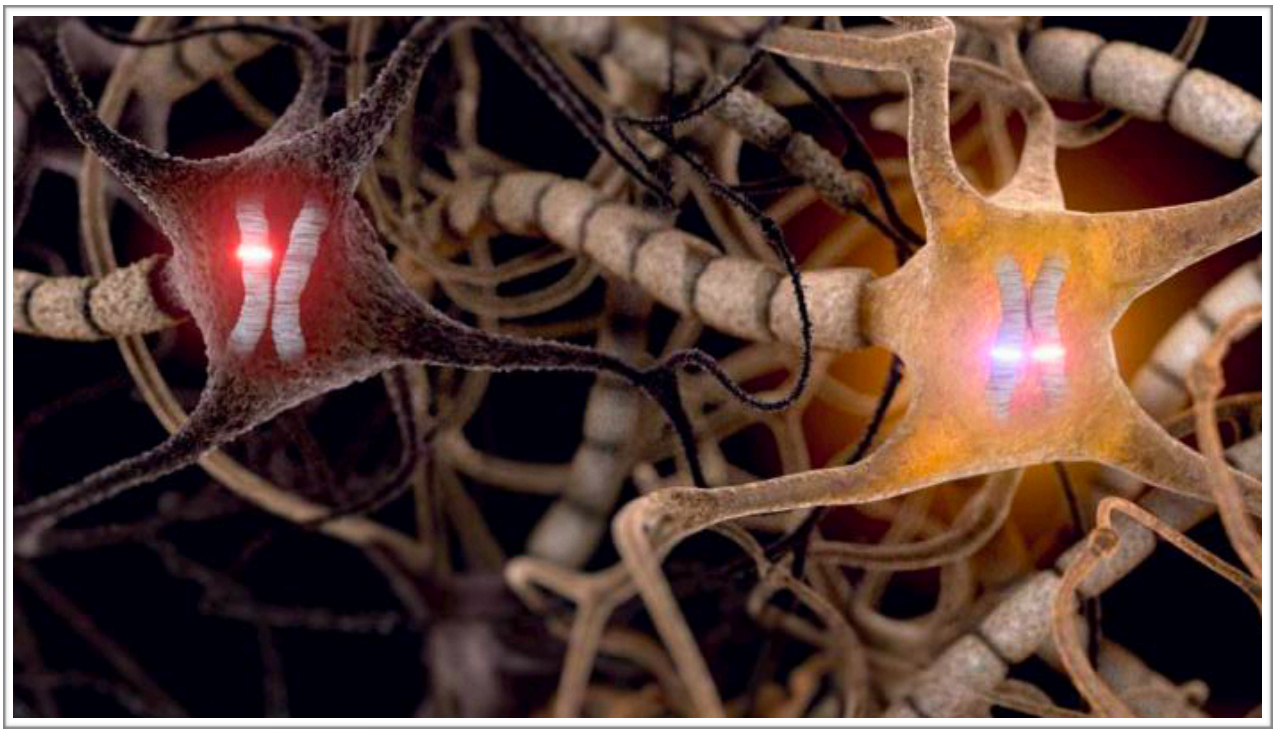
You Are What You Encounter:

The Influence of Altered Genetic Expression on Behavior and Vice-Versa



Tim Boyer
Honors Senior Thesis
Mr. Zontine
May 19, 2017

Introduction

A whole dimension to human genetics lies beneath the basics, only fully understood by avid news readers and biological scientists. Human genetics has been illuminated in terms of molecular structure and basic functioning; every high school student knows that he or she has DNA from his or her mother and father. Yet, during the course of the individual life, the surrounding environment is constantly interacting with DNA and influencing genetic expression. Traits relatively easy to visualize like organ shape and muscular diseases, and more obscure traits like sensory perceptions and complex behaviors, are all mediated by gene-environmental interplay (McClung & Nestler, 2008; Audesirk, Audesirk, & Byers, 2014). The environment physically develops every human by impacting genetic functioning.

As the volume of psychological studies being published has increased and the quality of medical technology has become more advanced, so too has our understanding of the link between the environment, psychology, and genetics. More and more studies are now being published about the ways in which a human's chemical environment influences behavioral development. For example, humans exposed to alcohol as fetuses are at a dramatically increased risk of being involved in criminal activity because of genetic mental disabilities (Fast, Conry, & Loock, 1999). On the other hand, dramatic experiences in the social environment can impact genetic expression in cells all around the body. For example, studies have shown that traumatic events such as rape and PTSD are correlated with decreased protein growth in the brain (Golub, et al., 2011; Wlassoff, 2015).

Through alternative genetic expression mechanisms, the chemical environment impacts human behavioral development, and the behavioral environment impacts physical and behavioral

human development. Human behavior is an enabler of genetic developmental change and is genetically-affected by diverse environments. The journey toward understanding genetic effects on behavior and vice-versa begins with exploring both the complexity and responsiveness of the genome. Second, the forces of genetic alteration (mutations, epigenetics, and plasticity) are discussed with relevant examples from non-human animals. Third, the brain is examined as the major force behind human behavior and ways in which genetic alterations influence neuronal behavior are considered. Finally, the previous topics are applied to aspects of human life with the subsections: behavior on health, health on behavior, toxins, parenting, child abuse, and teen and adult life. Ultimately, understanding the link between the environment, genetics, and psychology is necessary for proper therapeutic approaches and to better understand ourselves.

Section I

A Complex Genome

In understanding human developmental biology, it is necessary to have an appreciation for both the complexity and responsiveness of the genome. Every organismal cell contains sequences of over a hundred million nucleotides (one nucleotide consists of a five-carbon sugar, nitrogenous base, and phosphate group) attached adjacently. There are four types of nucleotides (guanine, cytosine, thymine, and adenine) and each one can chemically bind to one specific other (G-C; A-T). Two of these sequences of nucleotides form a double-stranded helix as nitrogenous bases from opposing strands are complementary bound together via hydrogen bonding. Collectively, this is known as a double stranded molecule of Deoxyribose Nucleic Acid or DNA.

Interactions between parts of a DNA strand and other intracellular molecules causes that segment of DNA to be used to direct the building of a similar molecule called mRNA (transcription). A strand of mRNA is next used in the cell as a template for intracellular molecules to construct particular proteins (translation). The development of every organismal anatomical structure occurs through this process. A segment of a DNA strand that encodes for a specific protein is known as a gene, and there are about twenty-thousand known functional genes in every human genome, waiting to be activated under the appropriate conditions. A DNA strand with thousands of gene segments that is wound around structural proteins called histones is called a chromosome. Every genetically-normal human has twenty-three pairs of chromosomes in every cell; one from mom and one from dad. Different genes will be expressed (used to make proteins) in different cells depending on cell type and location (Marcey, 2010; Starr, et al., 2013).

Moreover, instead of merely providing the necessary instruction for the production of only a single specific protein, one gene can produce multiple proteins, thereby contributing differently to development under different circumstances. Through a process known as alternative splicing, segments of a mRNA strand can be physically rearranged. “The dogma of one gene/one protein, a useful fable for its time, has been exploded; alternative splicing permits multiple proteins from a single gene” (Eisenberg, 2004). Consequently, multiple traits (i.e., anatomical structures and behaviors) of an individual can be influenced by one gene (pleiotropy). Conversely, multiple genes affect the development of any complex trait (polygeny) since the development of most phenotypes (e.g., eye shape, femur length) requires many different proteins. Additionally, polygeny includes epistasis, a process that occurs when the role of some genes is to

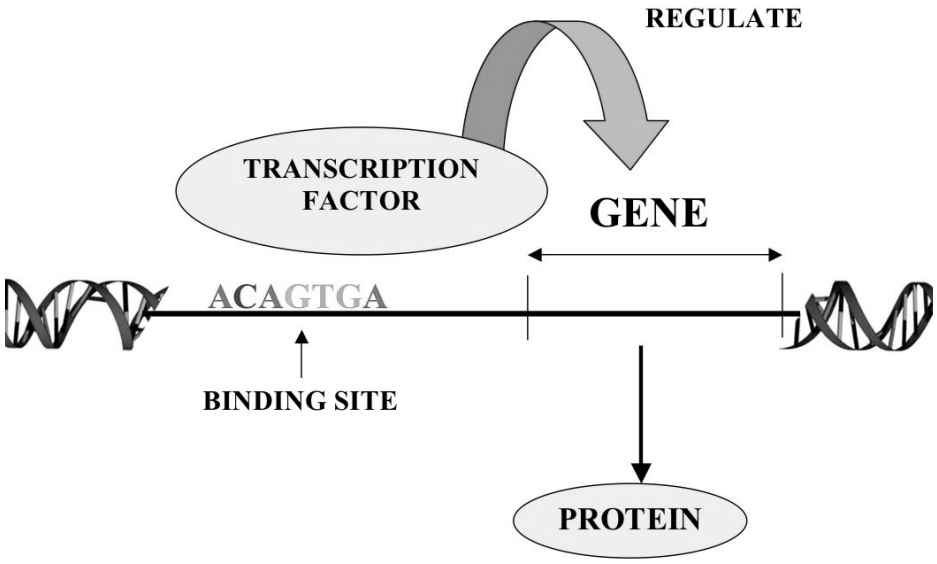


Figure 1: A transcription factor molecule binds to DNA at its binding site, and thereby regulates the production a protein.

create proteins called “transcription factors” that influence the expression of other genes, suppressing or amplifying them (Figure 1) (Starr et al., 2013).

It is worth recognizing that traits are not necessarily observable; behaviors and diseases that may be unnoticeable are also traits. Just like anatomical structures, behavior is also influenced by genetics since neurons in the brain, which processes external cues and translates them into actions, are ultimately built with proteins. “Genetic influences on behavior are multifactorial - that is they involve many genes, each with small effects” (Pettijohn, 1997). Understanding the complexity of the genome is important; whether it is the gene itself, transcribing the gene, or translating mRNA, a disruption anywhere along this complex protein production process has the potential to alter the development of one or more traits.

A Responsive Genome

The responsiveness of the genome is not as well known as its complexity. Chemicals in the environment can frequently interact with the genome to alter genetic expression. Throughout an individual's lifetime, the experiences every organism encounters will impact protein development. As a consequence, all organisms develop differently, in specific relation to their environment (Richards, Bossdorf, & Pigliucci, 2010).

The first realization that the environment interacts with human development was nearly four centuries before the discovery of DNA. In 1582, Englishman Richard Mulcaster identified both 'nature' and 'nurture' as forces contributing to human development: nature being inherited characteristics and nurture being acquired characteristics from an individual's early environment. He emphasized that they work in harmony to create the features of the individual (West & King, 1987). However, after the discovery of DNA, nature and nurture have commonly been used in opposition to each other. When talking to a friend about a personal behavior like physical aggression, one might suggest that one's genes inherited from parents (nature) are to blame without considering anything about the way in which he or she was raised (nurture). Others would suggest that the opposite is completely true. However, as Mulcaster suggested in the sixteenth century, both are of tremendous importance; genetic and environmental inputs are extraordinarily intertwined. "Individuals inherit not only a species-typical genome but also a species-typical environment, which, in combination, results in species-typical development" (Causey, Gardiner, & Bjorklund, 2008). Development is considered less of nature vs. nurture and more of nature *and* nurture (West & King, 1987; Pettijohn, 1997; Eisenberg, 2004; Plomin, 2004).

Furthermore, there is a third factor that many developmental biologists include in the nature and nurture discussion: the niche. Meredith West and Andrew King (1987) proposed this addition to the well-known phrase in their publication, "Settling Nature and Nurture into an Ontogenetic Niche." They argued that the niche is significantly different from 'nurture,' defining 'niche' as "the ecological and social circumstances inherited by organisms." Simply put, the habitat an organism lives in and its relationships to others around it can influence that organism's development. As discussed later, evidence suggests individuals exposed to poor parental environments express different genes than they would in a good parental environments. "Offspring inherit, along with their parents' genes, their peers and the places they inhabit" (Eisenberg, 2004). West and King add that nurture is the organism's development within the niche through factors such as maternal care. In contrast to nurture, both individuals and their parents share an niche that guides their development transgenerationally (West & King, 1987). Advances in developmental research reveal how dependent human psychology is on genetic and ecological biology, simultaneously.

Environmental Influences on Phenotypes

Some by-pass genetics in discussing phenotypic development and change. There are both genetic and non-genetic ways in which the environment influences phenotypic (including psychological) development. Here we make the distinction between phenotypic changes due to non-genetic vs. genetic mechanisms.

Besides the fact that genes build proteins that physically develop the brain, social learning is not caused by an alteration in genetic expression. For example, an animal learns to

associate sounds with feeding times. A dog will fire a set of neurons when he or she hears a bell ring. The dog will fire a different set of neurons when presented with food. If the dog is presented with food the same time he or she hears a bell ring, the dog will associate the firing of one set of neuron to the firing of another set of neuron (Starr et al., 2013; Williamson, Buckland, & Cunningham, 2013). As Donald Hebb brilliantly phrased in 1940, "neurons that fire together wire together" (Kephart, 2011). It is important to appreciate the complexity of neuronal activity in the brain; one neuron can communicate with thousands of other neurons (Williamson, Buckland & Cunningham, 2013). However, sets of neurons and the communication among neurons can be physically modified due to altered genetic expression.

On the other hand, genetics play a different role in phenotypic change. There are two ways in which the environment interacts with the genome. The sequence of nucleotides that make up the genome can be physically altered by the environment via mutations of the genome. Second, the genome may also be altered in expression without damage or changes to the nucleotide sequence. In the former, there are both hereditary and acquired mutations.

Hereditary mutations occur in the formation of sperm and egg cells. Mutations in one or both germ cells involved in conception are carried into the next generation ("What is a Gene Mutation?", 2017). A 2011 study found that excessive smoking causes mutations to sperm DNA that contribute to "birth defects and spontaneous abortions." Smoking physically alters the sequence of DNA nucleotides, causing "DNA to break and chromosome abnormality." Furthermore, a subsequent study found that paternal smoking increases the likelihood of offspring childhood cancer due to mutations in the genes of sperm cells (Marchetti et al., 2011).

Acquired mutations occur in bodily cells other than sperm or egg, and are accrued during the lifetime of individuals. For example, ultraviolet radiation from the sun and tanning booths can cause genetic mutations in skin cells ("What is a Gene Mutation?", 2017). In somatic cells a gene known as proto-oncogene produces a protein that regulates the speed at which cells replicate. Ultraviolet rays are known to be able to cause mutations to proto-oncogenes in skin cells, causing hyper-active, unregulated cell growth. Eventually, a tumor will form with many skin cells and some of these unregulated cells can spread to other parts of the body ("Skin Cancer", 2017). Additionally, a 2006 study found that, along with UV radiation, air pollution is damaging to the DNA of cells. Researchers performed gel electrophoresis, examining the genomes of indoor and outdoor workers' skin cells in highly polluted areas (DeMarini & Claxton, 2006). They found that workers in highly polluted areas had more mutations in brain cell genes.

Beside heritable and acquired mutations, the environment interacts with the genome via epigenetics. Contrary to mutations, epigenetics is a term used to describe altered genetic expression without physical change to the genes themselves (Starr et al., 2013; Audesirk, Audesirk, & Byers, 2014). Epigenetic studies are relatively new; the great majority of them have been performed within the past twenty years. As epigenetic research has increased tremendously, scientists have become more aware of its importance to human diseases and development.

DNA methylation is unquestionably the most understood epigenetic process. At cytosine nucleotides, methyl groups attach to DNA strands and reduce genetic expression (Robertson, 2015). Alterations to genetic expression are not necessarily positive or negative but context-dependent. Both over-accumulation and depletion in supply of a protein can have adverse effects.

Methyl groups also reduce expression by attaching to histones tails (structural proteins wound with DNA) and increase the tightness of DNA wrapped around histone spools. Genes that are wrapped too tightly around histones are not expressed. Increases or decreases in DNA tightness around histones is known as histone modification and can be influenced by other chemicals such as phosphate and acetyl groups (Weinhold, 2012; Starr et al., 2013). Conversely to methylation, acetyl groups loosen DNA around histones, making genes more accessible for transcription and translation (Audesirk, Audesirk, & Byers, 2014).

Methyl groups, acetyl groups, and phosphate groups can all be absorbed from the environment. For example, cigarette smoke adds methyl groups to cells in the body (Starr et al., 2013). Since one gene can influence the expression of others, impacts to the expression of one gene can change rates of expression of other genes. This can cause an altered pathway of genetic expression (discussed in the next section) and can even give rise to different traits (Hochberg, 2011). Remember, however, that the vast majority of associated genes all have small additive effects (Pettijohn, 1997); methylation of one of the many genes contributing to the formation of the head will not cause an organism to be headless.

In humans, methylation naturally causes partial silencing of genes that aids in prenatal growth and development. Since methyl groups are consumed with food, during a famine, individuals do not accumulate as many methyl groups as nutritionally healthy individuals and are able to express this prenatal growth gene more readily. A study found that nutritionally-healthy grandchildren born to malnourished parents lived thirty-two years longer on average. In this way, methylation can be an advantageous response to the environment (Starr et al., 2013). Food deprivation also has consequences to developmental physiology. “Nutrients can reverse or

change DNA methylation and histone modifications, thereby modifying the expression of critical genes associated with physiologic and pathologic processes, including embryonic development, aging, and carcinogenesis" (Weaver, 2017). In relation to psychology, methylation of the genome is a common byproduct of adverse psychosocial environments such as abusive and unsafe environments (see "Child Abuse"). Unfortunately, suicide rate correlates positively with methylation of particular sections of brain cell genomes (McGowan et al., 2009).

Developmental Plasticity

Another way in which traits, including behaviors, are altered by the environment without damage to DNA is through adaptive developmental plasticity. Plasticity refers to the ability of the genome to produce variant phenotypes. Chemical signals from an individual's surroundings can cause the development of different phenotypes in an adaptive manner (Hochberg, 2011). Plasticity, like epigenetics, is essential to understanding gene-environment interaction, yet many are unaware of its enormous importance, particularly to the field of developmental psychology.

To increase an organism's chances of survival and reproduction, plasticity can act as an adaptive response to changing environments (Smith-Gill, 1983; West-Eberhand, 1989; Hochberg, 2011). Alternatively, plasticity can be highly maladaptive (Smith-Gill, 1983). Sandra Smith-Gill (1983) makes an important distinction between an organism "genetically adapted to use specific environmental cues" versus "passively responding to the environment."

Adaptive plasticity is referred to as "developmental conversion" as organisms alter or "convert" their developmental trajectory or pathway of development (Smith-Gill, 1983). A genetic developmental trajectory refers to all the genes involved in producing a single trait, trait

complexes, or a whole organism. “Suites of genes” involved in a trajectory can be regulated depending on the expression of one master regulatory gene (Hochberg, 2011). “Master regulator is a gene that is expressed at the inception of a developmental lineage or cell type and participates in the specification of that lineage by regulating multiple downstream genes either directly or through a cascade of gene expression changes” (Sun-Kin Chan & Kyba, 2013). External pressures may cause an organism to convert its developmental plan and switch to an alternative trajectory - giving rise to a different phenotype. This can be an adaptive strategy in the face of challenging environments. For example, deciduous plants in the late fall will alternate their leaf formation genetic trajectory to produce leaves with “higher water use efficiency” in anticipation of winter, when water supply is reduced by freezing temperatures (Schlichting and Pigliucci, 1998).

Likewise, if an organism is simply introduced into a different habitat, its cells may have the ability to adapt to that environment by expressing an alternative trajectory. “Environmental input determines whether entire blocks of genes, in some cases organ anlage, will be expressed permanently” (Smith-Gill, 1983). Via developmental adaptiveness, some organisms have physiologically changed so dramatically that they have been classified as different species (Schlichting and Pigliucci, 1998). There are more than 3,000 different species of cichlid fish that have gone through rapid speciation due to niche specialization (Takahashi & Koblmüller, 2011). Species of cichlid fish, faced with different environments, expressed different sets of genes. The diverse sets of developmental traits each genome has the potential to produce are referred to as the “reaction norms” (Worltereck, 1909; West-Eberhand, 1989; Schlichting and Pigliucci, 1998).

As explored later, the early life social environment can determine the genetic pathway under which human cells, including brain cells, develop.

Maladaptive developmental plasticity is referred to as phenotypic modulation. In phenotypic modulation, the organism may simply fail to block out external perturbations and consequently increase its rate or degree of expression (Smith-Gill, 1989). Both adaptive and maladaptive plasticity influence the development of biopsychology in humans. While many instances of adaptive and maladaptive plasticity are not known and may not be for a while, an awareness of the interactiveness of the genome and the environment are vital to appreciate the endless individuality of humans worldwide.

Susceptibility to Developmental Change

Some organisms are both genetically more sensitive than other conspecifics to environmental signals; some are more sensitive at certain life stages than others. “Evolutionary reasoning suggests that children should vary in their susceptibility to environmental influences, including parenting.” Some individuals are more likely to be able to alternate developmental trajectories than others. As a result, some children suffering from early life adversity are not as affected emotionally as others. Additionally, individuals can be more or less susceptible to both “positive and negative experiences” (Belsky & Pluess, 2009).

Individuals are more susceptible to developmental change including plastic responses depending on their present life stage. Some organisms, like insects, undergo facultative diapause in which development is halted, and the environment has to activate genes for development to proceed from egg to pupae to adult (Smith-Gill, 1983). While humans do not undergo a diapause,

there are three main stages in humans whereby the environment has the most influence: the pre-natal, post-natal, and juvenile stage. “The window of developmental plasticity extends from conception to early childhood, and even beyond to the transition from juvenility to adolescence, and could be transmitted transgenerationally. It involves epigenetic responses to environmental changes, which exert their effects during life history phase transitions” (Hochberg 2011). The experiences that can occur in these different “windows of developmental plasticity” will be distinguished later as they have important consequences to behavioral development.

Phenotypic Plasticity in Non-Human Animals

To eventually understand human psychological plasticity, it is beneficial to discuss relevant observations of plasticity in other animals besides humans. Three different ways in which the environment can influence development are discussed. First, epigenetics affects prenatal and postnatal stages in the development of rats. Second, the genome produces alternative morphologies evolutionarily in marine isopods. Third, water fleas and sex-changing fish exhibit species-typical plastic responses based on variability in their environments.

Rodent experimentation has shown that a variety of early life factors influence brain and behavioral development. In rats and humans, production of a protein called brain-derived neurotrophic factor (BDNF) plays an important role in developing the brain and associated behavior (Yan, Zheng, & Yan, 2004; Champagne, 2010). A 2004 study showed that mother rats exposed to cocaine impact their developing fetus by epigenetically suppressing BDNF-producing genes. Additionally, exposure to cocaine prenatally has been shown to increase the expression of genes that promote brain cell death (Xiao & Zhang, 2008). One can only imagine all of the

pernicious effects cocaine may have on human genetic expression, and consequently, behavior.

Postnatal rat studies are textbook examples of epigenetics. In rat brains, the hippocampus processes external information into stress and fear responses. Studies have shown that an irregular hippocampus impacts the ability for rats to respond to frightening external signals such as lights, approaching human hands, etc. (Kjelstrup et al., 2002). Hippocampal activity is furthermore impacted by the postnatal social environment. Juvenile rats that receive maternal grooming from their mothers express glucocorticoid receptor (GR) promoter genes in hippocampal cells. The buildup of GR in the brain aids in rodent response to stress. On the contrary, rats that did not experience licking (maternal grooming) as juveniles had increased methylation of GR promoters and, consequently, were less responsive to frightening external signals. Subsequent studies have shown that these maternal effects have been carried throughout individual rat lifetimes. Ultimately, the early life experiences of rats affected the expression of genes in the brain - impacting hormone production and psychological development. “Natural variations in maternal care in rodents can, as in studies of human mother-infant interactions, be characterized and associated with changes in offspring brain and behavior” (Champagne, 2010). As focused on later, maternal involvement has a tremendous impact on how genes function in the brain cells of human children.

Other animal research relating to environmental influences on development include animal morphological changes over time. Stephen Shuster & Michael Wade (1991) studied alternative morphology in a type of marine isopod (*Paracerceis sculpta).* To mate with females, *P. sculpta* males develop physiologically into one of three morphologies (different forms produced by alternative suites of genes expressed) from one species-typical genome. Alpha male

morphs guard the entrance of intertidal sponges and regulate which individuals enter into sponge harems using courtship signaling. Alpha males develop the largest body compared to the other morphs and admit up to ten female *P. sculpta* into these sponges while trying not to admit any males. They then proceed to mate with their collected females, who can only reproduce one time. Beta males have an alternative reproductive strategy, developing a morph that mimics the anatomy and behavior of females. Beta males deceive alpha males guarding sponge harems to allow them to enter and mate with many of the accrued females. The third morphology, exhibiting another variant reproductive strategy, is the gamma male who is significantly smaller than the other morphologies and is able to sneak and hide within sponge harems (Shuster, 1987; Shuster & Wade, 1991). Variant reproductive strategies in *P. sculpta* illustrate how the genome has the ability to produce multiple reproductive strategies on an evolutionary time scale in response to challenging environmental situations.

The community and environment influence the phenotypic development of water fleas (*Daphnia pulex*). Water fleas living in a community with predator insects develop longer tail spines and have pointier heads than fleas living in communities that do not have insect predators. Through epigenetic mechanisms, chemicals emitted by predators induce a change in genetic expression, extending the length of the development of these structures. Additionally, water fleas may change their mode of reproduction. They reproduce asexually when in a cold and uncompetitive environment and sexually when water is warmer and in a competitive environment. In a competitive environment, resources are harder to acquire and rapid asexual reproduction provides offspring with a decreased chance of survival (Starr et al., 2013).

Fish that change sex are common examples of the impact of the social environment on development. In an unisex tank, bluebanded gobies (*Lythrypnus dalli*) form dominance hierarchies depending on how often each displays submissive actions. A 2007 study showed that individuals low on dominance hierarchies changed sex while individuals closer to the top of the hierarchy retained their sex. “Once a social hierarchy is established, individuals determined their sexual phenotype, regardless of initial sex” (Rodgers, Early, & Grober, 2007). Similar to *P. sculpta* and water fleas, the ecological niche influences development.

The Psychological Command Center

To understand how the environment influences both cognitive behavior and the subconscious mind, particular parts of the brain must be examined. Weighing an average of about three pounds, the brain keeps organs functioning, processes information, and initiates voluntary movement. Just like every organ in the body, the critical element to the brain occurs on the cellular level. The brain contains about one-hundred billions neurons, and each one has the ability to communicate with thousands of other neurons (Sdorow, 1998; Jabr, 2012). A neuron consists of a spherical (soma), and hundreds to thousands of branching arms. There are two different types of arms: dendrite arms receive electrical signals and axon arms give electrical signals. Every millisecond, neurons transmit an electrical charge by moving neurotransmitter chemicals to adjacent neurons at the end of an axon (synaptic bulb). When transferred to dendrites, neurotransmitters cause the pumping of positive ions into the adjacent neuron’s interior. The influx of these ions causes an electrical imbalance and a charge difference on the outside and inside of a section of the neuron. When this charge becomes too great, neurons will

pump positive ions into adjacent sections, creating an electrical charge that repeats for thousands of other neurons long. Every interneuron transfer decreases the electrostatic charge by a small amount until the charge becomes too weak to have any effect (Sdorow, 1998).

Different parts of neurons in the brain play different roles in regulating the body. Muscles of the body are flexed with information from the outermost region of the brain, the cerebellum. In the brain stem, right above the spinal cord, automatic motor functions (heart rate, blood pressure, breathing) are controlled. Between both these regions is the limbic system. Structures in the limbic system such as the hypothalamus, amygdala, and hippocampus are important to any discussion of behavior (Sdorow, 1998).

The discovery of the function of the hypothalamus occurred by accident. In 1954, James Old and Peter Milner attempted to test the response of a part of the midbrain, the reticular formation, when given electric shocks. A rat was put in a box with a lever that distributed food. However, the researchers accidentally attached the electric nodes to the wrong part of the brain: the hypothalamus. “To the experimenters’ surprise, the rats, even when hungry or thirsty, ignored food and water in favor of pressing the lever - sometimes thousands of times an hour until they dropped from exhaustion up to 24 hours later” (Sdorow, 1998). Despite having unintended harmful effects on the rodents, it soon became clear that the hypothalamus plays a role in pleasure. In addition, the hypothalamus secretes hormones from the pituitary gland which “regulate aspects of motivated behavior such as mating and aggression” (Baron, 1995). Located in the center of the brain, the hypothalamus translates responses from the environment to hormonal action. Like in every organ structure of the brain, neurons of the hypothalamus are subject to formation changes in the face of environmental perturbations (Sdorow, 1998).

Another important brain structure that is part of the limbic system is the amygdala. Like the hypothalamus, the amygdala processes information from the environment and "contributes to feelings of fear, anger, or relief." It is interesting to note how physical deformation of the amygdala can contribute to exaggerated feelings. In 1966, Charles Whitman randomly killed sixteen and injured thirty-one people at the University of Texas. After the incident, a diary of his was found detailing his struggle with homicidal urges. After he died in a shoot-out with the police, an autopsy revealed he had a tumor on his amygdala. It is uncertain if his homicidal urges were influenced by the tumor on this emotional section of the brain or if they were merely coincidental (Sdorow, 1998).

The final relevant structure of the limbic system is the hippocampus. The hippocampus is in charge of storing memory. In this region of the brain, long-term memory develops as neurons repeatedly form physical connections with each other (allowing for the passing of neurotransmitters) or by repeatedly firing together. When connections between neurons become broken, the memory is lost. Damage to the hippocampus leads to broken nerve connections and Alzheimer's disease (Sdorow, 1998; Adams, 2015). All of these parts of the brain have been affected by adverse social environments that have led to altered behavior. As delved into later, traumatic events that occur during a human's lifetime such as rape or war PTSD actually decreases the volume of parts of the brain. Consequently, this has negative impacts to emotional stability (Wlassoff, 2015).

Neuroplasticity

As organisms develop, their brains do as well. Heritability and experiences both impact the developing brain. IQ testing has shown that some children are simply more intelligent than others because of inherited genes (Croston, Branch, Kozlovsky, Dukas, & Pravosudov, 2015). However, epigenetics and alternative trajectories from the chemical and social environment also impact brain cell development and influence how humans think and act (Sdorow, 1998; McClung & Nestler, 2008).

One important way in which genetics influences brain function is known as neuroplasticity. Neuroplasticity refers to the ability of the brain to make new connections between neurons. This influences neuronal networking or simultaneous firing of neurons. In the face of environmental pressures, changes to brain learning and memory can be positively adaptive. For example, organisms increase their fitness and chance of survival if they are able to better associate stimuli with danger. On the contrary, drugs can cause negative effects by altering neuronal pathways. Like toxins, stress has negative effects. "Long periods of stress can lead to structural and excitatory changes associated with anxiety and depression." Just like how a cascade of genetic expression involves many genes, neuronal pathways include all the neurons involved when presented with a stimulus (McClung & Nestler, 2008). A stimulus can even be as simple as an object that causes one to recollect a memory; a spark to one neuron will initiate a pathway of neuronal activation. This is why memory recollection may be a long process.

R. F. Oliveria's work on fish highlights how genes are involved in response to social environments. To survive, animals must adjust to social life by "biochemically switching nodes of neural network underlying social behavior." This is accomplished by regulating master gene

expression (Sun-Kin Chan & Kyba, 2013) so that ultimately "different brain genomic and epigenetic states correspond to different behavioral responses." Previous interactions with other fish will cause such adjustment of genetic effects on activity of relevant neuronal networks (Oliveria, 2012).

I have observed the impacts of the social environment on behavior and color in *Melanochromis auratus* cichlids to help my understanding of neuro- and developmental plasticity. *M. auratus*, like many other fish, form dominance hierarchies. A male, who is dominant over all conspecifics in a tank, displays a black body coloration. Meanwhile submissive males and females display a yellow coloration. In an observational study I conducted in 2017, four un sexed juvenile *M. auratus* cichlids were placed in a 38 gallon tank, in which a female emerged as dominant over the three other smaller yellow *M. auratus*. After 27 days, I noticed a change in the behavior and color of one of the males; he displayed the dark black coloration and was dominant over all the other fish. The previously dominant female, who was currently mouth brooding, had lost her position on the dominance hierarchy. As the male rose in the dominance hierarchy, as with Oliveria's (2012) zebrafish, he likely responded to circumstances by expressing different genes in relevant neuronal centers, resulting in a coordinated alteration of behavior and color. The experiment was repeated with the same female and a different male, yielding nearly identical results.

Responsive genetic expression is a large part of long-term neuroplasticity. First, it is necessary to make note of and clarify the difference between two types of neuroplasticity with opposing effects. Long-term potentiation (LTP) is the strengthening of the connection between

neurons. In opposition, long-term depression (LTD) weakens the connection among neurons (McClung & Nestler, 2008).

McClung and Nestler (2008) note the effects of transcription factors on genetic expression can cause neuroplasticity. Transcription factors attach to gene promoters (100 nucleotides or so at the beginning of every mRNA strand) and can initiate or suppress genetic expression. Other transcription factors can bind directly to proteins involved in gene transcription. Activation of neurons in the hippocampus leads to a stimulation of transcription factors. When activated, transcription factors such as CREB (cAMP response element-binding protein) impact genetic expression to produce different proteins in the brain (McClung & Nestler, 2008). In relation to fish, activation of the neurons in zebrafish that pick up social stimuli causes the release of transcription factors, leading to alternate genetic expression and new neuronal pathways. Social stimuli, for example, includes "the opportunity to rise in social rank" and results in eventual alternate genetic expression (Teles, Cardoso, & Oliveira, 2016). In the amygdala, a rodent study has shown that increased levels of CREB transcription factors lead to "enhanced fear memory" (McClung & Nestler, 2008).

One of the many harmful effects of abusive drugs (such as morphine and heroin) is the fact that they invoke the release of dopamine, a neurotransmitter that over-stimulates pleasure centers in the brain. However, the genetic aspect of drug abuse makes it even more pernicious. Drugs stimulate reward and pleasure neurons of the brain that, when stimulated, release CREB. As a consequence to the pleasurable feelings drugs may neurologically stimulate, CREB transcription factors target a gene called *prodynorphin* which binds with other proteins to decrease the amount of dopamine production (McClung & Nestler, 2008). This is part of the

reason why heroin and morphine abusers do not experience as much pleasure from sex, entertainment, and other dopamine-inducing activities.

Section II

Human Application

The first half of this essay detailed the complexity and responsiveness of the genome, the various ways in which the environment can influence the genome, and the role of the brain and its dependence on genes. Only after these three biological phenomena are assimilated can a discussion of how exactly this applies to human psychological development can occur. There are two ways in which altered genetic expression is involved with human behavior. First, the environment through chemicals, influences genetic expression in the brain, resulting in altered social behavior. Chemicals that impact genetic expression come from a myriad of variant sources (e.g., drugs, air quality, chemicals passed from mother to fetus, nutrition, etc.) Each of these sources have harmful and/or beneficial effects to the brain, and consequently, human behavior (Nathanielsz, 1999; DeMarini, & Claxton, 2006).

Secondly, input to the brain from behavioral experiences can alter genetic expression affecting traits in all various parts of the body. “Socio-environmental processes regulate human gene expression by activating central nervous system processes that subsequently influence hormone and neurotransmitter activity in the periphery of the body” (Cole, 2009). Serious stress to the mind impacts the DNA of many cells epigenetically, including white blood cells. This is the biological explanation for why stress is associated with sickness (Weinhold, 2012).

Additionally, an individual may be genetically affected because of the social behaviors of other individuals. Knowing this could add a whole new dimension to psychology and therapy. "Social experiences alters gene expression for the long term. Thus, I am a celebrant: social psychiatry is not only alive and well, but it has a bright future precisely because of genomics" (Eisenberg, 2004). Social interaction (or lack of) between family members and a developing child can have tremendous effects to genetics expression. Lack of paternal and/or maternal care is associated with an increase in behavioral problems (Belsky & Pluess 2009) and may also impact genes in cells not involved in human behavior (Causey, Gardiner, & Bjorklund, 2008).

Human Stages of Sensitivity

There are three stages of human development that are the most sensitive to environmental influences. From fertilization to birth, the prenatal period completely relies on the mother for chemicals necessary for growth (Champagne, 2010; Hochberg, 2011). As Peter Nathanielsz argues in his book, *Life in the Womb: The Origin of Health and Disease*, the development of the fetus is the most critical developmental stage as early developing cells require proper nurturing before any later developmental stage can even be reached. The neurological development and behaviors of all humans depend on the the health of the mother before conception and the decisions she makes while pregnant.

Right after birth, the period popularly known as postnatal, is also a time when the environment has a tremendous influence. The postnatal stage begins with birth and ends at the juvenile stage. Even though newborns do not physically reside in the womb, they are still

dependent on maternal care. Quality of maternal care influences genetic expression at a time when anatomical structures are rapidly growing. Additionally, it is the time when the brain is actively processing information from many new experiences. Adverse situations that may arise in the lives of biological or adopting parents can have consequences to the adult behavior of that newborn. “Longitudinal studies of neglect indicate increased risk of cognitive impairment, social/emotional difficulties, and risk of mental disease.” Sadly, statistical analysis has shown that the amount of early trauma experienced by newborns and juveniles is negatively correlated to the volume of brain structures due to decreased genetic expression of growth proteins (a topic discussed in more detail later). Both the prenatal and postnatal stages are times when chemicals from the environment have the greatest effect to an individual’s behavior (Champagne, 2010).

The juvenile stage of human development is the start of when humans truly interact with the social environment and process social information. The age whereby the postnatal stage ends and the juvenile stage begins is ambiguous, but the juvenile period here will refer to the time when humans can process and reflect on social information (Champagne, 2010). Around the age of one, most psychologists believe babies can start understanding the meanings of words (Welsh, 2012). Starting at this age and continuing until maturity, the cognitive stimuli an individual encounters can affect genetic expression and genetic trajectories in cells throughout the body. “Environmental conditions that are experienced in early life can profoundly influence human biology, growth, and maturation, and long-term health and longevity” (Hochberg, 2011).

New technologies have emerged within the past twenty years that allow scientists to map all the genes actively being expressed in a particular cell at a specific time. This has allowed

scientists to visualize and record data on how external social factors influence genetic expression (Cole, 2009).

The Effect of Behavior on Health

The association between stress and sickness is well known. Several research articles use the term "under the skin" to describe the idea that the experiences an individual faces in his or her lifetime have consequences to genetic expression (Cole, 2009; Tung & Gilad, 2013). "Researchers have observed a correlation between increased childhood stress and adult methylation in a region of the promoter of glucocorticoid receptor gene in leukocyte DNA" (Weinhold, 2012). Leukocytes are white blood cells that are important in fighting foreign viruses and bacteria in the body. Glucocorticoids are chemicals that suppress inflammation and increase cell actions in fighting foreign substances after they bind to glucocorticoid receptors on cell surfaces (Baschant & Tuckermann, 2010). Since stress increases methylation of glucocorticoid receptor genes, it consequently decreases the amount of glucocorticoids that can bind to glucocorticoid receptor genes, resulting in less effective immune responses (Cole, 2009; Weinhold, 2012; Tung & Gilad, 2013). Consequently, stress in the postnatal and juvenile periods have been shown to increase an individual's risk of acquiring metabolic disorders, respiratory illnesses, and cardiovascular diseases (Belsky & Pluess, 2009; Cole, 2009; Hochberg, 2011; Tung & Gilad, 2013).

Likewise, maternal stress has effects on the developing fetus. In the brain, stimuli can cause stress by overloading the brain with sensory information. The sound of a gunshot would cause neurons in the brains to send signals to the body to increase heart rate, hormone

production, and respiration methods. Stress causes adrenal glands to produce hormones like cortisol that also cause cells to differentiate and to inhibit cellular growth. Cortisol can negatively harm the fetus by crossing the mother's placenta and causing premature cell specialization with cells that are not fully developed. Normally, the placenta is able to protect adrenal hormones like cortisol from entering the fetus by inactivating them; however, damage to the placenta or an unusual buildup of cortisol from maternal stress can cause the placenta to fail its filtration duties. Examples of adverse situations that can increase cortisol production and damage the placenta in mothers includes physical abuse, constant financial worry, drugs, and alcohol (Nathanielsz, 1999). Severe maternal stress during pregnancy has been associated with an increased risk for mental disorders (Champagne, 2010) and a reduction in neurodevelopment (Weinhold, 2012). "Maternal anxiety during late pregnancy predicts behavioral-emotional problems at age 7, even with postnatal anxiety and depression controlled" (Belsky & Pluess, 2009).

A 2009 study compared the genes in white blood cells of two groups of healthy individuals that differed in their social involvement. One group was reported to feel socially connected to others in the community for the previous four years, and the other group reported that they felt consistently lonely and socially disconnected with others. After gene expression was examined, the socially-distant group had an increase in genes contributing to inflammation, but a decreased expression of genes that aided in fighting viruses compared to the more social group. The fact that socially-isolated individuals showed a higher vulnerability to infections supports the idea that getting involved in the community is healthy to the immune system (Cole, 2009). Furthermore, it supports the idea that knowing the biology involved in psychology is important to therapeutic approaches.

The Effect of Health on Behavior

The link between psychology and genetics is not just about how psychological or sociological factors influence gene behavior, but also how genes influence human behavior by chemically interacting with the environment. Gene-environmental interactions in prenatal human development can have tremendous consequences to adult behavior. As Nathanielsz (1999) emphasizes, "It is easier to see the needs of young children standing before you than to be concerned with the special requirements of the unborn baby in the womb." As in all organisms, the beginning of development matters the most. Fruit-bearing garden plants only become successful if they are properly planted and consistently watered as seedlings. However, a farmer lays down many seeds in the hope of getting a small fraction of successful seedlings while forgetting about the large fraction of failures. For humans, that option is not possible; mothers wait nine months to produce one child. Yet, according to Nathanielsz, mothers care more for the postnatal child than they do about the fetus. Maybe this has to do with actually seeing the baby.

Thankfully, most doctors make strong nutritional recommendations for pregnant women. Sometimes, this is only perceived as ensuring the child's positive physical development, but nutrition impacts the brain via genes and, thus, behavior. In some circumstances the mother is not at fault, but is simply carrying a baby in a bad environment, such as a place of food or water scarcity, nutrient-poor conditions, low socioeconomic status, etc.

All cells require energy from food. Through cellular respiration, consumed molecules are turned into energy necessary to initiate cellular processes including genetic transcription and translation (Audesirk, Audesirk, & Byers, 2014). While malnourished children are seen as physically having small muscle and bone masses, they also have underdeveloped brains cells.

Nerve cells, glial cells, and blood vessels all require energy to regulate neurological development, and, when not fed, may cause abnormal behavior (Nathanielsz, 1999).

When nerve cells are created via rapid cellular division, they go through a migration period that involves moving to specific locations where they differentiate into the various types of neurons. Along their movement process, cells will interact with molecules on adjacent cell surfaces and either remain attached or move to a different location. They can attach to adjacent cells via adhesion proteins created by cells. “It is imperative that nerve and glial cells secrete the correct adhesion molecules at the correct times in the correct amounts.” Otherwise, the neurons will not be in the right place, and may become dysfunctional. As neurons need energy to drive genetic processes to create adhesion proteins, neuron connectivity is ultimately determined by maternal consumption (Nathanielsz, 1999).

This is only one example of many known and unknown ways in which nutrition affects brain development through genes. One must consider all the proteins involved in the normal functioning of brain cells. During the very early stages after conception, the emerging fetus starts as a small ball of cells called a blastula (Starr et al., 2013). Proper nutrition in those cells is especially important as they will multiply into many other cells. Early cell disruptions will cause a chain reaction of abnormal cells in the brain, resulting in potential developmental problems (Morgane, Moker, & Galler, 2002).

> Exogenous factors, such as malnutrition, can alter the activity of enzymes and interfere with protein synthesis and protein structure and, thereby, also interfere with the proper incorporation of lipids into various brain structures. Distortions of the coordinated maturation of different brain components, such as alterations in the sequential production of particular classes of neurons, will disrupt the orderly growth and elaboration of neuronal circuitry. Misdirected, mistimed or absent developmental cues can cascade to increasingly perturb the normally ordered

> progression of brain development, thereby impacting the highly complex expressions of brain function, including compromising logic and memory circuits, and thereby affecting cognitive processes. (Morgane, Moker, & Galler, 2002)

Additionally, lack of maternal nutrition can affect the fetus' genetic trajectory. When faced with reduced nutrition in the fetus, the baby will express different genes, altering its developmental trajectory, and develop traits more slowly or in a different way that involves less energy. Ultimately, this could have negative effects to the developing human's behavior as less energy could be set aside for the proper formation of the brain (Bateson, 2004).

Moreover, the Dutch Famine Study in 1992 showed that prenatal caloric restriction is associated with risk for mental diseases like schizophrenia, as well as hindering neurodevelopment (Champagne, 2010). According to the National Institute of Health, scientists know schizophrenia is epistatic and they believe that malnutrition of the fetus might cause it. On the molecular level, schizophrenia is caused by the lack of neuron connectivity, causing dysfunctional learning and memory (Nathanielsz, 1999; Newitz, 2011). Tying together research about malnutrition and it's effects to the brain and schizophrenia, it is conceivable that malnutrition is linked to schizophrenia: not enough energy is consumed to produce adhesion proteins leading to abnormal neuronal connectivity.

Neurons aren't the only cells in the brain that are affected by nutrition. Glial cells play an essential part in brain activity. They physically wrap around neuron axons and dendrites, acting as an insulator that speeds up the flow of electrical charges through neurons. For proper hastening of these electrical charges and enhanced psychological ability to process information, glial cells have to be in the exact right place on the neuron. This can only happen if both neuron

cells and glial cells are supplied with enough energy to use their genes to make adhesion proteins and other signaling molecules (Nathanielsz, 1999).

Toxins

Sadly, cocaine, tobacco, and alcohol are still used at alarming rates. The National Institute on Drug Abuse reported that in 2016, more than 16% of all American adults have tried cocaine at least once ("Cocaine," 2016). Cocaine easily flows from the mother's blood through the placenta to fetal blood. Directly to the developing fetus, cocaine interferes with genes that naturally produce neurotransmitters involved in emotion, memory, and arousal (Singer, Minnes, and Short, 2004; McClung & Nestler, 2008). At the same time, cocaine causes the secretion of hormones like norepinephrine which constricts blood vessels (Tantibanchachai & Zhang, 2013). As a consequence, nutrients have a harder time getting to the fetus.

Additionally because of blood constriction, cocaine causes premature uterine contractions. Normally, at times when oxygen levels are low in the womb, the baby conserves oxygen by not breathing or moving. However, premature contractions force the baby to move around the placenta, expending energy. As a result, oxygen in the brain is decreased in babies exposed to cocaine while they use it on movement (Nathanielsz, 1999). Since oxygen is important for all cells, including brain cells, to perform genetic and non-genetic processes, many mental problems are associated with cocaine such as cerebral palsy, a brain condition whereby motor functions are permanently impaired (Bishop, 2013).

Nathanielsz (1999) passionately argues about a court case involving the Medical University of South Carolina that threatened to arrest pregnant mothers if they continued to use

cocaine. The American Civil Liberties Union took the university to court to protect the mothers, a majority of which were black. Some suggested the university was being racist, but the local African American police chief saw it not as a racial issue, but about protecting children and asked, “Would it be acceptable for the mothers, white or black, to give their babies cocaine after birth?” Somehow, the fetal part of development is not regarded as being as important as the development of child after birth. In many cases, prenatal abuse is not even punished while postnatal abuse is a serious crime. “Cocaine is a major assault on the children in the uterus. An assault far worse than hitting a small child with the palm of your hand in a fit of anger” (Nathanielsz, 1999).

While cigarette smoking may not be considered as dangerous as hard drugs like cocaine, studies have also found that children are significantly more likely to have developed ADHD if their mothers smoked. Also, prenatal smoking has been found to stunt fetal growth, potentially leading to a variety of negative sociological factors as the child develops into an adult. Despite knowing that smoking is bad for the fetus, one-third of smoking women still refuse to quit temporarily when pregnant (Nathanielsz, 1999).

The immensity of the steps involved in neurodevelopment are too complex to put into a flowchart or even to identify in some circumstances. Ubiquitously known to scientists around the world, however, is that alcohol disrupts the normal gene-chemical-cellular processes in the brain. Fetal Alcohol Spectrum Disorders (FASD) can sometimes be identified in individuals based on abnormal facial structures. If the effect of alcohol can have this tremendous of an impact, imagine the damage it does to behavior. Preciously as imagined, studies have shown FASD symptoms included cognitive difficulties and lifelong behavioral problems (Ramasay, 2010;

Zhou & Mason, 2015) such as social problems and isolation. Cognitive difficulties includes deficiencies in language, memory, problem solving, and non-verbal learning (O'Brien & Mattson, 2011).

Normal neurodevelopment includes many beneficial epigenetic processes (see "Environmental Influences on the Phenotype") such as methylation and acetylation. Methylation and acetylation are essential for dictating which genes a cell should express into specific proteins necessary for building strong connections between neurons. However, FASD disrupts these normal epigenetic occurrences. "Several laboratories have reported altered epigenetics, including DNA methylation and histone modification, in multiple models of FASD. During development DNA methylation is dynamic, yet orchestrated as methylation progresses in a precise spatiotemporal manner during neurulation and coincides with neural differentiation" (Zhou & Mason, 2015). Additionally, a 1999 study showed that fetal alcohol exposure is linked to criminal behavior. Out of 287 youth who were convicted of criminal activity owing to mental disabilities, an astonishing 67 (23.3%) had some level of alcohol exposure as a fetus (Fast, Conry, & Loock, 1999). Compared this to the statistic that nationwide, about only ten out of 1,000 citizens (1%) are estimated to suffer from FASD (Ramasay, 2010). A mother who consumes alcohol while pregnant risks genetic alteration to their child's intelligence and behavior.

New research suggests that alcoholic fathers can also negatively impact their children. "Novel mechanisms for alcohol-induced phenotypes include altered sperm DNA methylation, hypomethylated paternal allele and heritable epimutation. These studies predict heritability of alcohol-induced epigenetic abnormalities and gene functionality across generations." It was

previously thought that alcoholic fathers had nothing to do with FADS, but new research like this has shown that sperm cell functioning can be genetically altered by excessive alcohol consumption (Zhou & Mason, 2015). In addition, a father's behavior towards the pregnant mother can induce stress or depression, which is sometime sadly sought to be alleviated with alcohol.

Parenting

Development of the human individual is not as genetically impacted by chemicals in the environment as it is the womb. Instead, the juvenile human is most genetically impacted when he or she interacts with his or her environment through experiences. These experiences can have genetic repercussions, positive or negative. An individual's intended developmental genetic trajectory can be altered based on early life experiences. The social attachment parents give to their children is about more than just making the child feel loved, it actually sets the pathway for genetic expression (Belsky & Pluess, 2009).

Individuals vary in their ability to be genetically plastic, or vulnerable, to external influences. This is known as susceptibility, and individuals vulnerable to susceptibility are typically the ones with difficult temperaments. Individuals with a great amount of genetic susceptibility experience the highs of the highs and the lows of lows when faced with beneficial or poor parenting respectively. "Two recent studies, each drawing on data collected for the large scale National Institute of Child Health and Human Development Study of Early Child Care found that infants who are rated as having difficult temperaments at six months by their mothers not only manifest more behavior problems in early childhood when experiencing low-quality

parenting or low-quality child care than do other children, they also display fewer problems and more social skills than other children when exposed to high-quality parenting or child care." Moreover, some juvenile humans can have variant susceptibility to environmental influences which actually improves his or her individual fitness. In the face of poor parenting, these individuals may not be as affected as other individuals. While regularly susceptible individuals might express new genes in bad situations, these variantly susceptible individuals may not be affected at all. Since the variant susceptibility increases fitness, natural selection favors it (Belsky & Pluess, 2009).

Long-term observational studies have been performed on Romanian orphans adopted by Canadian families. "Malnourished, they spent the majority of their days alone in cribs lacking in physical, social, auditory and visual stimulation." Owing to the lack of nutrition and parenting in early life, these children were delayed in both physical and cognitive growth compared to other children. This condition is referred to as psychosocial dwarfism (Le Mare & Audet, 2006).

In young females, the social environment in the home influences one's future sexual and marital life. The way a parent acts and communicates with his or her daughter can influence that daughter's future sexual and marital life, but, furthermore, the daughter is actually genetically affected by the quality of parental involvement. "The degree of security that is experienced during childhood sets development on alternative pathways, and adaptively shapes the individual's future reproductive strategy. A secure attachment will result in a reproductive strategy that is based on late maturation, a commitment to a long-term relationship, and a large investment in parenting" (Hochberg 3). On the contrary, lack of security in the home and nonexistent parental investment in females will cause menarche (the first occurrence of

menstruation) to happen at a younger age. When a female has less parental involvement in her psychological environment, her body genetically adapts to becoming an adult sooner. By changing her age of menarche, she must express genes to create proteins that contribute to menstruation sooner than normal. Early maturing females also consequently engage in sexual activity sooner, are more likely to have short-term relationships, and become parents with limited parental investment. This cyclical process shows how alternative genetic expression can be passed to the next generation without being heritable. Additional studies have found that the lack of a paternal figure in the house is associated with an decrease in age of menarche (Causey, Gardiner, & Bjorklund, 2008).

On the other hand, in males without father involvement, male puberty is reached later. The UK National Child Development Study reported that young males that lacked paternal care were more likely to reach puberty later in life. Just like females, the psychosocial environment influences expression of genes contributing to reproductive organs and hormones. Even though these male juveniles reached puberty later, they actually tended to have children sooner compared to young males with paternal interactions. This has multiple implications to parenting today such as the negative effects of divorce during a child's first 5-7 years and whether governments should support single parents (Back, 2011).

Child Abuse

Early life adversity manifests itself into the genes of juvenile humans, having the potential to impact behavioral development. Physical child abuse impacts both the endocrine system and the development of the brain. In times of stress, endocrine glands work together to genetically produce chemicals that change the function of cells in the body. In response to stress, the hypothalamus, anterior pituitary, and adrenal cortex work together to secret glucocorticoids.

> Internal and external signals trigger the hypothalamus to release corticotropin releasing hormone (CRH), which acts on the anterior pituitary to stimulate the synthesis and secretion of adrenocorticotropic hormone (ACTH). ACTH then acts on the adrenal cortex to stimulate the production and secretion of glucocorticoids. Acting on nearly every tissue and organ in the body, glucocorticoids function to maintain homeostasis both in response to normal diurnal changes in metabolism and in the face of stressful perturbations. (Oakley & Cidlowski, 2013)

When glucocorticoids bind to glucocorticoid receptors on cell surfaces, they cause cells to express proteins involved in suppressing the immune system and making energy more accessible (Kodama, 2003; Oakley & Cidlowski, 2013). In children that are frequently physically abused and constantly feeling afraid of their homes, the HPA stress response is over-worked and produces an abundance of glucocorticoids (Kodama, 2003; Champagne, 2010; Oakley & Cidlowski, 2013). Additionally, McGowan et al. (2009) found that physically abused children had methylated glucocorticoid receptor genes. When glucocorticoid receptors are lacking, glucocorticoids are in excess and have nowhere to bind. This can be a real problem in times of stress when the HPA axis produces an abundance of glucocorticoids. “Elevated glucocorticoids have been linked with outcomes such as impaired neuronal growth, modified immune function

(such as methylated leukocyte DNA), and accelerated cellular aging" (Weinhold, 2012). Unsafe household environments can hinder neurodevelopment and make children more prone to diseases and psychological problems, "environmental events that associate with decreased hippocampal glucocorticoid receptor expression and increased HPA activity enhance the risk of suicide" (McGowan et al., 2009).

Maltreatment also impacts neuroplasticity. Abused children compromise their lack of security by developing hyperactive brains that respond readily to any danger, meanwhile halting other areas of development. Hyperactive brains genetically alter neuronal pathways from normally developing. As a result, these children may have a difficult time interpreting the social world around them. "Consumed with a need to monitor nonverbal cues for threats, their brains are less able to interpret and respond to verbal cues, even when they are in an environment typically considered nonthreatening, like a classroom." Being on alert at all times causes some of these children to be labelled as having learning disabilities as they are not able to be calm enough for studying. Abused children also have physically smaller hippocampi, cerebellums, and cerebral cortex. Underdeveloped cortexes are associated with increased impulsive behavior (Child Welfare Information Gateway, 2005). Child abuse impacts hormone production, neuroplasticity, and brain volume.

Teen and Adult Development

Not only are the prenatal, postnatal, and young juvenile stages of human development prone to genetic change, but also cognitive experiences during teen and adult life can alter development (Eisenberg, 2004). A common misconception is that a human stops developing when he or she becomes an adult; however, a human never stops adapting to his or her environment until he or she dies. The human genome is constantly working in every millisecond of every living human. The genome is not a blueprint for design, but a military general, dictating how the complex body should be run throughout life.

Although there have not been many studies on how the adolescent social environment impacts genetic expression, it is known that stress caused by overworking, or feeling inferior to peers, impacts the HPA stress response. Additionally, peer pressure causes adolescents to make decisions that could alter how their genes are expressed. For example, peer pressure can cause teens or adults to consume unnecessary amounts of alcohol in a short period of time (Juskalin, 2010). Repeated binge drinking can result in unnatural histone modifications in the liver. Since the adrenal cortexes play a role in impacting other glands like the pituitary and hypothalamus in the brain, binge drinking ultimately effects the brain (Hurst, 2014). Ironically, colleges serve as both major learning establishments and the hub for brain-damaging binge drinking.

Traumatic events in teenage and adult life also can impact the development of the brain. Near-death experiences, sexual assault, rape, war experiences, among other traumatic experiences impact the growth and connectivity of neurons in the brain. As in child abuse, structures of the brain such as the hippocampus, amygdala, and prefrontal cortex are reduced in size (Wlassoff, 2015). This reduction in size is the result of an alteration in genetic expression.

For example, a 2011 study found that patients that experienced traumatic events in their lives had decreased expression of proteins associated with neuronal growth in their amygdalae (Golub, et al., 2011). The amygdala processes emotions in the brain and when underdeveloped, PTSD patients have anxiety when dealing with others' emotions regardless if they are related to their own traumatic experience (Wlassoff, 2015). Hyperactivity in the brain goes for all living beings; the most skittish household cats are the ones that were traumatized by frightening children banging on their glass cage at the pet store.

The hippocampus is the structure most reduced in PTSD victims. It is the area of the brain where memories are stored (see "The Psychological Command Center"), and when reduced in size, causes the misinterpretation of current events for past events. "Particular neural mechanisms trigger extreme stress responses when confronted with environmental situations that only remotely resemble something from their traumatic past. This is why a sexual assault victim is terrified of parking lots because she was once raped in a similar place. A war veteran still cannot watch violent movies because they remind him of his trench days; his hippocampus cannot minimize the interference of past memories" (Wlassoff, 2015). In traumatic circumstances, teens and adults genetically become the products of their experiences regardless of whether they are able to control it or not. Current psychological studies are focusing on other psychosocial effects to genetic expression during the teen and adult years (Choudhury, et al. 2006).

Looking Forward

At Riverside Counseling in Leesburg, Virginia, Professional Counselor Dan Towery has a unique approach to helping individuals cope with behavioral problems. Using information from The Adverse Childhood Experiences Study, a study conducted in the 1990s that surveyed adults who suffered from lack of parental care or child abuse (Brooks, 2012), he created a self-made seminar on Mindfulness Awareness Practice Application. Towery works with some individuals who already have abnormal genetic-neuronal problems including cognitive problems, PTSD, and chronic stress. In his seminar, Towery argues that humans can reverse their cognitive problems by undergoing a behavioral change.

Facing out of the corner of the room, he has a whiteboard with two rows: "The top row identifies behaviors that people don't like but they still do. The bottom row identifies how to make a change," he explains. The top row includes fears, addictions, and adverse thoughts while the bottom row includes mental remedies like "Healthy Self Talk," "Visualization Mental Rehearsal," and "Arousal Control." Towery's aim is literally to change the neuronal pathways of the brain through self-recognition therapy. This includes confronting fears and self-demonstrating a desire to change behaviorally. Towery admitted his first-hand experience with social influences on his own development: "My dad committed suicide six months before I was born, and so I was in the womb and it made a huge impact on my life. Actually, I am more and more convinced now even in the womb that I was impacted by it" (Towery, 2017).

Human behavior is completely interconnected with genetics. Abnormal genetic expression (including developmental plasticity and epigenetics) impacts human behavior and is caused by human behavior. Genes serve as a bridge between the chemical environment and the

development of the brain, and as an intermediary between the psychosocial environment and the formation of traits. From conception to death, the physical and social environments we encounter literally alters the way in which DNA is expressed in all of our cells.

Annotated Bibliography

Adams, A. (2015). Brain connections last as long as the memories they store, Stanford neuroscientist finds. *Stanford News Service.* 30

This article shared information about the present understanding of neurons, neuron networking, and how memories form. It included the basic biology of a neuron to explain how memories are formed. It was referenced when I explained the importance of the brain to psychology.

Audesirk, T., Audesirk, G., & Byers, B. E. (2014). *Biology: Life on Earth* (10th ed.). Boston, MA: Pearson.

This textbook includes information about all various fields of biology. It was used in discussion about epigenetics. This book provided examples of the ways in which acetylation unwinds DNA from histones and makes DNA transcription and translation easier for cells.

Back, A. (2011) Boys with absent fathers more likely to become young dads. *The Conversation.*

This journal article talked about how paternal involvement shapes and influences the social and reproductive future of their sons. It is easy to conceptualize this, but this article shows genetic evidence that is very powerful.

Bateson, P. (2004). Developmental plasticity and human health. *Nature, 430*(6998) 418-413.

This source links malnutrition to developmental plasticity. It was useful in explaining how the fetus adapts to disruptions in the environment by alternating its genetic developmental trajectory.

Baron, Robert A. (1996). *Essentials of Psychology.* Needham Heights, MA: Simon & Shuster.

Baron's textbook makes references to homosexuality and talks about biological basis for behavior. The source was useful as it uses statistics to back up its claims. It contains theoretical and empirical components to it.

Belsky, J. & Pluess, M. (2009). The Nature (and Nurture?) of Plasticity in Early Human Development. *Perspectives on Psychological Science, 4*(4), 345-351.

This sources offers insight into the current Nature vs. Nurture debate. It recognizes that nothing can quantified in this debate. The sources also recognizes psychologist views on genetic and environmental factors influencing behavior. Jay Belsky and Michael Pluess do a great job of citing multiple, different experiments in explaining how the phenotype is manipulated by genes and the environment.

Beschant, U. & Tuckermann, J. (2010). The role of the glucocorticoid receptor in inflammation and immunity. *National Center for Biotechnology Information,* 120(2-3), 69-75.

This source provided information on specifically the importance of glucocorticoid in the body. It talked about how glucocorticoid is produced and what affects it has on individual cells. It was used when talking about how the immune system is weakened by social environments.

Bishop, W. (2013). What Happens to a Baby That Isn't Getting Enough Oxygen in the Womb? *Livestrong.com*

This article was impactful in talking about the negative effects of toxins like cocaine to the development of the fetus. It provided non-genetic examples of how the fetus is affected prenatally.

Brooks, David. (2012). The Psych Approach. *The New York Times.*

This source talked about the 1990 study by Vincent Felitti and Robert Anda who surveyed child abused individuals and found out if they had any cognitive difficulties. My interviewee used information from this study to create his therapeutic approaches to helping people with cognitive difficulties.

Causey, K., Gardiner, A., & Bjorklund, D. (2008). Evolutionary Developmental Psychology and the Role of Plasticity in Ontogeny and Phylogeny. *Psychological Inquiry, 19*(1), 27-30.

This source talks specifically about how development influences psychology and linking biology with human behavior. In this source, Causey and others mention female menstruation experiments done that are relevant to developmental plasticity on psychological behavior. The source also zooms out to show the big picture and explain evolutionary implications.

Child Welfare Information Geteway. (2005). Understanding the Effects of Maltreatment on Brain Development.

This 2005 issue brief was an important source of information that discussed how the brain is affected by maltreatment. It specifically talked about how the brain response to stress and was a good source of information about epigenetics of maltreatment and impacts to the brain.

Champagne, F. A. (2010). Early Adversity and Developmental Outcomes: Interaction Between Genetics, Epigenetics, and Social Experiences Across the Life Span. *Perspectives on Psychological Science, 5*(5), 564-574.

This source talked about gene-environmental interactions in two ways: epigenetics and plasticity. The sources provided many animal and rat examples of epigenetics. It provided insight into the multiple stages where phenotypic change can occur: prenatal, postnatal, juvenile.

Chan, S. S.-K., & Kyba, M. (2013). What is a Master Regulator? *Journal of Stem Cell Research & Therapy*, *3*, 114.

This source taught me about master genes and was referenced twice throughout my work. This information was essential for understand how one gene, through epistatic effects can influences the expression of a cascade of genes.

Choudhury, S., Blakemore, S.-J., & Charman, T. (2006). Social cognitive development during adolescence. *Social Cognitive and Affective Neuroscience, 1*(3), 165–174.

This source provided information on brain development during the adolescent and adult life stage. It talked about neural plasticity as an indicator for adverse experiences faced in adult life.

Cole, S. W. (2009). Social regulation of human gene expression. *Current Directions in Psychological Science*, *18*(3), 132–137.

This source was helpful in detailing the stress response and how glucocorticoid molecules work to impact white blood cells. The source was used when talking about how stress impacts health. It also gave many side sources that were relevant.

Croston, R, Branch, C.L., Kozlovsky, D.L., Dukas, R., Pravosudov, V.V. (2015). Heritability and the evolution of cognitive traits. *Behav Ecol 26*(6), 1447-1459.

This source helped me in understanding cognition in the brain and how natural selection acts on cognition. I also used this source to reference IQ testing as being determined partially by inherited genes.

DeMarini, D. & Claxton, L. (2006). Outdoor Air Pollution and DNA Damage. *Occupational and Environmental Medicine, 63*(4), 227-228.

This source talked about air pollution influencing gene expression. It talked about how environmental pollution can damage DNA. I used this source when I talked about acquired mutations to somatic cells.

Eisenberg, L. (2004). Social psychiatry and the human genome: contextualising heritability. *The British Journal of Psychiatry, 184*(2), 101-03.

This source is excellent in talking about polyphenism in humans. It contributes thoroughly to the nature vs. nurture debate. Furthermore, it suggests a different meaning to nature vs. nurture by including “niche.”

Fast, D. K., Conry, J., & Loock, C. A. (1999). Identifying fetal alcohol syndrome among youth in the criminal justice system. *Journal of Developmental and Behavioral Pediatrics, 20*(5), 370-2.

This source provided the fact that a greater proportion of individuals exposed to alcohol prenatal tended to be involved in more criminal acts than not involved in criminal activity. This strengthened my argument that mothers should not consume alcohol prenatal.

Flannery, M. (1986). Art as a Neotenizing Influence on Human Development. *Visual Arts Research, 12*(2), 34-40.

This source talked about neoteny in humans and other organisms. I mainly assimilated knowledge about paedamorphosis from this source. This source was used when clarifying heterochrony to the reader.

Genetics Home Reference. (2017). What is a gene mutation and how do mutations occur? *US National Library of Medicine.*

This source gave an overview of the types of mutation: heritable and acquired (somatic) mutations. It made the distinction that heritable mutations can be passed down through generations while acquired mutations can not. This source was used when discussing epigenetic mechanisms.

Gluckman, P. D., Hanson, M.,A. (2007). Developmental plasticity and human disease: research directions. *Journal of Internal Medicine, 261*(5), 461-71.

This source was used when talking about the other side of unadaptive plasticity whereby alternative trajectories can cause harmful proteins to the body. This sources comes from the journal of medicine and specifically mentioned that diseases can be caused by unadaptive plasticity.

Golub, Y; Kaltwasser, S; Mauch, C; Herrmann, H; Schmidt, U; Holsboer, F; Czisch, M; Wotjak, C. Reduced hippocampus volume in the mouse model of Posttraumatic Stress Disorder. *Journal of Psychiatric Research, 45*,(5), 650-659

This source provided information on how genetic expression reduces the volume of amygdalae. It was especially useful because of the fact that it included the specific protein involved in increasing volume which was said to be down regulated when in the face of abnormal environmental pressures.

Hall, B. K. (2003). Evo-Devo: Evolutionary developmental mechanisms. *International Journal of Biology, 47*, 491-495.

This source was useful when discussing the history behind heterochrony. It credited Earnest Haeckel as being the first person to coin the term 'heterochrony.' This source was used to understand heterochrony.

Hochberg, Z. (2011). Developmental plasticity in child growth and maturation. *Frontiers in Endocrinology, 2*, 1-6.

Hochberg's article is one of the most useful. First it talks about the nature of plasticity. This was important part in the developmental plasticity part of my thesis. Next, it talks about human plasticity specifically. It talks about plasticity inducing social and psychological changes which is extremely pertinent to my thesis. It also makes reference to different growth trajectories humans undergo based on the environments they are in.

Hurst, Nathan. (2014). How binge drinking alters your genes. *Futurity.*

This source provided information about the negative effects of binge drinking on the human brain. I used this source when talking about the how adolescent decisions can negatively affect the brain.

Jabr, F. (2012). Know Your Neurons: How to Classify Different Types of Neurons in the Brain's Forest. *Scientific American.*

This sources talked about the types of neurons in the brain and the different roles in which they play. It also talked about the parts of the neuron. It was used when talking about the brain and neural pathways that respond to stimuli.

Janik, E. (2011). The Salamanders that refuse to grow up. *Smithsonian.com.*

This article was about neoteny in salamanders. Depending on environmental conditions, salamanders will retain juvenile forms. This source was used when providing specific examples of heterochrony in non-human animals.

Juskalian, Russ. (2010). How teen experiences affect your brain for life. *Newsweek Culture.*

This Newsweek article talked about the negative affects of binge drinking, pot, child abuse to the brain. It was used in my section about teens and adults. It talked about the importance of the adolescent developmental stage.

Kephart, J. (2011). Learning from Nature. *Science, 331*(6018), 682-683.

This source was used when explaining neuronal networking in the brain. I pulled a quote that this source mentioned that is a useful axiom to describe and remember that neurons are involved in pathways of responses.

Kjelstrup, K., Tuvnes, F., Steffenach, H., Murison, R., Moser, E., & Moser, M. (2002). Reduced Fear Expression after Lesions of the Ventral Hippocampus. *Proceedings of the National Academy of Sciences of the United States of America, 99*(16), 10825-10830.

This source was used to provide an example of how hippocampal activity is altered in rodents. Animal models such as this provide evidence for the ways in which the brain responds to environmental cues.

Kodama, T; Shimizu, N; Yoshikawa, N; Makino, Y; Ouchida, R; Okamoto, K; Hisada, T; Nakamura, H; Morimoto, C; Tanaka, H. (2003). Role of the glucocorticoid receptor for regulation of hypoxia−dependent gene expression. *Journal of Biological Chemistry,* 278(35), 33384–91.

This source was useful in explaining how the glucocorticoid receptor plays a role in the Hypothalamus-Pituitary-Adrenal axis. This was used when talking about the negative effects of child abuse to the brain.

Lively, C. (1986). Canalization Versus Developmental Conversion in a Spatially Variable Environment. *The American Naturalist, 128*(4), 561-572.

This source was useful when referring to on-off switches. On-off switches are part of developmental conversion and this source helped me clarify my explanation of on-off switches in development.

Le Mare, L., & Audet, K. (2006). A longitudinal study of the physical growth and health of postinstitutionalized Romanian adoptees. *Paediatrics & Child Health, 11*(2), 85–91.

This source wrote about psychosocial dwarfism in Romanian orphans. Due to very poor early life conditions, Romanian orphans developed reduced anatomical and cognitive development right after they were adopted.

Marcey, David. (2010). tRNA structure. *California Lutheran University.*

This source gave the basic information about the structure and function of tRNA. The source also provided a detailed model of the complex tRNA molecule. The information was used when explaining how tRNA interacts with the genome in the second section.

Marchetti, F., Rowan-Carroll, A., Williams, A., Polyzos, A., Berndt-Weis, M., & Yauk, C. (2011). Sidestream tobacco smoke is a male germ cell mutagen. *Proceedings of the National Academy of Sciences of the United States of America, 108*(31), 12811-12814.

This source was useful when talking about how DNA mutations can disrupt the sequence of nucleotides. It was used when explaining DNA damage as opposed to epigenetics.

McClung, C. A. & Nestler, E. J. (2008). Neuroplasticity Mediated by Altered Gene Expression. *Neuropsychopharmacology Reviews, 33*, 3-17.

This source talked about the role of transcription factors in the brain. It linked environmental stimuli with neuroplasticity through an thorough examination of transcription factors playing a role in neuronal alternative networking.

McGowin, P. O., Sasaki, A., D'Alessio, A. C., Dymov, S. V., Labonté, B., Szyf, M., Tureki, G., Meaney, M. J. (2009). Epigenetic regulation of the glucocorticoid receptor in human brain associates with childhood abuse. *National Neuroscience, 12*(3), 342-348.

This source talked specifically about how childhood abuse increasing methylation of the genome. Additionally, suicide victims were found to have more methylation in their brain than controls. This source was used when specifically talking about DNA methylation in the epigenetics section.

MedlinePlus. (2017). Skin Cancer. *U.S. National Library of Medicine.*

This source provided insight into the types of skin cancer and the severity of it. It was used when explaining how the environment can cause mutations of the genome. It provides a good example of somatic mutations in the human body.

Morgane, P. J.; Moker, D. J. & Galler, J. R. (2002) Effects of prenatal protein malnutrition on the hippocampal formation. *Neuroscience and Biobehavioral Reviews, 26,* 471–483.

This sources was used as a block quote as it perfectly told how chemicals from the environment influence genetic expression. It specifically talked about malnutrition, and was used in the second to last section.

Nathanielsz, P. (1999). *Life in the Womb: the Origin of Health and Disease.* Ithaca, NY: Promethian Press

This book covers everything about the prenatal period. It draws huge conclusions about how mothers' experiences tremendously impact the child. It was used throughout the last third in explaining how health can impact behavior.

National Institute of Drug Abuse. (2016). Cocaine. *National Institute of Health.*

This source provided shocking statistics about the prevalence of cocaine in the United States of America. I used statistics that included adult drug use and teen drug use in my section about toxins.

National Institute of Mental Health. (2016). Schizophrenia. *National Institute of Health.*

This source helped me assimilate and understand schizophrenia. It was interesting to learn what scientists currently believe contributes to schizophrenia.

Newitz, A. (2011). This is what schizophrenia looks like at the molecular level. i*o9 Neuroscience.*

This source provided validity to my argument about adhesion molecules being affected by nutrition. I found that schizophrenia is caused by neuron lack of connectivity. This thoroughly relates to the idea that memory is related to neuron connectivity.

Oakley, R. H., & Cidlowski, J. A. (2013). The Biology of the Glucocorticoid Receptor: New Signaling Mechanisms in Health and Disease. *The Journal of Allergy and Clinical Immunology, 132*(5), 1033–1044.

This source was used to talk about the glucocorticoid receptor, and its effects to the the brain. It also talked about what happens when corticoid chemicals are in abundance. It was used when talking about child abuse.

O'Brien, J. & Mattson, S. (2011). Fetal Alcohol Spectrum Disorders (FASD). *Encyclopedia of Early Childhood Development.*

This source provided information on FASD. It was used when talking about how genetic alterations can come about by consumption of alcohol prenatally. It provided evidence for how behavioral problems can arise because of FASD.

Oliveira, R. F. (2012) Social Plasticity in Fish: Integrating Mechanisms and Function. *Journal of Fish Biology,* (81), 2127-2150.

Oliveira's article does more than talk about social plasticity in teleost fish. It talks about social plasticity as a whole. This was useful in my thesis because the source talks about various mechanisms driving plasticity. The source also reflects on the reasons why we should care and do more social plasticity experiments.

Pettijohn, T. F. (1997), *Notable Selections in Psychology.* 2nd ed. Guilford, CT: Dushkin/ Brown & Benchmar.

This source talked extensively about the difference between heredity and gene-environmental interactions. The author brought up Mendel's pea plants in explaining genetic-environmental misconceptions that are not easily seen. I used this source to back up the claims I made in my thesis.

Plomin, R. (2004). Genetics and Developmental Psychology. *Merrill-Palmer Quarterly, 50*(3), 341-352.

This source started out by using many specific examples about twin adoption studies in order to point out that genetics is still a huge part of behavior. Plomin wants his readers to recognize that even though there has been much talk worldwide about environment interactions on the genome, an individual's genome has to have certain properties to be able to be acted upon. Further on, Plomin goes on to talk specifically about gene-environmental interactions producing multiple phenotypes.

Ramsay, M. (2010). Genetic and epigenetic insights into fetal alcohol spectrum disorders. *Genome Medicine, 2*(4), 27.

This source was useful in talking about the negative effects of fetal alcohol syndrome. It talked about how many mental disorders have come out of exposure to alcohol and emphasized the importance of mothers not to consume alcohol during labor.

Richards, C. L., Bossdorf, O., & Pigliucci, M. (2010). What Role Does Heritable Epigenetic Variation Play in Phenotypic Evolution? *BioScience, 60*(3), 232-237.

This source was used to back up the claim that organism's develop specifically depending on their environment. I used this source when referring to the interactiveness of the genome to respond to environmental influences.

Robertson, S. (2015). What is DNA Methylation? *News Medical Sciences.*

This source detailed the process of DNA methylation. It also pointed out the importance of epigenetics in development. This source was used when explaining methylation of the genome in the two major ways: histone modification and cytosine bonding.

Rodgers, E. W., Earley, R. L., & Grober, M. S. (2007). Social status determines sexual phenotype in the bi-directional sex changing bluebanded goby Lythrypnus dalli. *Journal of Fish Biology, 70*(6) 1660–1668.

This source talked about sex-changing blubanded gobies. These gobies change sex depending on their position on social dominance hierarchy. This example was used in parallel with color-changing fish.

Schlichting, C., & Pigliucci, M. (1998). *Phenotypic evolution: A reaction norm perspective.* Sunderland, MA: Sinauer.

Schlichting and Pigliucci's book covers everything from the historical figures in genetic development to an explanation of trajectories, heterochrony, etc. This sources was most helpful in making me aware of the various processes in evolutionary development. Throughout the first section of my thesis, I used Schlichting and Pigliucci's definitions.

Sdorow, Lester. (1998). *Psychology* (4th ed.). New York: McGraw-Hill.

This source linked the bridge between multiple phenotypes – (for example, between somatotypes and behavior). I was previously unaware of somatotypes; the fact that these types of physiological futures are connected to behavior is riveting and shows gene systems at play.

Shuster, S. M. (1987). Alternative Reproductive Behaviors: Three Discrete Male Morphs in Paracerceis sculpta, an Intertidal Isopod from the Northern Gulf of California. *Journal of Crustacean Biology, 7*(2), 318-327.

This source was useful in discussing polymorphism in *Paracerceis sculpta.* Shuster has proven to be the most invested researcher to this marine isopod. This source was particularly useful when talking about phenotypic plasticity using animal models.

Shuster, S. M. & Wade, M. J. (1991) Equal mating success among male reproductive strategies in a marine isopod. *Nature, 350*, 608 - 610

This source was useful when talking about equal mating success in male polymorphisms of marine isopods. It was interesting to see the different polymorphisms in *Paracerceis sculpta.* Additionally, this source provided data on how each distinct male morph could mate with female *P. s.* equally.

Singer, L.T.; Minnes, S.; Short, E.; Arendt, R.; Farkas, K.; Lewis, B.; Klein, N.; Russ, S.; Min, M.O.; & Kirchner, H.L. (2004) Cognitive Outcomes of Preschool Children With Prenatal Cocaine Exposure. *JAMA, 291*(20), 2448-2456.

This study was extremely useful as it provided me an example for the pernicious effects of cocaine on the body. It taught me many things including the fact that cocaine can readily pass through the placenta and also constricts maternal blood vessels.

Smith-Gill, S. J. (1983). Developmental Conversion versus Phenotypic Modulation. *American Zoologist, 23*(1), 47-55.

This source covered everything about the different types of plasticity. The two categories of plasticity Smith-Gill separates was previously unknown to me. Now, it seems essential to differentiate between developmental conversion and phenotypic modulation when explaining genetic developmental plasticity.

Starr, C., Taggart, R., Evers, C., & Starr, L. (2013). *Biology: The unity and diversity of life*. (10th ed.). Belmont, CA: Brooks/Cole.

This biology textbook provides information about all the basic information about biology from microbiology to evolutionary biology. This source is discussed in my thesis in epigenetics in regards to histone modification. I also used this source when discussing operant conditioning and learned behaviors.

Stephens, M. A. C., & Wand, G. (2012). Stress and the HPA Axis: Role of Glucocorticoids in Alcohol Dependence. *Alcohol Research : Current Reviews, 34*(4), 468–483.

This source was not cited in the text, but provided essential information about how the HPA axis works. It included a diagram of hormonal pathway from the hypothalamus to the pituitary to the adrenal cortex.

Tantibanchachai, C. & Zhang, M. (2013). Cocaine as a Teratogen. *Embryo Project Encyclopedia.*

This source was useful in talking about the specifics on how maternal blood vessels are constricted during interactions with cocaine. It was useful when talking about the harmful effects of toxins.

Teles, M. C., Cardoso, S. D., & Oliveira, R. F. (2016) Social Plasticity Relies on Different Neuroplasticity Mechanisms across the Brain Social Decision-Making Network in Zebrafish. *Frontiers in Behavioral Neuroscience, 10*(16).

This article talks specifically how fish activate the CREB transcription factor as a response to social stimuli. This source gave an example of a cichlid that alters genetic expression based on its social standing. This source was used when providing an example of neuroplasticity.

Tetsumi, T., & Koblmüller, S. (2011) The Adaptive Radiation of Cichlid Fish in Lake Tanganyika: A Morphological Perspective. *International Journal of Evolutionary Biology*, *2011*, 0-14.

This source talks about the adaptive radiation in cichlid fish that has led to rapid speciation. It describes how cichlids rapidly diversified because of different niche specialization. I used this source when providing an example of developmental plasticity.

Towrey, D. (2017, Jan. 16). Personal Interview

Dan Towrey is a Licensed Professional Counselor for Riverside Counseling. He has developed a system for helping individuals who suffer from neuronal adversity. He used to work in pastoral ministry for twenty-eight years at liberty university, and, before that, he worked with delinquent children. He currently has worked in counseling for seven years.

Tung, J., & Gilad, Y. (2013). Social environmental effects on gene regulation. *Cellular and Molecular Life Sciences, 70*(22), 4323–4339.

This source talked about stress and the response of white blood cells. It was used when talking about how white blood cells are mediated by social/environmental adverse situations. It provided in depth biology terms as well.

Weaver, I. (2017). Epigenetics in psychology. In R. Biswas-Diener & E. Diener (Eds), *Noba textbook series: Psychology.* Champaign, IL: DEF publishers.

This source wrote about the importance of methylation to the study of epigenetics. It expressed how methylation of the genome can be caused by both nutrients and bad environmental conditions. It was used when explaining methylation of the genome and giving specific examples.

Weinhold, B. (2012) A Steep Learning Curve: Decoding Epigenetic Influences on Behavior and Mental Health. *Environmental Health Perspectives. 120*(10). 396-401.

This source was all about epigenetics; it included specific and broad examples of how the environment interacts with the epigenome. This source was useful when both explaining epigenetics and making the reader aware to specific examples of epigenetics in human life.

Welsh, J. (2012). 6-Month-Old Infants Understand Words. *Life Science.*

This source talked about the cognitive process in babies. It was useful when I needed to explain the age at which humans start understanding words for them to act as social individuals.

West, M. J., & King, A. P. (1987). Settling nature and nurture into an ontogenetic niche. *Developmental Psychobiology, 20*(5), 549-562.

This source gave a background to the nature vs. nurture debate. It emphasized that nature and nurture were intended to be meant to work in harmony. However, that way of thinking has been transformed. This sources was used in giving a background to developmental biology.

West-Eberhard, M. (1989). Phenotypic Plasticity and the Origins of Diversity. *Annual Review of Ecological Systems, 20*, 249-278.

This source talks about phenotypic plasticity generically. It talks about the importance of phenotypic plasticity. The first section, “plasticity in the initiation and amplification of change” was used in catching the reader up to date with plasticity research that is currently going on. This source also wonderfully recognizes misconceptions about phenotypic plasticity.

Williamson J. L., Buckland, H. L., & Cunningham, S. L. (2013). Excuse Me, What Did You Just Say? *The American Biology Teacher, 75*(6), 424-425.

This source was useful when talking about neural networking in the brain. The firing of one neuron influences the firing of other neurons. This source was useful when explaining why dogs can sometimes associate sounds with feeding.

Wlassoff, V. (2015). How Does Post-Traumatic Stress Disorder Change the Brain? *Brain Blogger: neuroscience and neurology.*

This source talked about PTSD. It clarified that PTSD is not just a military condition but includes all the traumatic events one could have in their lifetime. I used multiple direct quotes for this source.

Worltereck, R. (1909). Further investigations of type variation, specifically concerning the nature of quantitative differences between varieties of Daphnia.

Woltereck is the creator of the idea of the reaction norm. He is referenced for his legacy in developmental biology in the early 20th century in Germany. Multiple other developmental biology sources reference him.

Xiao, D., & Zhang, L. (2008). Upregulation of Bax and Bcl-2 following prenatal cocaine exposure induces apoptosis in fetal rat brain. *International Journal of Medical Sciences, 5*, 295-302.

This source was used as an example of cocaine effects on cell apoptosis. It was used in tandem with Champagne and Xiao's research in explaining environmental effects on the phenotype in animal models.

Yan, Q. S., Zheng, S.Z., & Yan, S. E. (2004). Prenatal cocaine exposure decreases brain-derived neurotrophic factor proteins in rat brain. *NeuroReport, 9*, 933-936.[i]

This source was used as an example for cocaine effects in prenatal rat development. It explained the ways in which maternal environmental affects to drugs can influence phenotypic development. It is a useful to consider a similar hypothetical situation with humans. This source was listed with Champagne and Xiao's research.

Zhou, F. & Mason, F. (2015). Genetics and epigenetics of fetal alcohol spectrum disorders. *Frontiers.*

This source was useful in talking about the negative effects of fetal alcohol syndrome. It clarified how genetics are altered due to prenatal alcohol consumption from the mother. It also suggested that sperm DNA can carry alternative genetic trajectories.

Image Bibliography

Title:	http://sciencemediacentre.ca/site/?p=5398
Page 4:	http://www.bio.miami.edu/dana/pix/transcription_factor.jpg