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

by Lisa Marriott, Alison Charbonneau, Berk Moss, Jackilen Shannon, Kent Thornburg, and Mitchell Turker

DNA is the command center of cells, but it does not act alone: 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 and our social and physical environments as the piano players. Surprisingly, DNA seems to be fluid, responding to environmental changes sometimes within as little as 15 minutes, and these changes can be lifelong. So, even though the keys on the DNA keyboard remain the same, the song it plays does not (Feinberg and Fallin 2015; Feil and Fraga 2012). This is especially evident during development. For example, some cells in the developing fetus turn into brain cells, whereas others turn into liver cells. Even though these cells have the same set of DNA, they are responding to different signals that, in total, create all the tissues in the body.

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, a closed position, or somewhere in between, because of our diet, mood, or a physical injury. 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 the time—just like the volume of a radio—and it is the pattern of this expression that makes us who we are, just as the order, speed, and intensity of the notes we play on a piano keyboard determines the difference between a virtuoso performance of Chopin and the simple melody of "Chopsticks."

What is epigenetics?

Epigenetics 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 (adenine, cytosine, guanine, and thymine) referred to as As, Cs, Gs, and Ts. The order of these bases creates a code that tells your body what to do (e.g., make blood proteins to clot a wound on your finger or make 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; see "Pass the DNA, Please" on p. 36), the environment that you experience, including factors such as stress or diet, can make chemical tags that are placed on your DNA (Figure 1). These tags determine the amount of DNA that can be accessed and "read" by the transcriptional machinery, which uses the base sequences to make proteins in the cell. Blocking access to DNA results in less gene expression; increased access to DNA typically results in more gene expression. Figure 2 shows two examples of how access to 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

FIGURE 1 Examples of genetic and epigenetic changes

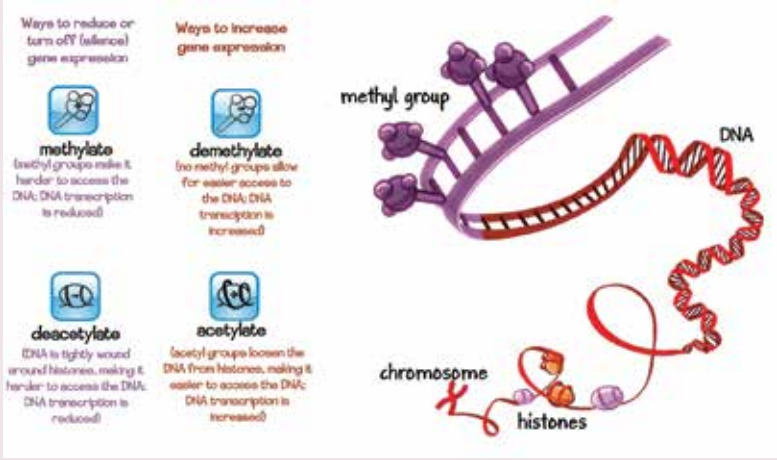
understanding that scientists keep discovering new ways in which the environment and DNA interact is important for conveying the evolving nature of science and the opportunities that result. Moreover, because different environmental stressors and experiences cause the chemical tags to be placed on different parts of 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 1,000 middle school students with great results during this past year alone. The story of epigenetics is interesting to students on two levels: It explains how students' environment influences their bodies and illustrates how science builds upon 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 appreciate 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 (Figure 3). The central theme is that epigenetics gives your students a scientific answer as to why their immediate social and behavioral choices matter—now, in their future, and in their children's and even grandchildren's futures.

FIGURE 2 The structure and function of epigenetics

Two examples of epigenetic mechanisms that show how changing access to the DNA can influence gene expression. These mechanisms illustrate the crosscutting concepts of Patterns, Cause and Effect, and Structure and Function, because 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. The effect of this reduced gene expression can be good or bad. For example, by reducing the expression of genes that signal cells to stop dividing, cancer cells are able to keep dividing without control, resulting in increased tumor growth. This illustration was adapted from the "Nurture Your Nature" interactive learning game (see Resources). Histones are proteins around which DNA is wound.



How epigenetics fits with the *Next Generation Science Standards*

Epigenetics is not mentioned by name in the *Next Generation Science Standards* (*NGSS*), though the desired learning outcomes fit well (see the sidebar on p. 10). 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 (NGSS Lead States 2013). 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 for protein levels. These proteins are used by cells to influence growth and the function of body systems throughout life. En-

vironmental 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 (NGSS Lead States 2013), as students explore the evolving process of this new field of science, especially with the development of 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 4A). 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 4B). You never know—one of your students may be the one to find a cure, based on epigenetics, for a disease.

Resource and reading list

New to epigenetics? Never fear—most scientists didn't learn about epigenetics in school, either. To bring you and your students up to speed, check out our list of recommended resources.

Resources

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.

- Teacher site—*http://teach.genetics.utah.edu*
- Student/learner site—*http://learn.genetics.utah.edu*

Hank Green's YouTube video about the power of epigenetics (9 minutes, 28 seconds)—*www.youtube.com/watch?v=kp1bZEUgqVI*

FIGURE 3 Examples of genetic and epigenetic changes

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 choices matter. The foods they eat, how they treat other people, the amount of sleep they get—all of these choices have impacts on their DNA and the DNA of others.
2. **Science is constantly advancing:** If you are looking to show your students the nature of science and how scientists are making new discoveries every day, then look no further than epigenetics for a complete shift in how scientists think about DNA. The last 40 years have 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 functions. New research is showing that these experiences might 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 creates 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 their health—both now and later in life—but that the environmental experiences of his or 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 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.

Let's Get Healthy! Based at Oregon Health and Science University, this program has materials on both epigenetics and the new field of Developmental Origins of Health and Disease.

- Web-based, interactive learning game/module that won a 2014 International Serious Play Award, Silver Medal—*www.letsgethealthy.org/students/games/epigenetics-game*
- Teacher-developed briefing sheets for students, parents, and your school administration. Also, teacher-tested, hand-held, student manipulatives that help to convey the topic—*www.letsgethealthy.org/about-the-research/station-descriptions/epigenetics*
- OHSU Moore Institute. The Moore Institute is an international leader in the field of developmental origins of health and disease and epigenetics—*www.ohsu.edu/xd/education/schools/school-of-medicine/departments/the-moore-institute* and their blog, *http://betterthefuture.org*

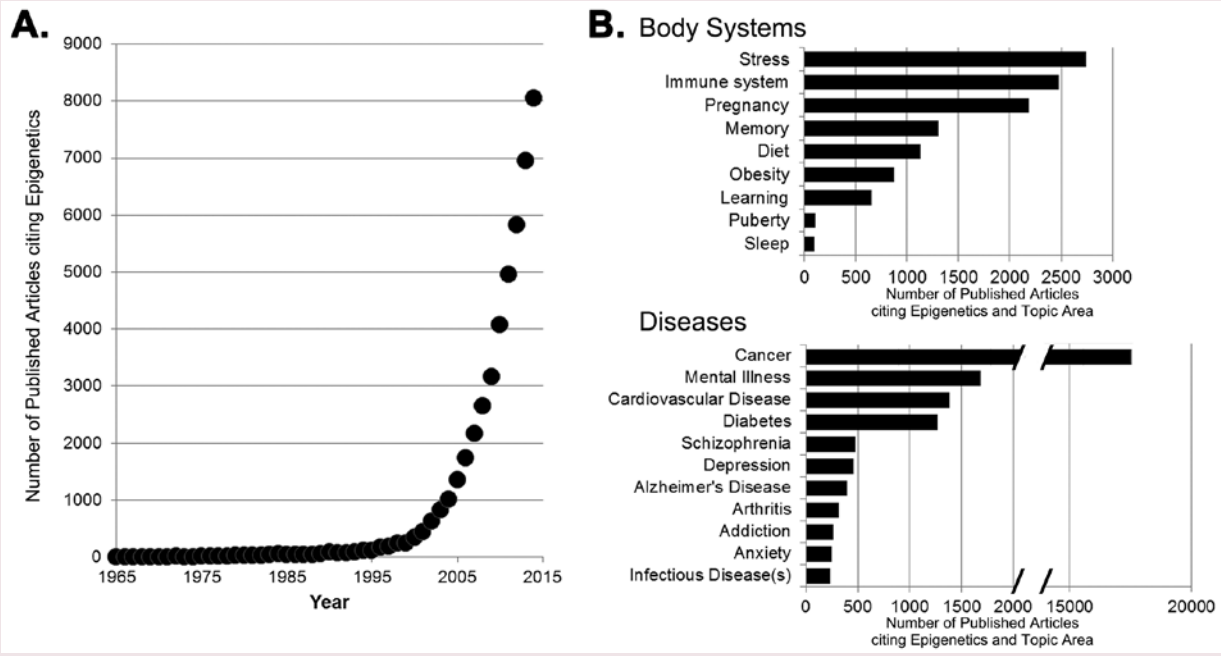
References and scientific review articles

Feil, R., and M.F. Fraga. 2012. Epigenetics and the environment: Emerging patterns and implications. *Nature Reviews Genetics* 13: 97–109.

Feinberg, A.P., and M.D. Fallin. 2015. Epigenetics at the crossroads of genes and environment. *Journal of the American Medical Association* 314 (11): 11-29–30.

FIGURE 4 **The new field of epigenetics**

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."



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		
Dimension	**Name or *NGSS* code/citation**	**Key messages for how epigenetics aligns to student learning goals**
Disciplinary core ideas	• LS1.B: Growth and Development of Organisms • LS3.A: Inheritance of Traits • LS2A: Interdependent Relationships in Ecosystems • LS2D: Social Interactions and Group Behavior	• 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	• Developing and Using Models • Engaging in Argument from Evidence • Constructing Explanations and Designing Solutions • Obtaining, Evaluating, and Communicating Information	• 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	• Patterns • Cause and Effect • Structure and Function • Scale, Proportion, and Quantity • Systems and System Models	• 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	• Interdependence of Science, Engineering, and Technology • Influence of Engineering, Technology, and Science on Society and the Natural World	• 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	• Scientific Investigations Use a Variety of Methods • Scientific Knowledge is Based on Empirical Evidence • Scientific Knowledge is Open to Revision in Light of New Evidence • Science is a Human Endeavor	The infancy of the 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*	• 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.	• 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.

Note: This short article presents an overview of the topic for medical doctors and could be appropriate as a primary source for students who want to read more about the topic.

Articles written for the public

Dobbs, D. 2013. The social life of genes. *www.psmag.com/books-and-culture/the-social-life-of-genes-64616*.

Middle school lessons and activities

Developmental origins of health and disease:
Charbonneau, A., G.B. Moss, and L.K. Marriott. 2015. The surprising patterns of health and disease. *Science Scope* 38 (7): 64–70. *http://digital.nsta.org/publication/index.php?i=247493&m=&l=&p=5&pre=*
Epigenetics—*www.letsgethealthy.org/teachers/classroom-lessons-an-activities*
Nurture your nature game—*www.letsgethealthy.org/students/games/epigenetics-game*

Lisa Marriott (*marriott@ohsu.edu*) is assistant professor in the OHSU/PSU School of Public Health at Oregon Health & Science University in Portland, Oregon. ***Alison Charbonneau*** (*alisonc@sthelens.k12.or.us*) is a life science and engineering teacher at St. Helens Middle School in St. Helens, Oregon. ***Berk Moss*** (*mossfam@teleport.com*) is a science education consultant with Woodside Consultants in Newberg, Oregon. ***Jackilen Shannon*** (*shannoja@ohsu.edu*) is associate professor in the OHSU/PSU School of Public Health, ***Kent Thornburg*** (*thornbur@ohsu.edu*) is professor of medicine, and ***Mitchell Turker*** (*turkerm@ohsu.edu*) is a senior scientist at the Institute of Occupational Health Sciences and professor of molecular and medical genetics, all at Oregon Health & Science University in Portland, Oregon.