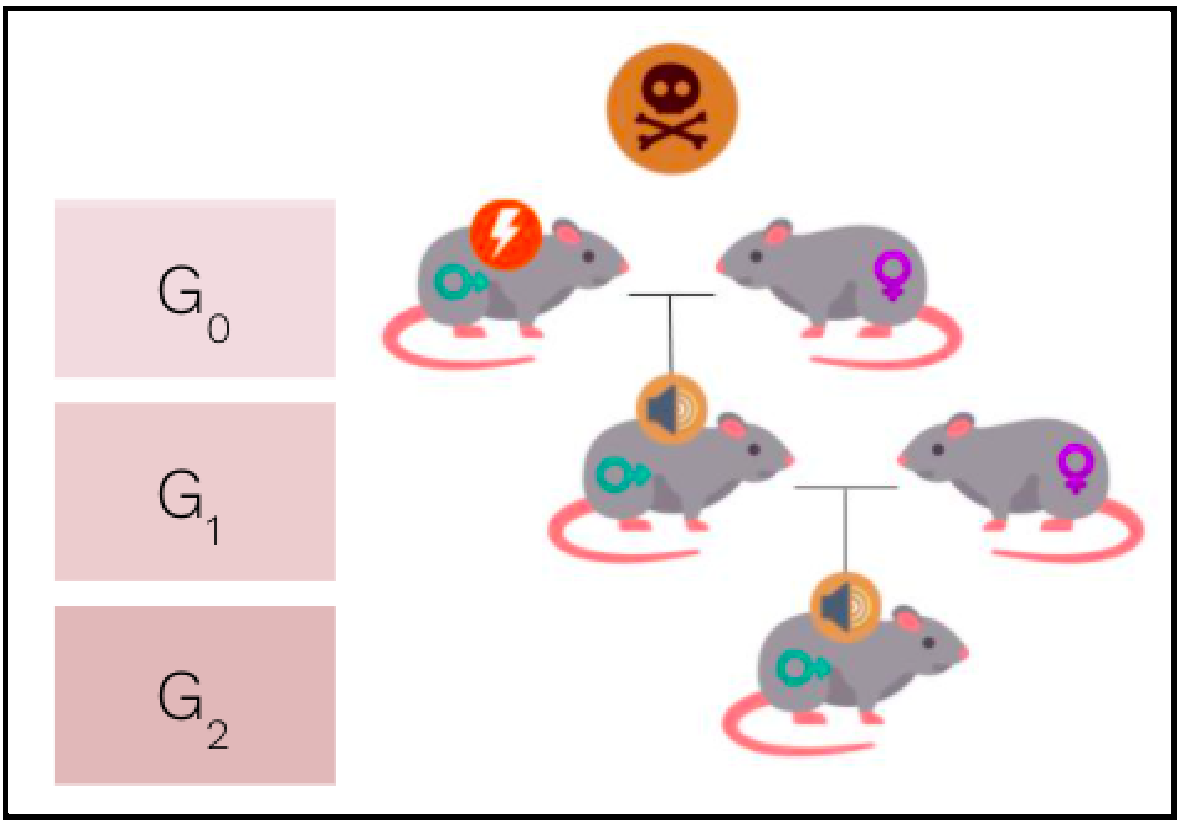

Figure 2: Epigenetic Inheritance of Odor: Fear Conditioning

The adaptations to the environment directly affect the behavior of the specimen that inhabit the region. Through the memories of an organism's ancestors, the newer generation will be more fit to live in their environment. In efforts of elaborating upon the connection between neurological characteristics and behavioral influence of evolution, memory may play a major contributing factor to biological success. One may be skeptical on how to quantify memory in an experiment; however, it has been proven in Figure 3 below. In Figure 3, a single yeast's gain-of-memory mutant, elp6Δ, was examined to enhance reinduction memory (Diana et al. 2020). The data suggests that the phenotype expressed is mediated through decreased histone occupancy at the GAL1 promoter, which explains why there is a higher expression of Gal 1 in the presence of the elp6Δ (Diana et al. 2020). This study shows how memory becomes a heritable trait, something that has not been considered in a genetic evolutionary success lens.

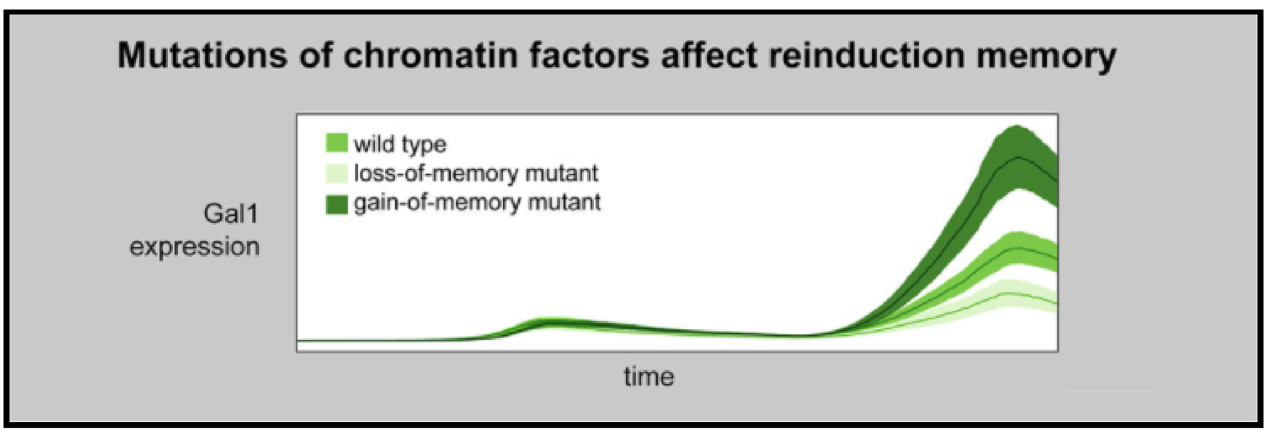

Figure 3: Mutations of Chromatin Factors Affect Reinduction Memory (Diana et al. 2020)

Additionally, it was observed the implementation of histone methylation in the budding of *S. cerevisiae* (Francesca et al. 2019). Their data shows how transgenerational epigenetic inheritance affects the future generations' memory to stress responses. This experiment shows that past knowledge is important for obtaining better survival techniques to better adapt to their environment. Another example of memory-induced behavioral development is in flatworms fissioning together after decapitation (Venkataraman, 2020). Venkataraman was fascinated by the flatworm because it presented a clear physical and behavioral demonstration of non-synaptic memory storage. This novel, non-RNA-related mechanism to regenerate may be a new key in the understanding of memory (Venkataraman, 2020). Through the current comprehension of past behavior affecting future development, memory may be fundamental in understanding future evolutionary trends.

Concluding Remarks

Consistently, evolution has manifested itself in realms scientists did not think of exploring at both the physical level as well as social levels. The same epigenetic concepts applied to physical phenotypes can be used in mental illnesses and behavioral performances. The biological basis of the Modern Synthesis can also be expanded by exploring memory retention as a feat in evolutionary success (Francesca et al. 2019). Thus, the debate between nurture versus nature has become a correlation between nurture and nature through the principles of epigenetics. Knowing that the behaviors completed in one generation will have a direct impact on future generations, the treatment for behavioral disorders such as addiction can be better diagnosed, prevented, and treated (Yeshurun et al. 2019). This knowledge can also be transferred to the psychiatric predispositions of one generation having a direct effect on future generations as it can contribute to the progression of diagnostics, prevention, and treatments for psychiatric disorders such as PTSD (Cunningham et al. 2019). The novelties in solutions can be better digested through the unearthing of behavioral evolutionary research and creating hallmarks of effective treatments for psychiatric and behavioral disorders.

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