IS5

Living Earth Instructional Segment 5: Structure, Function, and Growth (From Cells to Organisms)

Understanding the characteristics of life is a unifying theme of biology. Instructional segment 5 investigates the birth and operation of individual cells, something common to all life. After exploring life from the macroscopic level, students finally zoom down to the microscopic mechanisms with a focus on DNA's role in cellular operations.

LIVING EARTH INSTRUCTIONAL SEGMENT 5: STRUCTURE, FUNCTION, AND GROWTH (FROM CELLS TO ORGANISMS)

Guiding Questions

- What happens if a cell in our body dies?
- How does the structure of DNA affect how cells look and behave?
- How do systems work in a multi-celled organism (emergent properties) and what happens if there is a change in the system?
- How do organisms survive even when there are changes in their environment?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS1-1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. *[Assessment Boundary: Assessment does not include identification of specific cell or tissue types, whole body systems, specific protein structures and functions, or the biochemistry of protein synthesis.]*

HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. [Clarification Statement: Emphasis is on functions at the organism system level such as nutrient uptake, water delivery, and organism movement in response to neural stimuli. An example of an interacting system could be an artery depending on the proper function of elastic tissue and smooth muscle to regulate and deliver the proper amount of blood within the circulatory system.] *[Assessment Boundary: Assessment does not include interactions and functions at the molecular or chemical reaction level.]*

HS-LS1-3. Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis..[Clarification Statement: Examples of investigations could include heart rate response to exercise, stomate response to moisture and temperature, and root development in response to water levels.] *[Assessment Boundary: Assessment does not include the cellular processes involved in the feedback mechanism.]*

HS-LS1-4. Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms. *[Assessment Boundary: Assessment does not include specific gene control mechanisms or rote memorization of the steps of mitosis.]*

**LIVING EARTH INSTRUCTIONAL SEGMENT 5:
STRUCTURE, FUNCTION, AND GROWTH (FROM CELLS TO ORGANISMS)**

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-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	LS1.A: Structure and Function LS1.B: Growth and Development of Organisms	[CCC-4] Systems and System Models [CCC-6] Structure and Function [CCC-7] Stability and Change

CA CCSS Math Connections: F-IF.7.a–e, F-BF.1a–c; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.11–12.1, 8; WHST.9–12.2.a–e, 7, 9

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

Before starting IS5, teachers should assess what students know about the characteristics of life. For example, working in small groups, students can sort pictures of living and nonliving things into two categories and **support an argument [SEP-7]** for where they put each item. Objects can include plants, insects, mammals, electronics, plastic toys, as well as unusual examples and outliers such as a sponge, rock, lichen, tunicates, snakeskins, molds, and/or a skeleton. Students come to a consensus as to what goes in each category and why. After presenting their thinking to the entire class and listening to the thinking of their classmates, students re-sort the items. Groups discuss the similarities and differences between the living organisms. Instructional segment 5 also builds on other key ideas in life science that students engaged in during the middle grades, including: models of cells and how they interact in multicellular organisms (MS-LS1-1, MS-LS1-2 and MS-LS1-3). Formative assessments at the beginning of the course will help teachers determine what level of detail they will need to revisit to help students succeed.

Human skin cells have a lifespan of only a few weeks before they die, but we do not really notice because the new ones look identical to the old ones. We see evidence for this skin loss as we scrape off dead skin. How do cells do this? Students can watch cells divide during a video and observe that the two cells at the end look identical. What is the mechanism for making such exact copies?

In the middle grades, students developed a model of how genes stored information about how to make proteins (MS-LS3-2), but that model did not include DNA or how DNA is encoded in genes. Their model did include the fact that genes record information about traits or phenotypes. Now, students must **explain [SEP-6]** the mechanism by which the structure of DNA determines the structure of proteins and how this process determines the overall structure and function of the cell or organism.

As George Beadle (a biologist in the early twentieth century) said, "One ought to be able to discover what genes do by making them defective." Students can start with the idea that DNA holds the information necessary for all phenotypes of the organism. Cells do not need all of this information at all times or in all cells (analogous to a library that holds lots of books arranged by subject, but only some of those books are checked out at certain times). But which parts of the DNA sequence contain the information for which phenotypes? Often, genes are mapped to phenotypes by looking at mutations. If a mutation alters the phenotype, then the section of DNA that mutated must be responsible for that phenotype.

Once students recognize a **cause and effect [CCC-2]** sequence between mutated genetic code in DNA and changes in phenotype, they are ready to examine the precise mechanism: How does a DNA sequence blueprint get translated into a phenotype? Students can use a codon table along with colored beads as a **physical model [SEP-2]** for protein synthesis. The lineup of the nucleotides on the DNA strand is the template for the order of the amino acids, which then determines which specific protein gets made based on its **structure [CCC-6]**. Students do not need to understand the details of the translation process, memorize a codon table, or map out metabolic pathways.

Historically, most of these connections were made by looking at mutants, and now students can observe this by looking at loss of function in strains of bacteria[3] or mutant strains of quick growing plants.[4] Mutation gene maps for model organisms are available and students can refer to these as they look at mutated phenotypes. Students can then gather **evidence [SEP-7]** to construct an **explanation [SEP-6]** for how a specific DNA sequence causes a specific loss of function, and can use this specific case to support the claim that there is a connection among DNA, the proteins cells produce, and the physical

---

3. It is possible to buy safe bacteria strains that are resistant to antibiotics from many biological supply companies and compare those strains to ones that are not resistant or to ones that grow in the presence of lactose and ones that cannot breakdown lactose and therefore change color.
4. A search on the Internet should provide links to companies that maintain normal and mutant seed stocks.

features of an organism (HS-LS1-1). Relating back to the discussion of mutations in IS4, students can **plan and carry out investigations [SEP-3]** to determine if mutants can grow in varying environments. Because students will need to refer back to their data to look at variations within populations and effects of environment on individuals within populations, teachers will need to introduce an organizational structure such as science note booking or student-created Web pages describing investigations with data stored in collaborative Web based spreadsheets.

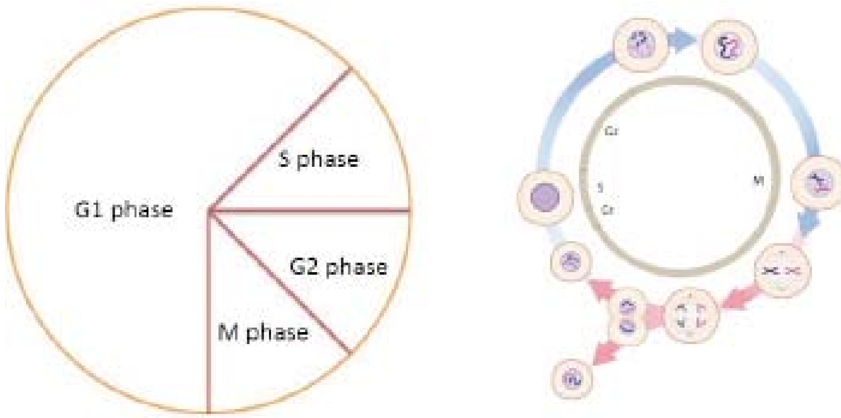
Mutations are technically tiny changes at the micro scale to DNA sequences, but how do these modifications affect the overall function of body systems at the **scale [CCC-3]** of an entire organism? While students constructed arguments that the body works as a set of interacting **systems [CCC-4]** in the middle grades (MS-LS1-3), now they are ready to understand some specific examples of interactions and the reason that these interactions are so important. Students can develop and use **models [SEP-2]** that show how a system works, then mutate part of it and observe the effects. A model that demonstrates how the movement of the diaphragm affects the pressure in the chest cavity allowing for our lungs to push out or take in air could either be pictorial (a labeled diagram showing interacting components of the respiratory system) or a physical model with tubes and plastic bags taped to a piece of cardboard to represent the lungs and diaphragm. If one lung is nonfunctional, what happens? Students should develop and use a model that explains not only how individual systems interact, but also how that interaction enables the functions of the entire organism (HS-LS1-2). While examples can come from any organism, this is a key opportunity within the CA NGSS to explore specific mechanisms within the human body.

One of the ways that cells work together in tissues, organs, and finally organ systems is to maintain **stability [CCC-7]** through homeostasis. Maintaining homeostasis means that despite changes in the environment an organism has the ability to maintain certain internal chemical and physical states. Students can measure their internal body temperature on a cold morning, a hot day, or after vigorous exercise. Even as the temperature outside spans as much as 40°C, a person’s internal temperature only varies by a few degrees. How does this happen and why does the body work so hard to maintain a constant temperature? The significance is in the functioning of proteins, especially when looking at enzymes, which must have stable environments to function correctly. Enzymes usually work in only a fairly narrow environmental range. For multicellular organisms, the first line of regulation is through their skin or outer layers (epithelium), which respond to stimuli in the environment. The brain then processes these stimuli and activates balancing feedback mechanisms to counteract the environmental change. When it is hot, mammals like humans sweat or pant, and when it is cold they shiver. Students can **plan and conduct investigations [SEP-3]** in which they change conditions for plants or animals and watch how they respond (HS-LS1-3). They can measure their own heart rate returning to normal after vigorous exercise, observe plants growing taller in the dark to reach new light sources, or observe the behavioral response of Planaria (flatworms) as the amount of light changes. Students do not need to explain the specific mechanisms that accomplish these changes (e.g., photosensitivity, hormone distribution, avoidance, etc.), but they should gather evidence that organisms respond to changes and use that evidence to construct a conceptual **model [SEP-2]** that can predict outcomes of future experiments that vary parameters from their initial trials.

One of the characteristics of life is the ability to grow (whether as a single cell or as a multi-cellular organism). In the 1860s, Rudolf Virchow proposed that new cells arose from pre-existing cells. As microscope technology advanced in the late 1800s, scientists were able to gather direct evidence supporting Virchow's claim. To go from a single cell (fertilized egg) to a multicellular organism, cells need to produce more cells. As unicellular organisms reproduce, they also make more cells. In both cases, information gets copied from the parent to the daughter cells. From IS4, students know that DNA records this information, but how do cells duplicate DNA?

Cells, just like organisms, have a life cycle referred to as the cell cycle (figure 7.9). The cell cycle is a conceptual model that describes the essential events in a cell's life. The assessment boundaries for HS-LS1-4 and HS-LS3-1 are clear that rote memorization of different stages of the cell cycle or mitosis is not the goal of the CA NGSS. One of the common consequences of differentiating between these stages is that students think of them as separate and independent events rather than a continuous evolution. Students should be able to describe the events and sequence of the cell-cycle model. They should be able to describe the stages that contribute to the overall goal of the process. In particular, students should ensure that their model includes the idea that organisms that reproduce sexually contain two sets of genetic material, one variation from each parent. Students should begin to ask questions about how these duplicate copies of DNA determine which traits offspring inherit from their parents (HS-LS3-1). Students must be able to use their model of the cell cycle to explain how organisms grow, how multi-cellular organisms copy the same genetic code but differentiate into different cell types, and how organisms replace dead cells with new ones (HS-LS1-4). Students can also apply their model to predict what happens when there are mistakes in this process. For example, what would happen if the stages of mitotic cell division do not occur in order (i.e., if cytokinesis occurs before mitosis)? Students can also use the model to explain cancer[5] and the effects of unchecked, out-of-control cell division on normal cell function.

Figure 7.9. Two Pictorial Models of the Stages of the Cell Cycle



Stages of the cell cycle. On the left, the size of the pie is proportional to the time spent in each phase. On the right, the icons visually depict what happens at each stage. *Source*: V. Vandergon; Genomics Education Programme 2014

Cell division is the first part in the growth of an organism and as new cells are formed in multicellular organisms, they differentiate into specific cell types. These specific cell types then participate in the formation of a tissue, which then forms organs that are often parts of a physiological system in multicellular organisms (this links back to IS1). Many multicellular organisms stop growing once they reach adulthood, but mitosis does not stop. Some cells die off as they reach the end of their life cycle and these dead cells need to be replaced. This replacement of dead cells occurs through mitosis of the remaining living cells. Extensions of this instructional segment might include discussions of stem cells that have not yet differentiated and have the ability to become a variety of types of cells, leading to new tissue and organ formation. Stem cells used in organ transplant provide a way for scientists to help decrease rejection of transplanted organs by the recipient of the donated organ. Stem cells can be used to generate signals for the recipient's body so that their immune system thinks that the organ belongs there.

This instructional segment culminates with students researching and **constructing an explanation [SEP-6]** about how different diseases cause a cascade effect in the

5. Resources are available to look at cancer rates and types. See Cancer Research Center http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link166 which has short YouTube videos as well as the latest on cancer research. Make sure to use reputable government supported research sites.

interdependent **systems [CCC-4]** of the human body (HS-LS1-2). Amyotrophic Lateral Sclerosis (ALS, also known as Lou Gehrig's disease) is a good example of a disease that results in multiple effects on the body systems, but there are many such diseases in humans (e.g., cystic fibrosis, muscular dystrophy). The cause of ALS is still uncertain and only about 5–10 percent of cases can be traced to genetic inheritance of a mutated gene. Most of the time there is a random event that causes a neurodegenerative progression of the nerve cells in the brain and the spinal cord so that the muscles in the human body do not receive messages and therefore begin to atrophy from disuse. As the muscles atrophy, other systems in the body are affected. For example, muscles in the respiratory system stop working and the individual with ALS has trouble breathing. Students should also obtain information about treatments and solutions that modern medicine has found for these diseases. In diseases where organs fail, teachers can highlight the importance of organ transplants and how donations of working organs and tissues from others can save lives.

Engineering Connection: Organ Donation

Students can learn about the role of engineering to meet critical medical needs to solve another problem in organ donation: matching suitable donors with patients. In addition to striking examples of engineering like magnetic resonance imaging (MRI) and robotic surgery, some engineers also develop important processes such as matching donors and patients by breaking down the problem into smaller, more manageable problems. Students can consider the different aspects of the problem of donor matching (e.g., awareness about the process by potential donors, rapid and reliable genetic testing, etc.) and brainstorm and evaluate possible solutions to them.

High School Three-Course Model Living Earth Snapshot 7.4: How Did We Eradicate Diseases in the US?

Anchoring phenomenon: Tuberculosis used to kill millions of people but it is no longer common.

Ms. H. introduced a historical case study about the different factors that go into eradicating diseases. Even though students may not remember it, most children admitted to school in California are tested for TB. Despite this common practice, it's likely that many students have never met anyone who had TB and may not even know that it stands for tuberculosis. So why all the fuss with TB tests? Ms. H told students that if she were teaching 200 years ago, the class would have lived in fear of this disease. During the nineteenth century, TB caused as many as 20 percent of the deaths in some years. Today, fewer than 250 people in all of California die of the disease in an average year (California Department of Public Health 2015). How did society accomplish this change?

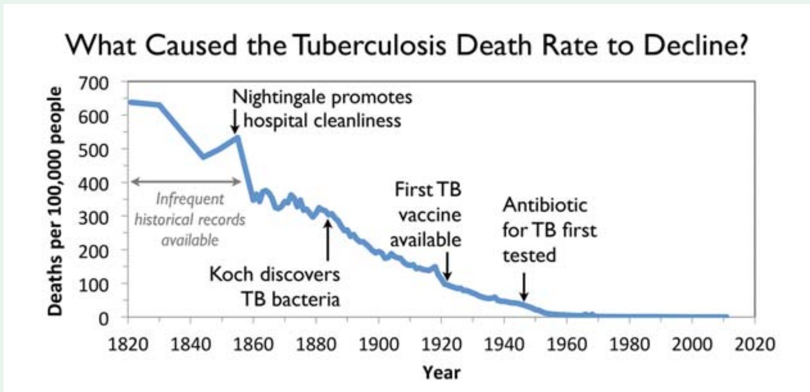
Ms. H divided the class into two groups that **obtain and evaluate information [SEP-8]** from different articles that introduce historical case studies of two major scientific innovations: (1) the origin of modern germ theory, including the discovery of tuberculosis bacteria by R. Koch in 1882; and (2) the application of science practices to randomized controlled drug trials, including the very first large-scale trial which tested an antibiotic to combat tuberculosis. Each group answered focus questions about the nature of science and core ideas about disease transmission. What effect did each of these innovations have on tuberculosis death rates?

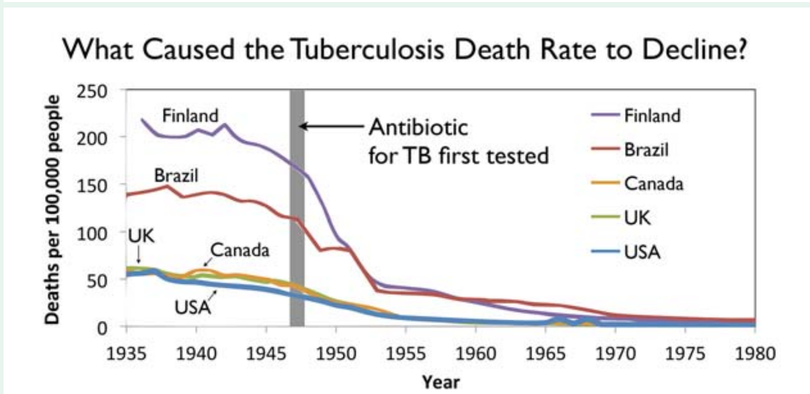
Investigative phenomenon: The death rate from tuberculosis dropped several times during the last 200 years.

Ms. H provided each group with a graph (figure 7.10) showing how death rates changed around the time of the events described in their article. Students **analyzed the graphs [SEP-4]**, identifying **trends [CCC-1]** and looking for evidence of possible **cause and effect relationships [CCC-2]** between events labeled on the graph and changes in the death rate. Students reorganized in jigsaw style—two students from the group that discussed Koch's investigation **communicated [SEP-8]** their findings to two students that discussed the antibiotic trial (and then they switched). Students had to present an **argument [SEP-7]** about whether or not their group's innovation led to a significant decline in TB-related death rates (using their group's graph as evidence). Students realized that there was evidence that both sets of innovations may have helped, but also that rapid declines in death rates seem to happen even before some of the major events.

High School Three-Course Model Living Earth Snapshot 7.4: How Did We Eradicate Diseases in the US?

Figure 7.10: Two Graphs of the Decline of Tuberculosis





Charts by M. d'Alessio with data from Antunes and Waldman 1999; United States Census Bureau 1975; Official Statistics of Finland 2010; Public Health England n.d.; Gallant, Ogunnaike-Cooke, and McGuire 2014; Wikipedia 2016

Ms. H wanted her high school students to move beyond the simple understanding of linear **cause and effect relationships [CCC-2]** from elementary school. According to the progression of CCCs in appendix 1 of this framework, high school students should recognize that changes in systems may have various causes that may not have equal effects. This is especially true when it comes to the health revolution that eradicated so many diseases like TB (Aiello, Larson, and Sedlak 2007). Innovations in medicine (drawn directly from scientific discoveries) influenced cultural norms for sanitation (such as hand washing) and led to changes in public policy and land use. These innovations occurred within the context of new technologies such as water filtration and sewage treatment that enhanced the standard of living in the United States and other western countries. Students watched a short video highlighting some of these key advances that dramatically increased life expectancy. Monitoring efforts, including the TB tests taken by most

High School Three-Course Model Living Earth Snapshot 7.4: How Did We Eradicate Diseases in the US?

California students, are part of this process. No individual factor is the singular cause of this health revolution. Ms. H led a whole-class discussion during which they generated a collaborative concept map representing society as a **system [CCC-4]** in which changes to different components result in the revolutionary overall system behavior where infectious disease no longer dominates our lives and deaths.

IS6 Living Earth Instructional Segment 6: Ecosystem Stability and the Response to Climate Change

In this instructional segment students will study the effects of natural and human-induced changes on ecosystems and the populations within them. In the middle grades, students learned that any change, either physical or biological, to an ecosystem can lead to a change in populations living in that ecosystem (MS-LS2-4). They now build on that knowledge to explore more complicated changes, many relating to shifts in global climate.

LIVING EARTH INSTRUCTIONAL SEGMENT 6: ECOSYSTEM STABILITY AND THE RESPONSE TO CLIMATE CHANGE

Guiding Questions

- What effects changes in ecosystems that ultimately effect populations?
- What are the changes that are happening in the climate and what effects are those having on life?
- How are human activities impacting Earth's systems and how does that affect life on Earth?
- What can humans do to mitigate their negative impact on the environment?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption or sea level rise.]

HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.* [Clarification Statement: Examples of human activities can include urbanization, building dams, and dissemination of invasive species.]