IS4 Living Earth Instructional Segment 4: Inheritance of Traits

Middle grade students are introduced to genes and the connection to genes and proteins, including what happens if there are mutations in gene sequences (MS-LS3-1) and the variation within individuals that are the result of the inheritance of genetic traits (MS-LS3-2). This instructional segment defines the mechanisms for inheritance that were introduced in IS3 and provides a motivation for understanding IS5 in which students learn how organisms use DNA to code for amino acids, the building blocks of proteins. While this instructional segment provides the big picture view of inheritance by DNA, IS5 goes into more detail about cell division and explains the mechanism of inheritance at the scale of the cell itself.

LIVING EARTH INSTRUCTIONAL SEGMENT 4: INHERITANCE OF TRAITS

Guiding Questions

- How are characteristics of one generation passed to the next?
- What allows traits to be transmitted from parents to offspring?
- How does variation affect a population under selective pressures?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS3-1. Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. *[Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.]*

HS-LS3-2. Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors. [Clarification Statement: Emphasis is on using data to support arguments for the way variation occurs.] *[Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.]*

HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population. [Clarification Statement: Emphasis is on the use of mathematics to describe the probability of traits as it relates to genetic and environmental factors in the expression of traits.] *[Assessment Boundary: Assessment does not include Hardy-Weinberg calculations.]*

HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment. [Clarification Statement: Emphasis is on using evidence to explain the influence each of the four factors has on number of organisms, behaviors

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morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models such as simple distribution graphs and proportional reasoning.] *[Assessment Boundary: Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and co-evolution.]*

HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait. [Clarification Statement: Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations.] *[Assessment Boundary: Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.]*

The bundle of performance expectations above focuses on the following elements from the NRC document *A Framework for K–12 Science Education*:

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	LS1.A: Structure and Function LS3.A: Inheritance of Traits LS3.B: Variation of Traits LS4.B: Natural Selection LS4.C: Adaptation	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-3] Scale, Proportion, and Quantity

Highlighted California Environmental Principles and Concepts:

Principle I The continuation and health of individual human lives and of human communities and societies depend on the health of the natural systems that provide essential goods and ecosystem services.

Principle II The long-term functioning and health of terrestrial, freshwater, coastal, and marine ecosystems are influenced by their relationships with human societies.

Principle III Natural systems proceed through cycles that humans depend upon, benefit from and can alter.

Principle IV The exchange of matter between natural systems and human societies affects the long-term functioning of both.

CA CCSS Math Connections: MP.2; MP.4

CA CCSS for ELA/Literacy Connections: RST.11–12.1, 9; WHST.9–12.1.a–e, 2.a–e, 7, 9

CA ELD Connections: ELD.PI.11–12.1, 5, 6a–b, 9, 10, 11a

One way to help students meet HS-LS3-1 and better appreciate the nature of science is through a historical approach. Students obtain information about the study of DNA, learning about what scientists knew, what questions they asked, and how they designed investigations to answer those questions. Discussing the scientists themselves shows that science is a human endeavor. The historical approach also illustrates how ideas have unfolded over time, showing that scientific knowledge is open to revision in light of new evidence. See chapter 11 on instructional strategies for specific advice about teaching science through historical case studies.

At the turn of the twentieth century, Mendel's conclusions about inheritance were accepted, and it was understood that chromosomes were passed from generation to generation in all living organisms. It was also known that chromosomes were composed of DNA and proteins. However, in the early 1900s it was not clear to scientists how these chromosomes could provide the codes for all the phenotypes present in an organism. Were the proteins or the DNA most important? As scientists grappled with this, they began to ask more focused questions about what exactly was directing the translation of proteins. Frederick Griffith, one such scientist, was trying to find a cure for pneumonia and was using mouse models to address specific questions about how mice contracted pneumonia. He found that he could inject strains of bacteria into mice and transform strains of non-pathogenic bacteria into pathogen-causing bacteria. The full experiment might be demonstrated by a slide presentation showing the first part of Griffith's experiment on one slide while asking students to predict the outcomes. Then show the outcomes on the next slide, continuing this pattern with the next set of experiments as students predict the outcomes. Then see what comes next by switching to the next slide and building on that knowledge, continuing with the next set of experiments along with predictions. Students can deduce the control and variables Griffith used in his original work. The conclusion of his work was that some agent transformed the non-pathogen-causing strains into pathogen-causing strains of bacteria and the mice developed pneumonia.

MacLeod and McCarty attempted to answer that question. They discovered that DNA was the transforming agent, which they concluded after testing the individual components of the bacteria cell in a cell culture system. Scientists were not entirely convinced. Therefore, Alfred Hershey and Martha Chase radioactively labeled parts of viruses and provided even more evidence that the DNA was being transported into hosts' cells and transforming those host cells into virus-making machines. It was also around this time that Erwin Chargaff and his students who, while working on separating nucleotides in different organisms, noticed that adenine and thymine were always in the same amounts as were guanine and cytosine.

They also noticed that the total amount of adenine and thymine was not equal to the total amount of guanine and cytosine. A final piece of the puzzle was the X-ray photograph of DNA that Rosalind Franklin generated showing the regular pattern and the helix formation of the molecule. These experiments, along with other evidence gathered during this time, led to the building of the **model [SEP-2]** of DNA by Watson and Crick. (There is an excellent educational resource regarding the history of this scientific discovery through the UC Berkeley Museum of Paleontology, The structure of DNA: Cooperation and competition http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link10.)

Building physical **models [SEP-2]** can help explain data and observations (for Watson and Crick, it helped them merge together all that they had learned from others) and predict new possibilities (for Watson and Crick, it helped others think about how DNA replicates) but models also have limitations. For example, Watson and Crick's model could not show how the code determined amino acid order. Having students build this model can help them make the connections that Watson and Crick made with the data produced from theirs and others' experiments. Students can also begin to see what happens if a component of the model changes. What happens if you switch a thymine with an adenine? Students should see that having an A nucleotide across from an A nucleotide alters the structure, which can help them make predictions about the effect of mutations. Students can improve their ability to **obtain information [SEP-8]** from scientific journals by reading an annotated version of Watson and Crick's original paper. Even though it is only two pages long, it has profoundly influenced the direction of the science of genetics and molecular biology.

Much of the work done in the first half of the twentieth century looked at the effect mutations had on phenotypes. If a genetic disease resulted, it gave the geneticists evidence of the function of that gene, though they could not directly observe the genotype (see IS1). In the latter half of the twentieth century and into the twenty-first century, techniques and tools have improved so that scientists can actually test how specific changes in a gene sequence alter phenotypes. Technology has also enabled scientists to map out entire genomes of a large variety of organisms, and large online databases exist that students can browse freely (see National Center for Biotechnology Information http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link11).

Once scientists started mapping out entire genomes, they realized that the simple relationships between DNA sequences and phenotypes are more complicated than originally thought. Genomes contain far fewer gene sequences than scientists originally thought and many phenotypes are the results of more than one gene. Students can look at phenotype studies and **ask questions [SEP-1]** regarding what changes in DNA result in changes

in phenotypes of humans (or other living organisms) and the effect of DNA changes on individuals. Students can go to National Center for Biotechnology Information and link to case studies done in humans by looking at the Online Mendelian Inheritance in Man (OMIM) link or they can expand the exercise and look at other animals or plants.

Students can investigate organ and tissue donation by **obtaining information [SEP-8]** about how doctors use genotypes to find successful matches for people who need new organs or tissue. The success of these transplants is much higher when the doctors can find a genotype match for certain traits (for additional information see organdonor.gov http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link12). Which genes are most important for identifying the right match? What other traits do those genes influence?

This instructional segment can now meld classic Mendelian genetics with the molecular genetics just discussed. Variation is the result of mutation and recombination events that happen at the genetic level. Students can apply a physical **model [SEP-2]** of chromosomes (such as clay or pipe cleaners) to visualize and provide **evidence [SEP-7]** about how variation happens. With this model, students can demonstrate how pairs of chromosomes physically exchange parts to create new combinations of sequences (one method of variation) and can show that the random line up of the chromosome pairs during meiosis results in different arrangements of chromosomes during sexual reproduction (another method of variation). Students can also use Punnett squares as a model that illustrates how variation can arise from the mating of two biological parents. **Analyzing [SEP-4]** the **quantity and proportion [CCC-3]** of possible outcomes helps explain the variation we see in individuals even between siblings who have the same biological parents.

Mutations in DNA can result in a change in genotype. Some mutations result in viable cells and can produce new genes that are then inherited by the next generation, others result in cell death, and still others in uncontrolled replication that leads to cancerous tumors. Sometimes, the traits caused by mutations result in a viable cell that somehow lacks certain functionality, and we refer to these mutations as genetic diseases. A single nucleotide change in the gene sequence for hemoglobin results in sickle cell anemia. A similar mutation in the gene that is used to form proteins that form a channel for movement of particles into and out of cells produces the condition known as cystic fibrosis (though it should be noted that there can be several single changes that result in the cystic fibrosis phenotype). Errors in copying or division of the X chromosome can lead to a disease resulting in Turner syndrome. Students should be able to use evidence from these genetic diseases to **construct an argument [SEP-7]** that variations are caused by genetic code that is inherited or altered either during DNA replication or by environmental factors (HS-LS3-2).

Students should also be able to relate this argument not only to genetic disease but also to any variation in traits.

Other mutations can actually make it harder for diseases to affect humans. Students could **obtain information [SEP-8]** about how a mutation in the gene that creates the protein CCR5 can delay or prevent acquired immune deficiency syndrome (AIDS) symptoms in people infected with the human immunodeficiency virus (HIV). They **develop a model [SEP-2]** of how viruses enter cells by matching protein receptors. Viruses like HIV, bubonic plague, and smallpox cannot enter the cell in people that lack the CCR5 protein receptor. Does this mutation provide clues to create an HIV treatment or vaccine? Students can also **analyze data [SEP-4]** from maps showing how common this mutation is in different parts of the world and **ask questions [SEP-1]** about why this mutation became so prevalent in northern European countries.

Once students understand how variation can occur, they can predict what combinations are possible in offspring. Punnett squares are a simple and common model used to predict traits, but they are cumbersome to use for predicting multiple traits. For example, predicting the outcome of a tri-hybrid cross requires a cumbersome eight by eight Punnett square. Instead, students can use statistical tools that include the product and sum rules of probabilities (CA CCSSM S-CP.7–8). Pedigrees are another model used to look at patterns of inheritance across generations. Students can evaluate possible genetic combinations and predict the chance of traits appearing in individual offspring. Students can use interactive computer simulations to create phenotypes of an organism by looking at combinations of genotypes and again predict what combinations are plausible. Students should be able to use information from genetics and their ability to calculate probabilities of different traits to explain the distribution of particular traits within a population (HS-LS3-3).

While genetics dictates many aspects of variation, environment also affects phenotype expression. Some environmental components can affect the phenotype without a change in genotype. In humans, nutrition is an environmental component that affects height or muscle formation. Just because an individual possesses the genotype to be tall or strong does not mean he or she will reach full genetic potential. Failure to meet genetic potential does not affect how genes are inherited, so malnourished parents can give birth to offspring that end up being much taller than their parents. Using statistics (**mathematical thinking [SEP-5]**), students can **analyze [SEP-4]** the frequency or distribution of traits observed in a population and compare it to the probability of certain traits occurring based on genetics alone (CA CCSSM S-CP.4). If students identify a mismatch, they should be able to construct an **argument [SEP-7]** that environmental factors have affected phenotypes.

Linking IS3 with this instructional segment will help students draw connections between how variation exists and how selection can act on the population. Natural selection acts on the phenotype of an individual, for example the size of a shell or beak. The selective pressure that favors one size over another will translate into a change in proportion of individuals with the favored size in the next generation—if the change is a result of inheritance. In other words, the individuals that have the favorable phenotype reproduce and pass on the favorable genetic code that generated that phenotype. The frequencies of favored traits are ultimately what change from generation to generation. Students can **model [SEP-2]** these changes using computer simulations of populations (see Howard Hughes Medical Institute "Color Variation Over Time in Rock Pocket Mouse Populations" at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link13) and use **probabilities [SEP-5]** to determine whether or not there is evidence of changes in populations over time (see Howard Hughes Medical Institute "Stickleback Evolution Virtual Lab" at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link14) (HS-LS4-3). Using these simulations as examples, students should be able to tie together their knowledge in the course to construct an explanation of how organisms evolve (HS-LS4-2). Their explanation should note how (1) organisms can reproduce to grow in numbers; (2) offspring of organisms are slightly different from their parents due to processes of mutations and sexual reproduction; (3) organisms compete for limited resources; and (4) organisms with traits that enable them to survive and obtain resources are most likely to reproduce and pass on their traits such that the population increases in the proportion of these successful traits.