I

The Fixed-Brain Myth

ARE WE SHORTCHANGING OUR STUDENTS' BRAINS? HAVE WE INSTITUTIONALIZED mediocrity? Is the basic belief system in education to sort, then maintain status quo? That's quite possible. Why? The whole basis of U.S. education—everything we think we know about learning and education and all the resulting policies that affect millions of children and eventually all of us as adults—is based on the pernicious myth that each child has a fixed allotment of brainpower. This allotment was supposedly determined by our genetic inheritance, and just as supposedly cannot be changed over the course of a lifetime. I think of this as the "genes run your life" myth.

The theory seems obvious enough. After all, two tall parents will have tall kids, two white parents will have white kids, and two black parents will have black kids. How hard is that to understand? Genes run the world, and we can't influence them, right?

Not so fast. Not only is this myth dead wrong, it has led great numbers of people to give up because they think they are stuck with the brains they have. Yet it's become clear that actually we change our brains and our brains change us every day. Imagine that: our life experience changes our brains, and the changed brains change our life! As an analogy, if you recently remodeled your house, in many cases the remodeling changed your lifestyle. Your brain said, "Remodel!" and the result of the remodel was a changed house, which changed your lifestyle, which changed your brain. For this chapter to lay the groundwork for the rest of the book, let's begin with four core brain principles.

Principle 1. All human processes are a function of the complex interplay of mind, emotions, body, and spirit. Everything we put into and see emerging from our students, from the simplest to the most complex cognitive expression, is a product of the unique and dynamic brain state that each of us is in at any moment. This includes all actions, thinking, speaking, literature, music, and art. Principle 1 reminds us that there is a basis, an engine and platform, from which all behaviors emerge. It's our body-brain systems!

Principle 2. The body-brain system is governed by a wide range of factors. Some of the factors are hardwired into our DNA. Genes and their protein products are significant players in the equation. Their contribution is often called the "nature" or genetic part of the human equation. The prevailing doctrines claim that the balance between the effects of nature and nurture on our behavior is about fifty-fifty, meaning that half of what makes us who we are is genetic and half is the result of the environment. We now know that it is far more complex than that.

Principle 3. A genetic basis does not by itself explain the wide variances of a human being. Social, environmental, or developmental factors also contribute to cognition and behavior, both directly and indirectly. Directly, we can observe a command to a child or stimulus-response learning event. But indirectly, many factors exert actions on the brain by feeding back upon it to modify the expression of genes and thus the function of nerve cells. Our brains "learn" not just new content in school, but to alter key life processes, which is known as gene expression. In this way, genes continue to play a part in our lives, not by what was inherited, but by what has been "learned" by life. Thus "nurture" is eventually expressed as "nature."

Principle 4. There is a host of factors known to influence brain function. Each operates on different levels, with different outcomes. These include exercise, stress, and new learning. By understanding the factors that regulate the student's brain, we can orchestrate more positive outcomes. As a by-product, this opportunity to influence the brain's potential by the managing of school factors brings with it a moral and ethical responsibility to maximize potential in all students. Now let's make some sense of these concepts.

Our New Understanding of Genes and the Environment

It's worth examining genes and their role because the idea that genes are what your parents passed on to you and you're stuck with what you have is one of the main tenets of the fixed-brain myth. If you're past high school and college, you can throw out much of what you learned in high school biology about genes. Gene expression, gene splicing, and genetic engineering used to be the realm of science fiction, but today they are science fact. Yet how did we go from the old nature-nurture debate to a new understanding?

In 1953, Watson and Crick cracked the genetic code, showing the elegant double helix structure of the DNA molecule that governs it. For years, many biologists assumed that it is our DNA that controls who we are. After all, it was believed that genes held the information needed to guide the growth and development of all our cells. But that's not the whole story. The old paradigm was that our genes are the blueprints that make copies called RNA (ribonucleic acid, which is a "messenger and translator" molecule) involved in cell replication. Those copies activate transcription factors that in turn activate proteins, which influence our behaviors (Figure 1.1).

The way that happens is extraordinarily complex, but a simple example would be the process of aging. As we get older, certain genes activate signals that decrease the amount of hormones such as estrogen and testosterone that are released into our bodies. Those changes in turn influence our immune systems, cognition, and behaviors. This is clearly one of the functions of genes, to guide and replicate cell development. But what if genes had more flexibility than that? What if genes could be "read" or "not read"? What if genes could even change? If these assertions were true, it might seriously damage the old "fixed brain" myth.

- Humans have about 25,000 genes.
- Genes are a unit of hereditary information carried on our chromosomes as DNA.
- Genes have two functions: (1) to serve as a reliable template for making copies, and (2) to serve as a transcription factor, influencing proteins as gene expression.
- The second function is highly susceptible to environmental influences.

Figure 1.1. What Are Genes?

The Real Source of Human Complexity

Only a few short years ago, scientists thought humans had about two hundred thousand genes. The expensive, complex Human Genome Project was undertaken to discover, label, and code all of the human genes for the scientific good. Imagine the surprise of scientists in 1999, when they discovered that humans have closer to thirty thousand genes. Since then, the number was revised downward again to twenty to twenty-five thousand genes. This discovery was surprising, for many scientists had automatically assumed that people *must* have many more genes than a frog or a fish. Just for comparison, a chicken and a spotted puffer fish also have about twenty-five thousand genes. Wow! Are we at the same genetic level as a seemingly simple organism? If so, where on earth does all the human complexity come from?

Complexity cannot come *only* from genes; we share 70 percent of the same genes as a pumpkin! Even chimpanzees share 98 percent of the same genes as humans! Understanding the genetic code is not yet helpful for understanding human behavior.[1] If you think of the individual genome as a book, the difference between a high school dropout and a Nobel Laureate is little more than 1 percent of DNA. That's the equivalent of about two to three words per page. It must be that genes do not supply all of our complexity or our destiny!

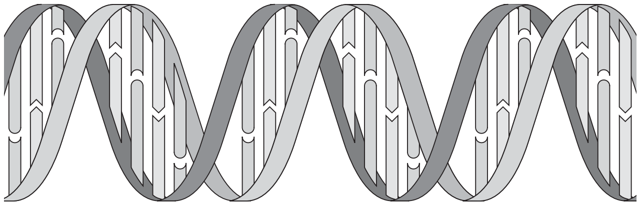
The Discovery of Gene Expression

We have fifty trillion cells in our bodies, and every cell has tulip-shaped structures called *receptors* that receive information. Different cells have different receptor sites for different molecules. Things such as light or heat activate some receptors. Other receptors are receptive to and activated by histamines, stress hormones, nutrition, or androgens. Amazingly, receptor sites don't just process this information, they begin an electrochemical cascade of activity that eventually can affect our genes.[2] So although there is a core of genes that maintain your basic functions, often called "housekeeping genes," there are thousands of others that are responsive to environmental signals.

If genes are not the sole force shaping our lives, what does shape it? It's the environment! That's why genes are often grouped into their "types" of responsiveness to environmental stimuli:

- Early activated
- Intermediate activated
- Late activated
- State dependent
- Activity dependent

Genes generate interplay among themselves because of the complexity of environmental signals. How they respond to the environment depends on the type of signal. In short, if you're exposed to a trauma, you'll activate the expression of multiple genetic factors. Your brain becomes highly mobilized to make changes based on the negative life experience. There's a name for this process; it's called *gene expression* (Figure 1.2).



- Gene expression is the process by which genetic information is translated into action.
- Genes provide blueprints and transcription factors for proteins—both influence cell structure and function.
- Cell functions can influence our behaviors.
- The old paradigm was that information flow only moved outward from genes to proteins.
- The new paradigm is that genes can be activated by everyday environmental signals.

Figure 1.2. What Is Gene Expression?

For decades, we thought of the human body and brain as being a one-way street, unfolding from our genes outward. The new science tells us otherwise. It's actually a two-way street, in which genes influence our lives and our lives influence our genes (Figure 1.3). The meaning of this is profound. The fact that the process goes *both* ways is a revolution in biology, and it has implications for us in education. We now know that it is possible to influence gene expression purposefully, and it's done in laboratories every day.[3]

The critical understanding is that genes have two core functions; one is well-known to laypersons, the other is not. First, the more well-known function of genes is to serve as highly reliable templates, similar to a blueprint, that can replicate perfectly. Every gene, in every cell of the body, provides you and me with high-quality copies of its information. The fidelity of this template is impeccable, and everyday experience won't typically change it. Only rare, random mutations can influence the quality of our genetic blueprints.

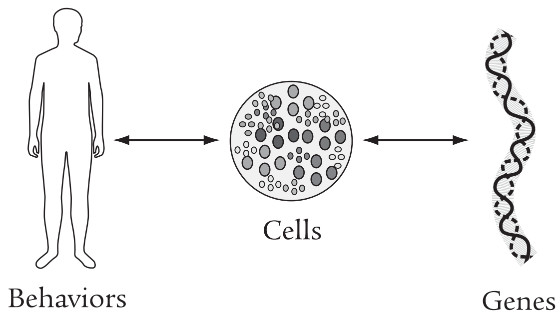


Figure 1.3. A Two-Way Street.

The second function, which is less well-known to the general public, is that genes have what is known as a transcriptional function. This means that they can influence the structure, function, and other biological characteristics of the cell in which each is transcribed (or expressed). And while every cell has all the genes of your whole body, a particular cell will only express or activate a small portion (estimates are 10 to 20 percent) of its genes. Why? A kidney cell will remain a kidney cell partly because the portion of the genes that are unique and intrinsic to that cell type (a kidney, for example) will get expressed, and the other "non-kidney" genes are effectively repressed. When genes are expressed in a cell, that activation changes the phenotype (characteristics) of that cell. In fact, it directs the manufacture of specific proteins that, in a typical human, characterize that cell.

This is where it gets interesting. Although the first function of genes, the blueprint function that was mentioned earlier, is impervious to the outside environment, the *other* function, the transcription function, is susceptible to the environment. Alterations in what the organism considers "status quo" will influence the expression of genes by altering their messages to proteins. Factors such as stress, nutrition, exercise, social factors, trauma, and even extended emotional states can each influence gene expression. This information is new and highly relevant, not just to scientists, but to those interested in education and parenting.

In 2000, the Nobel Prize for physiology went to Eric Kandel, whose lifelong work on memory has now turned to the genes and environment interactions. Kandel explodes the idea of fixed genes. Here's how he summarizes his findings. First, he says, "The subjective experiences of human consciousness, our perception of free will, behavior, and social dynamics can modulate gene expression, and vice versa." That's astonishing enough by itself. But he continues, "The regulation of gene expression by social factors makes bodily functions, including all functions of the brain, susceptible to social influences." And finally—read this next sentence twice—he maintains, "These social influences will be biologically incorporated in the altered expressions of specific genes in specific nerve cells of specific regions of the brain."[4] By social factors, Kandel means a host of possibilities: (1) being alone, or being happily married, (2) being in a group or team or partnership, (3) being in a crowd, or (4) living in crowded conditions or in wide-open spaces. Each social condition might be seen in a typical school, so there's clear relevance to educators. The environments affect our cells.

What Genes Can and Cannot Do

Twins, who have identical genes, often grow up with a great deal of similarities. But remember, environment is not powerless, even with twins. It's possible for them to develop differences in their bodies and, amazingly, different metabolic rates. One study tested twins who lived apart, one staying at sea level and the other going to live in the mountains.[5] Their metabolic rates adapted to the different climates. Even with twins, one can grow very different if one works in a much colder climate or at a much higher altitude than the other. Thus, gene expression is powerful enough even to influence what used to be sacred between identical twins, metabolism.

This tells us that genes alone do not determine outcomes. Yes, genes have a great deal of influence on many things. But anytime someone tells you there's a "spelling gene," a single "IQ gene," a "math gene," a "depression gene," or even a "cancer gene," you can have a good laugh.

Why? Genes may play a part in some of those things, but they are not the whole story.

Very few of your genes create inevitability (eye color and skin color are visually obvious, exceptional examples). If both your parents are African American, it is inevitable; you will be born with dark skin. If both your parents were over six feet tall, you might not play for the Bulls or Lakers, but you will be tall for your culture (that's assuming a positive state of nutrition; in cases of extreme neglect, even a child from tall parents would be much shorter than predicted).

Now we see that the environment can influence gene expression. And the result of alterations in a gene's activity can change height, weight, response to stressors, the immune system, and a host of other outcomes. Amazingly, we have some influence over this complex process. And, if orchestrated well, it is possible to tip the genetic-environment equation in favor of the environment. Here are some examples of everyday environmental activators for gene expression:

- Stress
- Trauma
- Nutrition
- Exercise

To summarize, all cells in your body have sensors that read their environment, assess the incoming data, and act to maintain their survival. The signals travel from the environment to the genes and from the genes to proteins, going both ways. On a larger scale, it's the interaction between the genes and the environment that determines the life of the organism. But what if the environment was so bad that your genetic material wasn't cutting it? What if the environment was so toxic, you had to mutate to survive? Could you mutate?

The Fixed-Genes Myth Debunked

The very idea that any gene would ever change used to elicit laughter (or outrage) from most biologists. But pioneering scientist John Cairns showed that an organism could actively rewrite its own genes to adapt to new stressful environments. This seminal experiment with bacteria showed that not all mutations were random.[6] Instead, the bacteria he looked at were able to change their own genetic make-up. Cairns put bacteria in a test tube and subjected them to highly stressful conditions—they were stuck with no available food sources. Well, more accurately, the test tube contained food that the bacteria were not designed to eat, process, or metabolize. Yet the bacteria survived—by mutating into forms that could use the available resources. This amazing biological event was reinforced in another experiment in which genes in a parasite actively changed to accommodate a new environment.[7] Now, more and more scientists are questioning the rigidity of the theory of genetic control.[8] Instead of the more stringent explanation by Richard Dawkins in *The Selfish Gene,* a newer understanding is Ridley's *The Cooperative Gene.*[9]

It is now established that contrasting, persistent, or traumatic environments can and do change the actions of genes. The new field is called epigenetic ("outside of genes") control of an organism. And if you look up the word *epigenetic* on the Internet, every reference is from within the past few years—it's a completely new understanding of biology. One scientific paper showed how change could happen prenatally.[10] Exposure to prenatal distress influenced the genetic material in the newborn *after* conception. In another study, researchers showed that the actual genes do not even have to change, but instead, heritable changes in gene expression can occur without a change in DNA sequence.[11] This is a revolutionary new insight because it suggests that the environment has even more to do with outcomes in behavior than we ever thought. Charles Mann writes that although the developing insight has not eliminated genetic influences on behavior, it has tilted the table a bit more in favor of environment.[12]

Can You Program Your Future?

Genes are the coding for brain and body processes in much the same way that blueprints define, but don't make a house. And just as in the process of building a house, modifications can and do happen. We remodel our houses, too. Every day, genes influence proteins, which influence molecular activity. But it goes the other way as well. The stunning news is that your lifestyle, the environment you live in, can also influence your perception of stress, and that can influence the release of cortisol, which can influence protein messaging, which, in turn, can influence genetic material. The way you perceive life (as either stressful or not) can alter your body's reaction to events, thus influencing whether your body produces stress hormones. You can influence your brain and the expression of your own genes. Thus, a genetic blueprint is not a mandate. It's just a part of the big picture.

The son or daughter of an Olympic athlete such as Marion Jones, Michele Kwan, or Mia Hamm may have a good heritage—and parents who care about fitness and athletic perfection—but that does not guarantee becoming a famous athlete. Not even genetic engineering can put a lock on that (yet). Unfortunately, you'd still need to work your tail off to become a top athlete or musician, even if you hit the genetic lottery. For example, Jack Nicklaus will probably keep his legend intact. He's one of the greatest golfers of all time, and his son Gary is a pro too, but Gary Nicklaus is simply a very good golfer. He played for years on the lower-tier before making the PGA Tour. He just qualified for it after nine years of trying. There are no "golf genes"—and there are no genes for any other discipline, either. There's no doubt genes play a role, but it is our varied experiences that create the greatest complexity and widest variation in brains.

Changing Brains Through Experience

It's also very clear that the human brain is highly experience-dependent. That means that the life you lead influences your brain—sometimes for the worse, sometimes for the better. The research on this is over thirty years old; it's become institutionalized in neuroscience by now.[13] You don't just start with a small brain at birth that simply gets bigger and fills up with information as you grow. Every infant's brain is a highly malleable, highly complex structure with more than a trillion connections (known as synapses) already in place at birth. These connections ensure that the infant can eat, breathe, and respond to the environment. But they are not fixed; some will die from disuse and others will flourish with constant usage.[14] Our one hundred billion cells are awaiting the wonders of life experience to decide whether to live, grow, or die. Brains will produce new neurons, lose neurons, make connections, and lose other connections, all based on our experience.

For example, going to college and taking hard classes changes the brain more than taking easy classes.[15] In short, the human brain is designed to interact with the world and make changes, depending on the quality of interaction. If the interactions are positive and sustained, you'll get one set of changes. If the interactions are negative and intense, you'll get a different set of changes. We change based on our life experiences. This makes the "fixed brain" myth dead in the water and simply outdated and incorrect science.

Negative Experiences Can Change the Brain

Infants are often glamorized on television or in magazines as having amazing, fast-learning, soak-up-the-world brains. But it works both ways: a brain that soaks in a brand-new language is the same one that soaks in trauma, abuse, and negative environments, too. Children are not resilient; they need time to develop resiliency. If you give a child an interesting, loving, and safe environment, you can expect healthy brain development. But expose a child to abuse, neglect, injury, poor nutrition, or other environmental risk factors, and what you can expect—and what you will almost certainly get—is far different.

One way to measure brain changes is with a soft tissue scan of the brain, a process called magnetic resonance imaging, or MRI. Studies of the normally developing brain in childhood and again in adolescence show constant changes. White matter volume (myelin) increases with age. The volume or mass (gray matter) increases during childhood, then slowly decreases before adulthood. Yet these changes are both genetic *and* environmental. Prenatal exposure to drugs can cause massive brain cell death.[16] Figure 1.4 shows what neglect looks like by comparing a healthy brain with a neglected one. Under conditions of severe neglect,

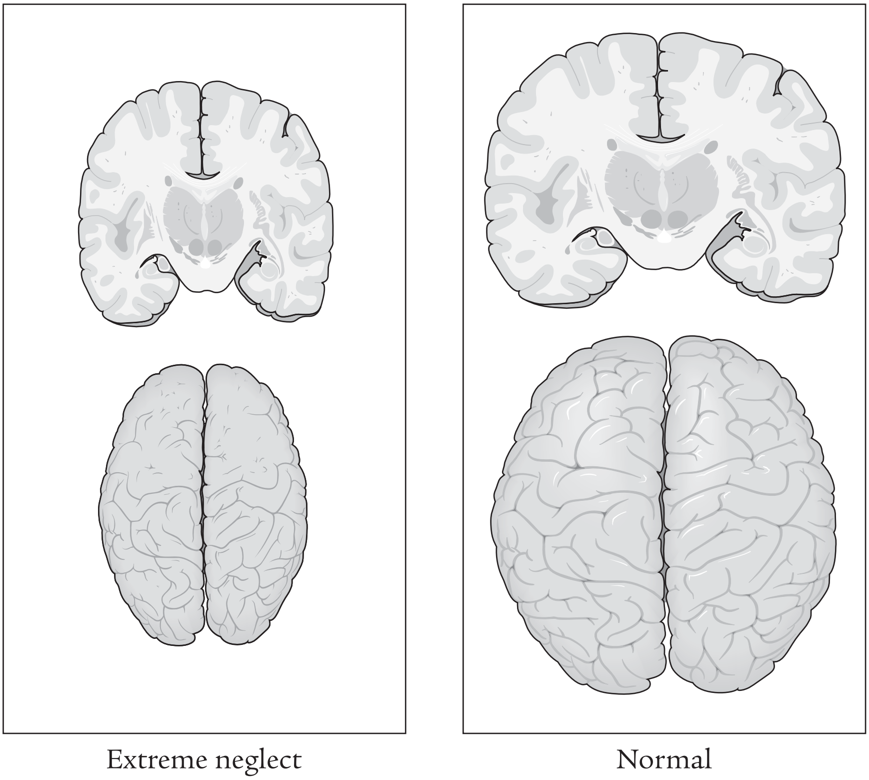


Figure 1.4. Brain Comparison of Three-Year-Old Children.

the genes that code for growth are disrupted. The message to the body's cells is to "conserve" and not grow. The results are often dramatic. These two brains are both three years old. The smaller brain shows the response to neglect; when resources are scarce, the brain grows less, so there will be less to maintain. The smaller brain can recover to full healthy size only if given immediate, comprehensive, and long-term enrichment.

A child who has been severely neglected may have a brain weight of 25 percent less than that of a typical healthy child. Expose a child to early stressors such as abandonment, threats, or violence, and you may get a brain with a dysregulated stress response system and lower IQ.[17] This child will be statistically more likely to suffer from stress and anxiety disorders and even depression. Expose a brain to toxins, chemicals, alcohol, or other environmental contaminants, and you increase the risk for mental retardation and, later, even Parkinson's disease. The brain changes, sometimes for the better, sometimes for the worse, and genes are only a small part of the equation.

CATASTROPHIC BRAIN CHANGES. Exposure to catastrophe can lead to very dramatic change indeed—but the response can vary according to the age of the sufferer. For example, the loss of the left hemisphere through injury can be devastating in a sixty-year-old human, including loss of language capacity and a large portion of memory. In a three-year-old child, however, the exact same loss would likely have a very different outcome. With proper rehabilitation, the child's right hemisphere may take over the lost functions from the left brain and allow the child to lead a full life. The *plasticity* or ability of the brain to remap itself wholesale is markedly stronger in earlier years. The speculation and theory for why the young brain can make greater changes across the board goes like this:

- The young brain has many areas (mainly in the cortex of the temporal, parietal, and frontal lobes) that are not yet committed to any function.
- The young brain also has an overproduction of synapses (brain cell connections) that are not all in use—many are uncommitted to any specific function.
- The young brain also has high levels of androgens, nerve growth factors, and neurotransmitters, all of which help support brain function and the capacity of the brain to rewire itself.

Two famous cases in brain research history illustrate the extent of the changes people can suffer—and live through. The first involves a patient known as "H. M.," who went for treatment of seizure disorders in August 1953. These seizures were dominantly found in his temporal lobes (located on the sides of the head, around the ears), as is common. In those days, before effective anti-seizure drugs such as Tegretol, surgery was used in the hope that it would alleviate recalcitrant seizures. Dr. William Scoville performed a bilateral resection of the patient's medial temporal lobe, including the hippocampus, and the seizures decreased significantly. That was the good news. The bad news was that there were quite severe side effects.

At the time, the surgeons didn't know all of what the hippocampus did. They surely know now: it's the part of the brain that helps form, store, and retrieve explicit daily memories. H. M. remembers things that happened before the surgery, but he cannot form any new verbal or picture memories. If you were to meet him and introduce yourself, he would be gracious and be able to repeat your name. But if you left the room and came back five minutes later, he'd have no idea who you were. Decades later, his brain has shown little improvement. He can, however, show some priming effect. If you repeat a first and last name often, he can sometimes come up with the last name if prompted with the first.[18] But this is a far cry from the typical memory for someone of his age. By the way, H. M. has repeatedly taken intelligence tests—and usually measures in the "above average" range.

Fortunately, H. M. remembers how to do physical tasks, and can even learn new ones—though he won't remember doing so, or exercising them, even though his performance keeps improving. Any experiments given to him involving word-based explicit learning tasks are tricky since they require memory. He can even recall events from his childhood, remembers the names of all of his relatives, and can remember the jobs he had had from his youth all the way up to the surgery in his late twenties. He clearly understands what's said to him. In H. M.'s case, his memory is devastated because of the surgery. Unfortunately, what was removed was both important and irreplaceable.

FROM GAGE TO RAGE. Here's another, more dramatic example of a changed brain. In September of 1848, Phineas Gage entered neuroscience history. Picture in your mind a James Cagney-type man; tough and street smart. Gage, a twenty-five-year-old railway foreman, was among the best workers; skilled, intelligent, and a good people-person. To blast rock areas and make for straighter rail lines, dynamite was used. The process was to drill a bore into the rock, place a charge and then the fuse, then fill the hole with sand. To make the explosion blow the rock apart, the sand must be tamped down solid. Gage was good at this process and used a forty-two-inch long metal tamping rod, over an inch in diameter. After tamping, the fuse is lit and the rocks fly apart (it is hoped).

According to local records, Gage prepped a rock, waited for the sand to get placed in it by another, looked away, and assumed the sand was in place. He then pounded down the tamping rod, and the dynamite exploded—sending the rod back into his face like a long bullet. It entered under his left cheek, went up and through his left eye, streaked through the frontal lobe of his brain and blasted out the top of his skull. The deadly projectile landed some 150 feet away. As would be expected, Phineas Gage staggered and fell to the ground. But soon he got up, in shock and bleeding. He actually talked to others as they took him to a doctor for help. He survived the accident, and the next day's headlines proclaimed a miracle. Most amazingly, Gage lived, the wound healed, and he survived twelve more years.[19]

But what really happened to Gage? He had been bright, kind, smart, and a responsible worker. Because of the accident, he'd lost an eye yet amazingly, his intelligence and memory were intact. But after the accident, he was very different. This formerly kind man suddenly used profanity, had fits of anger or rage, and became an unreliable worker. He often confabulated stories and was morally corrupt. In his final dozen years, Gage appeared in a circus and held two other jobs, both of them driving stagecoaches.

The thirteen-pound tamping iron caused considerable damage to Gage's orbito-frontal cortex.[20] That's the area right behind the eye socket, and it's the area responsible for integrating emotions into everyday life. This brain area helps us feel guilt, empathy, and shame. It helps us in decision making. The area right above it helps us make more socially responsible decisions. In Gage's brain, nothing inhibited the impulsive, crazy, careless, and irresponsible thoughts that stir in any human being. Whatever entered his mind, came out. He became a nuisance to everyone including his family. His final years on earth, by all accounts, were not happy or productive ones. Yes, the brain can change for the worse.

Positive Experiences Can Change the Brain

It's much more obvious when one is exposed to trauma, disease, or long-term adversity that the brain changes and becomes different. But what about the opposite effect? Can we alter and improve the trajectory of the developing brain? The answer, thankfully, is yes. The same brain that is receptive to damage is also receptive to positive effects. Amazingly, even changes in social contact can alter genetic expression, suggesting that the choice of our friends, our workplace, and our children's classroom conditions are changing the brain.[21]

This regulation of gene expression by environmental factors makes people susceptible to social influences for good as well as ill. The effects of these social influences become incorporated in the altered expressions of specific genes. In other words, our subjective experiences, our behavior, and social dynamics can and do modulate gene expression and vice versa. This conclusion would have been considered laughable a generation ago. Today, we know all bets are off and there is far greater potential for change in the human brain. A good deal of this book will be dedicated to showing how it happens and what the evidence is for making positive changes. Even more of the book will be showing you exactly what you can do and how you can take advantage of this revolution both in neuroscience and potentially in education.

Summary

This chapter has provided the groundwork for the rest of the book. We've explored how the fixed-genes myth is outdated. In addition to the high-tech side of gene changing through harmless retroviruses, there are much lower-tech avenues for change. Environmental influences, from stress to nutrition, social contact, and trauma, can alter genes in freshly discovered ways. And while this is not household knowledge today, it will be in just a few years. Genes have two functions, one fixed and the other modifiable by environmental input, and your son or daughter could be the beneficiary of this new understanding. In the next chapter, we'll explore how this new understanding of human possibility plays out in the myths about intelligence.