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Epigenetics: A new science for middle school – and why you should teach it

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Abstract

Epigenetics is a new field of science that underscores why your students' choices matter. Epigenetics describes how the environment and your experiences can control the rate at which your DNA works. Instead of changing the bases of the DNA, which would be a mutation, the environment that you experience can make chemical tags that are placed on your DNA. These chemical tags serve as a volume control by changing your DNA's ability to be “read”, thereby causing changes to your body's structure and function. This article describes this new field of science, some of its mechanisms, why students have been interested in the topic, how it covers NGSS learning objectives, and concludes with a resource and reading list for teachers. Epigenetics illustrates the evolving nature of science and provides the context for how famine, wartime stress, and pollution can have lasting effects for generations. Students can use this new science to explore the crosscutting concepts of patterns, cause and effect, and structure and function to realize a single key understanding that epigenetics offers a ‘memory’ of our experiences by changing our DNA's ability to be “read” and serves as the science behind our past, present, and future.

Keywords

Structure and function; Nature of science; History of science; Patterns; Cause and effect; Engaging in argument from evidence; Obtaining, evaluating, and communicating information, NGSS; Body systems; Mutations

Introduction

DNA is the command center of cells, but it does not act alone. It turns out that our environment plays a major role in the orders that DNA gives to direct how our cells function. We can think of DNA as a piano keyboard where our social and physical environments are the piano players. Surprisingly, DNA seems to be fluid, responding to environmental changes sometimes within as little as 15 minutes, and sometimes these changes are life-long -- so that even though the keys on the DNA keyboard remain the same, the song it plays does not.

Day by day, week by week, our genes are responding to our environment. The molecules we eat, the stress we feel, and the air we breathe can cause our DNA to play a different protein song. Sometimes a gene gets stuck in an open position, or a completely closed position, or somewhere in between, because of something we are eating, or because we are being abused, even possibly just because we feel alone. Barring random mutations, our genes don't normally change, but their expression is constantly being adjusted, as the science of epigenetics is showing. Genes are dialed up or down all of the time -- just like the volume of a radio -- and it is the pattern of this expression that makes us who we are, just like the order, force, and speed with which we play a piano keyboard determines the difference between a virtuoso performance of Chopin and the simple melody of "Chop Sticks".

What is Epigenetics

Epigenetics ("epi" meaning "above") is the name of a powerful biological process by which gene switches can be regulated. The process uses chemical tags on DNA. These tags provide a "volume control" for the things that our DNA does. Our DNA is made up of four bases referred to as A's, C's, G's and T's. The order of these bases creates a code that tells your body what to do (like making blood proteins to clot a wound on your finger, or making keratin to grow fingernails and hair). Epigenetics can control the rate at which your DNA works -- turning it up or down, on or off. Instead of changing the bases of the DNA (which would be a mutation), the environment that you experience, like stress or diet, can make chemical tags that are placed on your DNA (Figure 1). These tags change how much of the DNA is able to be accessed and "read" by the transcriptional machinery that use the base sequences to make proteins in the cell. Blocking access to the DNA results in less gene expression; increased access to the DNA typically results in more gene expression. Figure 2 shows two examples of how access to the DNA can be changed by these chemical tags -- processes known as "methylation" and "histone acetylation". Do your students need to know these exact mechanisms -- no, but understanding that scientists keep discovering new ways that the environment and DNA interact is important for conveying the evolving nature of science and the opportunities that result. Moreover, because different environmental

stressors and experiences cause the chemical tags to be placed on different parts of the DNA, which then causes different effects in our bodies, students can explore the crosscutting concepts of patterns, cause and effect, and structure and function to realize a single key understanding: *epigenetics is caused by environmental experiences – indeed it provides a memory of these experiences – and serves as a volume control by changing DNA's ability to be “read”, thereby causing changes in our body's structure and function.*

Why does it matter to your students?

Now you may be thinking, “Why should I teach this to my students? They have enough trouble learning about genetics!” or “They're too young for this”, but we urge you to reconsider. We have worked with over 1000 middle school students this past year alone with great results. The story of epigenetics is interesting to students on two levels. It is about how their environment influences their bodies, and also about how science takes in new information to refine our understanding of the world we live in. Epigenetics serves as a “hook” to get your students thinking about the larger picture – not only about science, but specifically about themselves and why their choices matter. It also helps students visualize the larger picture and how one person's actions can affect families, communities, or societies around the world. We have proposed the top five reasons why we think it is important to teach epigenetics to your students (Table 1). The central theme is that epigenetics gives your students a scientific answer as to why their immediate social and behavioral choices matter -- 1) now, 2) in their future, and 3) their children's and even grandchildren's futures.

How it fits with Next Generation Science Standards

Epigenetics is not mentioned by name in the Next Generation Science Standards (NGSS), though the desired learning outcomes fit extraordinarily well (Table 2). For example, while epigenetics describes outcomes that affect protein levels through structural changes to genes (MS-LS3), epigenetic pathways do not specifically create a mutation characterized by a change in DNA sequence. Instead, as described above, the structural changes are chemical modifications that allow the transcriptional machinery to have more or less access to the DNA – serving as a volume control, of sorts, for protein levels. These proteins are used by cells to influence growth and how body systems function throughout life. Environmental changes that affect resource availability (e.g. famines, wars, pollution) can produce epigenetic effects that affect protein levels (MS-LS2). Students can use epigenetics to describe and predict interdisciplinary outcomes on human health throughout the lifespan (MS-LS1).

Likewise, epigenetics helps to show ‘Connections to the Nature of Science’ and ‘Connections to Engineering, Technology, and the Applications of Science’, as students explore the evolving process of this new field of science, especially with the development of new technologies that have made it possible to detect and measure epigenetic changes. Finally, new advances in epigenetics are being discovered every day and we are on the steepest part of our scientific learning curve (Figure 3A), so help your students follow the discovery process in their own lifetimes – including how this new area of science is showing up to influence many body systems and disease processes previously unknown (Figure 3B).

You never know, one of your students may be the one to find a cure for a disease based on epigenetics.

Resource and Reading List

New to epigenetics? Never fear – most scientists didn't learn about epigenetics in school either! Table 3 has a reading and resource list to help you and your students up to speed.

	A Genetic Mutation	An Epigenetic Change
From this	ATCGGGATTCACG	ATCGGGATTCACG
To this	ATAGGGATTCACG	AT [*] CGGGATTCACG

Figure 1. Examples of genetic and epigenetic changes

Figure 2.

Two examples of epigenetic mechanisms that show how changing access to the DNA can influence gene expression. These mechanisms illustrate the cross-cutting concepts of patterns, cause and effect, and structure and function, since despite using different types of chemical tags -- and in different areas (DNA versus histones) -- the end result is the same: decreasing access to the DNA will reduce the amount of gene expression. This illustration was adapted from the “Nurture Your Nature” interactive learning game (see Resources). Histones are proteins around which DNA is wound.

Figure 3.

Epigenetics is a rapidly growing field of science. A. In the past fifty years, there has been an exponential rise in the number of scientific publications citing epigenetics. The publication search was conducted in PubMed, the primary source scientists use to find peer-reviewed scientific articles. Each dot denotes the number of published articles for that calendar year combined with the search term “epigenetic*” (where the asterisk (*) denotes derivatives of the word such as epigenetics, epigenetically, etc). B. Epigenetics is involved in an increasing number of scientific areas, including body systems (top) and disease processes (bottom). These graphs show the number of published articles indexed on PubMed to date (through 12/31/2014) which include the search terms “epigenetic*” and the topic area listed on the Y axis. Cardiovascular disease includes “heart disease or cardiovascular disease”.

Table 1
Five reasons to teach epigenetics to your middle school students

1	Their choices matter -- Epigenetics is the science behind why your students' choices matter. You tell them this every day, but epigenetics describes the mechanics behind why it is important. The foods they eat, whether they choose to bully others, the amount of sleep they get -- all of these choices have impacts on the DNA of themselves and others.
2	Science is constantly advancing -- If you are looking to show your students the nature of science and how scientists are learning new discoveries every day, then look no farther than epigenetics for a complete shift in how scientists think about DNA. The last 40 years has seen a huge surge in epigenetics research (see Figure 2).
3	Impact on Society -- Famine, wartime stress, and pollution can all affect how our DNA function. New research is showing that these experiences also affect how our grandchildren's DNA functions. Knowing this, your students now have a vast amount of information to frame the implications of world events. What obligations do we have to ourselves and others?
4	It helps to teach how to be critical consumers of information -- As epigenetics expands in the scientific literature and popular press, there will likely be many articles that misrepresent the science, overextend interpretations, or make false claims or product pitches (e.g. epigenetic bubble gum, epigenetic cleansing tonic, or the amazing 48 hour epigenetic diet -- guaranteed to methylate your bad genes!). Use this opportunity to prepare your students for bogus claims and how to find reputable sources for their information.
5	It is our past, present, and future -- Scientists are discovering that it is not only your students' choices that affect his/her health -- both now and later in life -- but that the environmental experiences of his/her parents and grandparents can have an impact. This new field of science is called "Developmental Origins of Health and Disease" and scientists are currently studying how epigenetics can have an impact across generations.
Bonus Reason -- It is timely and personally relevant --Your students are growing up when they will get to see this field evolve as they continue through school. This is a brand new area of science and they are among the first to be taught it.	

Table 2
Connecting Epigenetics to the Next Generation Science Standards and Common Core State Standards

Standards MS-LS3 Heredity: Inheritance and Variation of Traits MS-LS1 From Molecules to Organisms: Structures and Processes MS-LS2 Ecosystems: Interactions, Energy and Dynamics		
Performance expectations MS-LS3-1 - Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism. MS-LS1-5 – Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms. MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.		Alignment through Epigenetics While epigenetics fits very well for describing outcomes that affect protein levels through structural changes to genes, epigenetic pathways don't specifically create a mutation characterized by a change in DNA sequence. Instead, the structural changes are chemical modifications that allow the translational machinery to have more or less access to the DNA – serving as a volume control on a radio, of sorts, for protein levels. Proteins are used by cells to influence growth and how body systems function throughout life. Environmental changes that affect resource availability (e.g. famines, wars) can produce epigenetic effects that affect protein levels. Students can use epigenetics to describe and predict interdisciplinary outcomes for human health throughout the lifespan.
Dimension	Name or NGSS Code/Citation	Key Messages for How Epigenetics Aligns to Student Learning Goals
Disciplinary core ideas	<ul style="list-style-type: none"> LS1.B Growth and Development of Organisms LS3.A: Inheritance of Traits LS2A: Independent Relationships in Ecosystem LS2D: Social Interactions and Group Behavior 	<ul style="list-style-type: none"> Environmental factors during pregnancy (e.g. diet, stress) can influence the growth of organs and tissues in the developing fetus, which can produce lasting effects on how these organs function later in life (developmental origins of health and disease). Environmental factors throughout life can influence gene expression to regulate the amount of protein being made. Social interactions can increase or decrease stress levels. Chronic stress can produce epigenetic effects to immune system and brain, influencing health and memory.
Science and engineering practices	<ul style="list-style-type: none"> Developing and Using Models Engaging in Argument from Evidence Constructing Explanations and Designing Solutions Obtaining, Evaluating, and Communicating Information 	<ul style="list-style-type: none"> Students use models of DNA folding to predict how transcriptional machinery would have more or less access to DNA. Students apply scientific reasoning to predict how changes to organ growth can influence their function. Students gather and read epigenetic information from media sources to assess the credibility, accuracy and possible bias of publications.
Crosscutting concepts	<ul style="list-style-type: none"> Patterns Cause and Effect Structure and Function Scale, Proportion and Quantity Systems and System Models 	<ul style="list-style-type: none"> Patterns in historical data and records show a relationship in timing between resource availability and health Epigenetic changes to DNA can produce effects on organ systems, though observable health effects may not be present until years later. There are time periods during human development that are most sensitive to environmental effects (pregnancy, puberty) due to epigenetic changes to egg and sperm.

Connections to Engineering, Technology and Applications of Science	<ul style="list-style-type: none"> • Interdependence of Science, Engineering and Technology • Influence of Engineering, Technology and Science on Society and the Natural World 	<ul style="list-style-type: none"> • Advances in technology enabled scientists to explore larger regions of the genome for epigenetic changes. This enabled new genes involved in disease (e.g. cancer) to be identified. • Human activity draws on natural resources that can produce short- and long-term changes on human health.
Connections to Nature of Science	<ul style="list-style-type: none"> • Scientific Investigations Use a Variety of Methods • Scientific Knowledge is Based on Empirical Evidence • Scientific Knowledge is Open to Revision in the Light of New Evidence • Science is a Human Endeavor 	<ul style="list-style-type: none"> • The infancy of epigenetics field provides ample opportunities for student discussions about the nature of science. Students can explore the milestones of the field to explore how scientific theories evolved over time from empirical evidence. Students also explore how epigenetic advances in one area of science (e.g. botany) are tested in other fields (e.g. cancer). These scientific patterns reveal mechanisms that can be explored in other areas.
Connections to Common Core State Standards	<ul style="list-style-type: none"> • CCSS.ELA-LITERACY.RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). • CCSS.ELA-LITERACY.WHST.6-8.9 Draw evidence from informational texts to support analysis, reflection, and research. 	<ul style="list-style-type: none"> • Students read about historical events and apply an understanding of epigenetics to describe how these events or experiences may shape human health outcomes. • Students develop an appreciation for and understanding of others based on the experiences some individuals may have had to endure.

Table 3
Reading and Resource List

<p>Online Resources</p> <ul style="list-style-type: none"> Genetic Science Learning Center – University of Utah has a great introduction to genetics and epigenetics. Their site is terrific for understanding the basics to the most complex of topics. <ul style="list-style-type: none"> – For their teacher site: www.teach.genetics.utah.edu; – For their student/learner site: www.learn.genetics.utah.edu <i>Let's Get Healthy!</i> Based out of Oregon Health and Science University, this program has materials on both epigenetics and the new field of Developmental Origins of Health and Disease <ul style="list-style-type: none"> – Web-based interactive learning game/module that won a 2014 International Serious Play Award, Silver Medal: http://www.letsgethealthy.org/students/games/epigenetics-game/ – Teacher-developed briefing sheets for students, parents, and your school administration. Also, tested manipulatives that students can hold that help to convey the topic: http://www.letsgethealthy.org/about-the-research/station-descriptions/epigenetics/ Hank Green's YouTube Video about the power of epigenetics (SciShow; 9 minutes and 28 seconds; https://www.youtube.com/watch?v=kp1bZEUgqVI) OHSU Bob and Charlee Moore Institute for Nutrition & Wellness– The Moore Institute is an international leader in the field of developmental origins of health and disease and epigenetics. http://www.ohsu.edu/xd/education/schools/school-of-medicine/departments/the-moore-institute/ and their blog http://betterthefuture.org/ <p>Articles written for the lay public</p> <ul style="list-style-type: none"> Dobbs, D. (2013). The Social Life of Genes. Pacific Standard, September 3, 2013. Retrieve from: http://www.psmag.com/books-and-culture/the-social-life-of-genes-64616 <p>Middle School Lessons and Activities</p> <ul style="list-style-type: none"> Epigenetics: http://www.letsgethealthy.org/teachers/classroom-lessons-an-activities/ Developmental Origins of Health and Disease: Charbonneau, A., Moss, G.B. and L.K. Marriott (2015). “The Surprising Patterns of Health and Disease”. Science Scope, 3, 64-70. http://digital.nsta.org/publication/index.php?i=247493&m=&l=&p=5&pre=