2018 Virginia Science Standards of Learning

Curriculum Framework

Board of Education

Commonwealth of Virginia

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The *2018 Virginia Science Standards of Learning Curriculum Framework* can be found on the Virginia Department of Education's website at http://www.doe.virginia.gov/testing/sol/standards_docs/science/index.shtml.

Introduction

The *2018 Virginia Science Standards of Learning Curriculum Framework* amplifies the *Science Standards of Learning for Virginia Public Schools* (SOL) and defines the content knowledge, skills, and understandings that provide a foundation in science concepts and practices. The framework provides additional guidance to school divisions and their teachers as they develop an instructional program appropriate for their students. It assists teachers as they plan their lessons by identifying enduring understandings and defining the essential science and engineering practices students need to master. This framework delineates in greater specificity the minimum content requirements that all teachers should teach and all students should learn.

School divisions should use the framework as a resource for developing sound curricular and instructional programs. This framework should not limit the scope of instructional programs. Additional knowledge and skills that can enrich instruction and enhance students' understanding of the content identified in the SOL should be included in quality learning experiences.

The framework serves as a guide for SOL assessment development. Assessment items may not and should not be a verbatim reflection of the information presented in the framework. Students are expected to continue to apply knowledge and skills from the SOL presented in previous grades as they build scientific expertise.

The Board of Education recognizes that school divisions will adopt a K–12 instructional sequence that best serves their students. The design of the SOL assessment program, however, requires that all Virginia school divisions prepare students to demonstrate achievement of the standards for elementary and middle school by the time they complete the grade levels tested. The high school end-of-course SOL tests, for which students may earn verified units of credit, are administered in a locally determined sequence.

Each topic in the framework is developed around the SOL. The format of the framework facilitates teacher planning by identifying the enduring understandings and the scientific and engineering practices that should be the focus of instruction for each standard. The categories of scientific and engineering practices appear across all grade levels and content areas. Those categories are: asking questions and defining problems; planning and carrying out investigations; interpreting, analyzing, and evaluating data; constructing and critiquing conclusions and explanations; developing and using models; and obtaining, evaluating, and communicating information. These science and engineering practices are embedded in instruction to support the development and application of science content.

Science and Engineering Practices

Science utilizes observation and experimentation along with existing scientific knowledge, mathematics, and engineering technologies to answer questions about the natural world. Engineering employs existing scientific knowledge, mathematics, and technology to create, design, and develop new devices, objects, or technology to meet the needs of society. By utilizing both scientific and engineering practices in the science classroom, students develop a deeper understanding and competence with techniques at the heart of each discipline.

Engineering Design Practices

Engineering design practices are similar to those used in an inquiry cycle; both use a system of problem solving and testing to come to a conclusion. However, unlike the inquiry cycle in which students ask a question and use the scientific method to answer it, in the engineering and design process, students use existing scientific knowledge to solve a problem. Both include research and experimentation; however, the engineering design process has a goal of a solving a societal problem and may have multiple solutions. More information on the engineering and design process can be found at https://www.eie.org/overview/engineering-design-process.

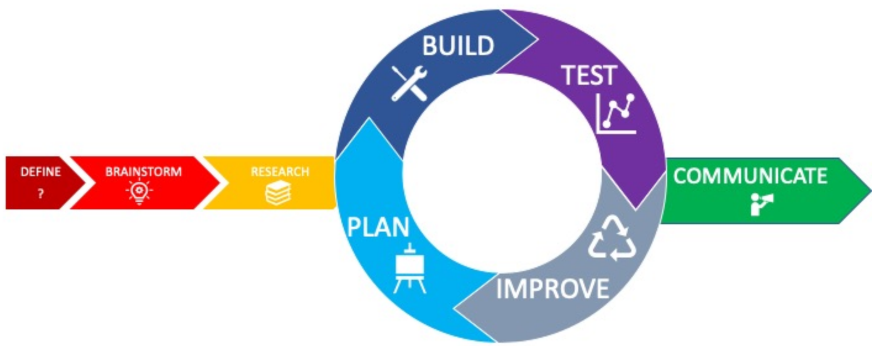

Figure 1: Engineering Design Process image based on the National Aeronautics and Space Administration (NASA) engineering design model.

The Engineering Design Process:

- Define: Define the problem, ask a question
- Imagine: Brainstorm possible solutions
- Research: Research the problem to determine the feasibility of possible solutions
- Plan: Plan a device/model to address the problem or answer the question
- Build: Build a device/model to address the problem or answer the question
- Test: Test the device/model in a series of trials
  - Does the design meet the criteria and constraints defined in the problem?
    - Yes? Go to Share (#8)
    - No? Go to Improve (#7)
- Improve: Using the results of the test, brainstorm improvements to the device/model; return to #3
- Share: Communicate your results to stakeholders and the public

Computational Thinking

The term *computational thinking* is used throughout this framework. Computational thinking is a way of solving problems that involves logically organizing and classifying data and using a series of steps (algorithms). Computational thinking is an integral part of Virginia's computer science standards and is explained as such in the *Computer Science Standards of Learning*:

> *Computational thinking is an approach to solving problems that can be implemented with a computer. It involves the use of concepts, such as abstraction, recursion, and iteration, to process and analyze data, and to create real and virtual artifacts. Computational thinking practices such as abstraction, modeling, and decomposition connect with computer science concepts such as algorithms, automation, and data visualization. [Computer Science Teachers Association & Association for Computing Machinery]*

Students engage in computational thinking in the science classroom when using both inquiry and the engineering design process. Computational thinking is used in laboratory experiences as students develop and follow procedures to conduct an investigation.

Structure of the *2018 Virginia Science Standards of Learning Curriculum Framework*

The framework is divided into two columns: Enduring Understandings and Essential Knowledge and Practices. The purpose of each column is explained below.

Enduring Understandings
The Enduring Understandings highlight the key concepts and the big ideas of science that are applicable to the standard. These key concepts and big ideas build as students advance in their scientific and engineering understanding. The bullets provide the context of those big ideas at that grade or content level.

Essential Knowledge and Practices
Each standard is expanded in the Essential Knowledge and Practices column. What each student should know and be able to do as evidence of understanding of the standard is identified here. This is not meant to be an exhaustive list nor is a list that limits what is taught in the classroom. It is meant to be the key knowledge and practices that define the standard. Science and engineering practices are highlighted with a leaf bullet (see footer).

The *2018 Virginia Science Standards of Learning Curriculum Framework* is informed by the Next Generation Science Standards (https://www.nextgenscience.org/).

Biology

The Biology standards are designed to provide students with a detailed understanding of living systems. Students investigate biochemical life processes, cellular organization, mechanisms of inheritance, dynamic relationships among organisms, and the changes in organisms through time. Skills necessary to examine scientific explanations, conduct experiments, analyze and communicate information, and gather and use information in scientific literature continues to be important. The importance of scientific research that validates or challenges ideas is emphasized at this level. Tools and technology, including calculators, computers, probes and sensors, and microscopes are used when feasible. Students will use chemicals and equipment safely. Mathematics, computational thinking, and experiences in the engineering design process are important as students advance in their scientific thinking.

Scientific and Engineering Practices

Engaging in the practices of science and engineering helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the many ways to investigate, model, and explain the world. These scientific and engineering practices include the use of scientific skills and processes to explore the content of science as outlined in the *Science Standards of Learning*. The engineering design practices are the application of science content to solve a problem or design an object, tool, process, or system. These scientific and engineering practices are critical to science instruction and are to be embedded throughout the year.

BIO.1 The student will demonstrate an understanding of scientific and engineering practices by

a) asking questions and defining problems

- **ask questions that arise from careful observation of phenomena and/or organisms, from examining models and theories, and/or to seek additional information**
- **determine which questions can be investigated within the scope of the school laboratory or field to determine relationships between independent and dependent variables**
- **generate hypotheses based on research and scientific principles**
- **make hypotheses that specify what happens to a dependent variable when an independent variable is manipulated**

b) planning and carrying out investigations
- **individually and collaboratively plan and conduct observational and experimental investigations**
- **plan and conduct investigations or test design solutions in a safe and ethical manner including considerations of environmental, social, and personal effects**
- **determine appropriate sample size and techniques**
- **select and use appropriate tools and technology to collect, record, analyze, and evaluate data**

c) interpreting, analyzing, and evaluating data
- **construct and interpret data tables showing independent and dependent variables, repeated trials, and means**
- **construct, analyze, and interpret graphical displays of data**
- **use data in building and revising models, supporting an explanation for phenomena, or testing solutions to problems**
- **analyze data using tools, technologies, and/or models to make valid and reliable scientific claims or determine an optimal design solution**

d) constructing and critiquing conclusions and explanations
- **make quantitative and/or qualitative claims regarding the relationship between dependent and independent variables**
- **construct and revise explanations based on valid and reliable evidence obtained from a variety of sources including students' own investigations, models, theories, simulations, and peer review**
- **apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and design solutions**
- **compare and evaluate competing arguments or design solutions in light of currently accepted explanations and new scientific evidence**
- **construct arguments or counterarguments based on data and evidence**
- **differentiate between a scientific hypothesis and theory**

e) developing and using models
- **evaluate the merits and limitations of models**
- **develop, revise, and/or use models based on evidence to illustrate or predict relationships**
- **develop and/or use models to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems**

f) obtaining, evaluating, and communicating information
- **compare, integrate, and evaluate sources of information presented in different media or formats to address a scientific question or solve a problem**

- **gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and credibility of each source**
- **communicate scientific and/or technical information about phenomena in multiple formats**

Biology Content

BIO.2 The student will investigate and understand that chemical and biochemical processes are essential for life. Key ideas include

a) water chemistry has an influence on life processes;
b) macromolecules have roles in maintaining life processes;
c) enzymes have a role in biochemical processes;
d) protein synthesis is the process of forming proteins which influences inheritance and evolution; and
e) the processes of photosynthesis and respiration include the capture, storage, transformation, and flow of energy.

Central Idea: Organisms are complex systems that require energy and materials to support biochemical processes that maintain metabolism.

Vertical Alignment: Students are introduced to the fundamental life processes in Life Science to include the transfer of energy through photosynthesis and cellular respiration, the flow of matter via the carbon, water, and nitrogen cycles, and the role of DNA in making proteins (LS.4, LS.5, LS.10). In Biology, these life processes are explored at greater depth as students explore the mechanics of each of these processes and the effects of the processes at the system level (cellular, organism, population, and ecosystem).

Enduring Understandings	**Essential Knowledge and Practices**
The structure of an object or living thing determines many of its properties and functions. ● Water has chemical and physical properties that facilitate metabolic activities in living cells. Water is a solvent and dissolves chemicals, minerals, and nutrients that are used to support life processes. The polarity of water molecules causes them to be strongly attracted to one another and gives	In order to meet this standard, it is expected that students will ● relate the chemical and physical properties of water that contribute to metabolism (BIO.2 a) ● recognize that living cells are composed of relatively few elements (BIO.2 b) ● differentiate the four major categories of macromolecules (lipids, carbohydrates, proteins, and nucleic acids) through their primary roles and functions (BIO.2 b)

rise to surface tension and cohesion. Water is also a thermal regulator in living systems (BIO.2 a). ● Carbon and other elements play a key role in determining the structure and function of macromolecules needed to sustain life processes. Life processes include growth and repair, reproduction, gas exchange, metabolism, and response (BIO.2 b). ● Cells make a variety of macromolecules needed for life processes from a relatively small set of monomers. These macromolecules include carbohydrates, proteins, nucleic acids, and lipids (BIO.2 b). ● Carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules (BIO.2 b). The structure of enzymes moderates their function in chemical reactions in living things. ● Enzymes are a group of proteins that function to moderate the rate of metabolic reaction by acting as catalysts (BIO.2 c). The structure of DNA serves as a code for the production of proteins through the process of protein synthesis. ● Proteins carry out the essential functions of life processes through systems of specialized cells (BIO.2 d). ● Protein synthesis is a biochemical process that uses information coded in DNA to construct proteins (BIO.2 d). Sustaining life processes requires substantial energy and matter inputs. The complex structural organization of organisms accommodates the capture, transformation, and elimination of the matter and energy needed to sustain life.	● describe the structure of enzymes and explain their role in acting as catalysts to control the rate of metabolic reactions (BIO.2 c) ● plan and conduct an investigation to determine the effect of an enzyme on a biochemical reaction and apply biological principles and evidence to explain the results (BIO.2 c) ● explain the process of protein synthesis, including transcription and translation (BIO.2 d) ● use a DNA or RNA codon chart to determine protein strands based on a segment of nucleic acid (BIO.2 d) ● explain how biological systems use energy and matter to maintain organization, to grow, and to reproduce (BIO.2 e) ● illustrate and explain the process in which photosynthesis transforms light energy into stored chemical energy (BIO.2 e) ● explain the interrelatedness of photosynthesis and cell respiration, including energy transfer (BIO.2 e) ● describe how the presence of oxygen affects the amount of energy available to an organism (BIO.2 e).

• As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. As a result of these complex chemical processes, energy is transferred from one system of interacting molecules to another (BIO.2 e). • The breakdown of nutrient molecules provides energy to the cell. This energy is stored in specific chemicals that are used to carry out the life functions of the cell (BIO.2 e). • Metabolism refers to all interactions among molecules within the well-ordered environment of the cell. Photosynthesis and cellular respiration are two important metabolic activities within living cells important in the transfer and transformation of energy for life processes. Energy transfer and transformation are subject to conservation laws (BIO.2 e). • Chloroplasts and mitochondria act as change agents within the cells of plants to make energy available for life processes (BIO.2 e). • Plant cells and many microorganisms use solar energy to combine molecules of carbon dioxide and water into complex, energy-rich organic compounds and release oxygen into the environment (BIO.2 e). • Chloroplasts convert radiant energy from sunlight into chemical energy with the help of the pigment chlorophyll. Chlorophyll aids in the energy transformation of sunlight (radiant energy) to chemical energy in sugar (BIO.2 e). • The sugar molecules produced from photosynthesis can be used immediately by plants and animals for energy, stored for later use, or rearranged into other compounds to carry out life processes (BIO.2 e).	

• Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, or to release energy. In most animals and plants, oxygen reacts with carbon-containing molecules (sugars) to provide energy (in the form of ATP) and produce carbon dioxide and water (BIO.2 e). • Cellular respiration is a chemical reaction in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that store energy in a useful form for use by living cells (BIO.2 e). *Students are not expected to know the complex multistep processes of photosynthesis and respiration.* • The energy released during cellular respiration comes from chemical bonds. When these bonds are broken, energy is released. Most of this energy is lost as thermal energy but some is captured in the bonds of small molecules of ATP. ATP bonds are broken each time energy is needed by the cell for life processes (BIO.2 e).	

BIO.3 The student will investigate and understand that cells have structure and function. Key ideas include

a) the cell theory is supported by evidence;
b) structures in unicellular and multicellular organisms work interdependently to carry out life processes;
c) cell structures and processes are involved in cell growth and division;
~~d)~~ the structure and function of the cell membrane support cell transport; and
e) specialization leads to the development of different types of cells.

Central Idea: All living things are composed of cells. Although there are many different types of cells in terms of size, structure, and function, all cells have certain characteristics in common. The cell theory encapsulates the current understanding of the cell. Both theories and laws describe natural phenomena and are equal in terms of scientific validity.

Vertical Alignment: Students are introduced to cell structure as a critical part of the system that allows for processes such as photosynthesis, cellular respiration, and asexual reproduction (mitosis) in Life Science (LS.2). In Biology, students learn of the role of cells in performing and maintaining life processes in both unicellular and multicellular organisms. The processes include, but are not limited to, mitosis and meiosis, protein synthesis, aerobic and anaerobic respiration, photosynthesis and cellular respiration, and cell transfer.

<table>
<tr><th>Enduring Understandings</th><th>Essential Knowledge and Practices</th></tr>
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The cell theory is a shared understanding that encapsulates our current understanding of the cell. The development of this theory illustrates the nature of science.
Advances in science and technology have added to our understanding of the cell. In addition to the original three tenets of the cell theory (which students learned about in Life Science), the current cell theory contains the following: metabolism occurs within cells, hereditary information (DNA) is passed from one cell to another, and all cells have the same basic composition (BIO.3 a). Students are not responsible for describing the contributions of specific scientists.
Organisms are complex, organized systems built on a hierarchical structure, with each level providing the matter and energy foundations for the next. This occurs from the chemical foundation of elements and atoms, to the cells and systems of individual organisms, to species and populations living and interacting in complex ecosystems.

Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level (BIO.3 b).
Cells and organisms have structures that perform specific functions that allow for the movement of matter and energy to maintain life processes (BIO.3 b).
Some organisms exist as a single cell, while others are composed of many cells, each specialized to perform distinct metabolic functions. A single-celled organism has to conduct all

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In order to meet this standard, it is expected that students will

provide examples to illustrate how additions to the original cell theory illustrate the nature of science (BIO.3 a)
differentiate among a scientific hypothesis, theory, and law (BIO.3 a)
compare how life processes are maintained within cells and within organisms (BIO.3 b)
explain how the organelles function individually and in a system to support life processes (BIO.3 b)
explain how the levels of cellular organization contribute to division of labor in multicellular organisms (BIO.3 b)
use an argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells (BIO.3 b)
plan and conduct an investigation to provide evidence that mechanisms maintain homeostasis within living things, such as heart rate response to exercise, stomate response to moisture and temperature, and root development in response to water levels (BIO.3 b)
model and describe the parts of cell cycle to include the processes involved in each stage of mitosis (BIO.3 c)
explain the importance of DNA replication in cell division (BIO.3 c)

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life processes by itself. A multicellular organism has groups of cells that specialize to perform specific functions (BIO.3 b). ● Cellular activities necessary for life include chemical reactions that facilitate energy acquisition, reproduction, and the maintenance of life processes (BIO.3 b). Reproduction is a life process by which living things transfer genetic information to their offspring. Reproduction (of cells and organisms) is essential to the existence of all living things. In multicellular organisms, cell division creates new cells for growth, development, and repair. ● A typical cell goes through a process of growth, development, and reproduction called the *cell cycle* (BIO.3 c). ● *Mitosis* refers to division of the nuclear material and produces two genetically identical cells. *Cytokinesis* is the division of the cytoplasm and organelles (BIO.3 c). ● During DNA replication, enzymes unwind and unzip the double helix and each strand serves as a template for building a new DNA molecule. Free nucleotides bond to the template (A-T and C-G), forming a complementary strand. The final products of replication are two identical DNA molecules (BIO.3 c). Living things must move materials into, out of, and within the cell. ● The life processes of a cell are maintained by the plasma membrane, which is comprised of a variety of organic molecules. The membrane controls the movement of material in and out of the cell, communication between cells, and the recognition of cells to facilitate multiple metabolic functions (BIO.3 d).	● describe how the composition of the cell membrane contributes to cell function (BIO.3 d) ● construct and use models and simulations to represent and explain how substances move across the cell membrane by osmosis, diffusion, facilitated diffusion, and active transport; evaluate the limitations of models used when appropriate (BIO.3 d) ● describe how the cell's surroundings influence the direction and type of cell transport (BIO.3 d) ● plan and conduct investigations related to how concentration affects the rate of diffusion across a semipermeable membrane, using proper sampling techniques, data collection, and analysis procedures (BIO.3 d) ● compare the energy needed to move substances across the cell membrane by osmosis, diffusion, facilitated diffusion, and active transport (BIO.3 d) ● describe the role of cell specialization (or lack thereof) in the life processes of unicellular and multicellular organisms (BIO.3 e) ● provide evidence to support the idea that a cell's *form fits its function* within a multicellular organism (BIO.3 e).

• Substances can move across the cell membrane passively (i.e., osmosis and diffusion) or actively (i.e., active transport) (BIO.3 d). • Two passive processes that allow for this exchange of materials are diffusion and osmosis. These processes require no energy on the part of the cell. Substances merely move toward equilibrium (from an area of high concentration to an area of low concentration) (BIO.3 d). • The processes of diffusion, osmosis, and facilitated diffusion require no energy (BIO.3 d). • Active transport requires energy. Endocytosis and exocytosis are examples of active transport (BIO.3 d). A key concept in science is that *form fits function*. In multicellular organisms, cells have specialized shapes that enable them to perform specific roles within the organism. • Organisms differ from one another in cell structure and chemistry. The diversity that exists ranges from simple prokaryotic cells to complex multicellular organisms (BIO.3 e). • Multicellular organisms possess different types of cells to carry out life processes. Each specialized cell type has a specific structure that helps it perform a specific function (BIO.3 e). • Organelles perform specific functions in the cell. Different types of cells have different numbers and types of organelles (BIO.3 e).	

BIO.4 The student will investigate and understand that bacteria and viruses have an effect on living systems. Key ideas include

a) viruses depend on a host for metabolic processes;
b) the modes of reproduction/replication can be compared;
c) the structures and functions can be compared;
d) bacteria and viruses have a role in other organisms and the environment; and
e) the germ theory of infectious disease is supported by evidence.

Central Idea: Bacteria have diverse structures and metabolic functions and affect other organisms and the environment. Viruses have similarities to living organisms but are not living, even though they affect host organisms.

Vertical Alignment: Students have studied the classification of organisms and general characteristics of each of the domains and kingdoms in Life Science (LS.3); however, Biology is the first time students will take an in-depth look at both bacteria and viruses.

Enduring Understandings	Essential Knowledge and Practices
Viruses can dramatically affect living things. The influenza, West Nile, and Ebola viruses have killed millions of people. Plants, too, can be infected by viruses. By studying viruses, scientists can develop vaccines and antiviral medicines to reduce their lethality. ● Viruses are small, infectious agents that replicate only inside the living cells of organisms. Because viruses transmit DNA or RNA into the host cell, they can introduce genetic variation into the hosts. Viruses that infect bacteria may give an organism a selective advantage and enable it to fight off an infection (BIO.4 a). ● Viruses do not share many of the characteristics of living organisms. Viruses are not cells. Basic viral structure consists of a nucleic acid core surrounded by a protein coat.	In order to meet this standard, it is expected that students will ● explain in simple terms how viruses infect host organisms (BIO.4 a) ● use evidence to support the description of bacteria as living and viruses as nonliving (BIO.4 a) ● compare a virus and a bacterium in relation to genetic material and reproduction (BIO.4 b, c) ● examine effects of bacteria and viruses on human health (BIO.4 d) ● provide an evidence-based explanation that connects the germ theory to the nature of science, such as describing the effects of Pasteur's and Koch's experiments on the understanding of disease transmission (BIO.4 e)

Viruses can reproduce only inside a living cell, the host cell (BIO.4 a). ● Viruses reproduce through the lytic cycle. The lysogenic cycle results in delayed viral reproduction but eventually concludes with the lytic cycle (BIO.4 b). ● Virus structure consists of a nucleic acid (single or double-stranded RNA or DNA) and a protein coat (capsid) which serves as a protective covering (BIO.4 c). ● Viruses are important microbial predators that influence global biochemical cycles and drive microbial evolution (BIO.4 d). Bacteria play important roles in the global ecosystem, including a lead role in the cycling of nutrients (BIO.4 d). ● Bacteria reproduce sexually (conjugation) and asexually (budding and binary fission). Sexual reproduction in bacteria is rare (BIO.4 b). *Students are not expected to know other types of sexual reproduction in bacteria or the mechanisms of either sexual or asexual reproduction in bacteria.* ● Bacteria can also be classified according to how they obtain energy for cellular respiration or fermentation. Bacteria may be heterotrophs, photoautotrophs, or chemoautotrophs (BIO.4 c). The germ theory is a shared understanding that encapsulates our current understanding of disease transmission. The development of this theory illustrates the nature of science. ● Throughout history, people have created explanations for disease. The introduction of the germ theory led to the understanding that many diseases are caused by	● describe how germ theory exemplifies the nature of science as supported by evidence (BIO.4 e) ● use evidence from scientific literature and research to support a claim on the use or misuse of vaccines or antibiotics (BIO.4 e).

microorganisms. Changes in health practices have resulted from the acceptance of the germ theory of disease (BIO.4 e). ● Modern health practices emphasize sanitation, the safe handling of food and water, aseptic techniques to keep germs out of the body, and the development of vaccinations and other chemicals and processes to destroy microorganisms (BIO.4 e). ● Vaccines and antibiotics are used to prevent or cure diseases. Vaccines are used to prevent diseases by exposing hosts to a dead or weakened forms of a virus. The body's immune system builds an immune response that will be employed with future exposure to the same virus. Antibiotics are used to cure a bacterial disease by killing the bacterium (BIO.4 e).	

BIO.5 The student will investigate and understand that there are common mechanisms for inheritance. Key ideas include

a) DNA has structure and is the foundation for protein synthesis;
b) the structural model of DNA has developed over time;
c) the variety of traits in an organism are the result of the expression of various combinations of alleles;
d) meiosis has a role in genetic variation between generations; and
e) synthetic biology has biological and ethical implications.

Central Idea: Traits of living things are influenced by genetic makeup and can be predicted using genetic information. Genetic information can be determined and altered through synthetic means.

Vertical Alignment: Students begin their study on the mechanisms for heredity in Life Science through an introduction to the process of meiosis (LS.10). Although this process is introduced, the steps involved in meiosis are outside the scope of Life Science. Students predict the probability of a trait being expressed with monohybrid crosses. Terminology is introduced in Life Science to include: *homozygous*, *heterozygous*, *dominant*, *recessive*, *gametes*, *genotype*, and *phenotype* (LS.10).

Enduring Understandings	**Essential Knowledge and Practices**
The structure and function of DNA are intimately linked.	In order to meet this standard, it is expected that students will

• Scientists use 2-D, 3-D, and virtual models to represent the structure of DNA. Models are used when the object is too small or too complex to be studied directly (BIO.5 a). • DNA is a helical macromolecule consisting of nucleotides. Each nucleotide is identified by the base it contains: adenine (A), guanine (G), cytosine (C) or thymine (T) (BIO.5 a). • Nucleotides are connected by covalently bonded sugar and phosphate molecules (BIO.5 a). • The information encoded in DNA molecules provides instructions for assembling amino acids, which ultimately form protein molecules. The code for specific amino acids is virtually the same for all life forms (BIO.5 a). • Modern advances (since 1990) in science and technology have added to our understanding of the structure of DNA and its function (e.g., Sanger technique, Human Genome Project, sequencing chromosomes) (BIO.5 b). *Students are not responsible for describing the contributions of specific scientists.* A complex system functions to pass characteristics (traits) from one generation to the next. The interaction of heredity mechanisms and the environment creates both stability from one generation to the next and drives change that produces the diversity of life on our planet. • All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins (BIO.5 a). • Organisms transfer their genetic information to their offspring when they reproduce (BIO.5 c).	• compare a variety of DNA models and evaluate them for their effectiveness in explaining its structure and function (BIO.5 a) • provide examples to illustrate how modern advances related to DNA structure and function illustrate the nature of science (BIO.5 b) • relate the expression of a phenotype to a given genotype (BIO.5 c) • use a Punnett square to predict all possible combinations of gametes and the likelihood that a given combination will occur in monohybrid and dihybrid crosses (BIO.5 c) • predict possible genotypes and phenotypes of non-Mendelian traits (BIO.5 c) • identify sources of genetic diversity and explain how it can be an advantage for populations (BIO.5 c) • apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population (BIO.5 c) • describe in general terms the stages of meiosis and explain the processes occurring at each stage; differentiate these from the end products of mitosis (BIO.5 d) • explain why meiosis is important for sexual reproduction (BIO.5 d) • compare the process of mitosis and meiosis and determine which conditions are necessary for each process to occur (BIO.5 d) • make and defend a claim based on evidence from scientific literature that inheritable genetic variations may result from o new genetic combinations through meiosis o viable errors occurring during replication

- Sexual reproduction involves the production of sex cells (gametes). Sex cells each carry half the parent's genetic material (on chromosomes) (BIO.5 c). - In sexual reproduction, each parent contributes half of the genetic information acquired by the offspring, resulting in variation between parent and offspring (BIO.5 c). - Genes and chromosomes are present in pairs (e.g., allele B or b) in individuals (for diploid organisms). All genes assort independent of other genes during sex cell production in meiosis. The probability of a sex cell containing either allele from the pair is 50 percent (BIO.5 c). - Asexual reproduction produces offspring which are genetically identical to the parent (mitosis) (BIO.5 c). - Genetically diverse populations are more likely to survive changing environments. Recombination and mutation provide for genetic diversity. Some new gene combinations have little effect, some can produce organisms that are better suited to their environments, and others can be deleterious (BIO.5 c). - Each chromosome consists of a single, very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet-known function (BIO.5 c).	o environmental factors (BIO.5 c, d) - evaluate and use credible, accurate, and unbiased resources to gather and summarize scientific and technical information about how genetic engineering tools and technologies can be used to alter the genome of an organism (BIO.5 e) - debate the pros and cons of synthetic biology (BIO.5 e) - evaluate data from databases or experimentation to support an argument for the transmission of traits across generations (BIO.5 e).

● Mendel's laws of heredity are based on his mathematical analysis of observations of patterns of inheritance of dominant-recessive traits (BIO.5 c). ● Geneticists apply mathematical principles of probability to Mendel's laws of heredity to predict the results of simple genetic crosses. The laws of probability govern simple genetic recombinations (BIO.5 c). ● A Punnett square is a mathematical model that shows the probability of certain genetic combinations in offspring (BIO.5 c). ● Genotype describes the genetic make-up of an organism and phenotype describes the organism's appearance based on its genes. Phenotype describes the observable physical or biochemical characteristics of the organism (BIO.5 c). ● Variations of dominant-recessive expression of alleles include incomplete dominance and co-dominance (BIO.5 c). *Students are not responsible for describing sex-linked and polygenic inheritance.* In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization. ● Meiosis refers to division of the nuclear material. Cytokinesis is the division of the cytoplasm and organelles (BIO.5 d). *Students are not responsible for identifying the stages of meiosis.* ● Many organisms combine genetic information from two parents to produce offspring. Sex cells (gametes) are produced through meiosis. This allows sexually reproducing organisms to produce genetically differing	

offspring and maintain their number of chromosomes (BIO.5 c). Science and technology are tightly linked. Technologies have improved our understanding of DNA, its function, and how its code can be manipulated for a variety of purposes. ● Genetic engineering techniques are used in a variety of industries, in agriculture, in basic research, and in medicine. There is great benefit in terms of useful products derived through genetic engineering (e.g., human growth hormone, insulin, and pest- and disease-resistant fruits and vegetables) (BIO.5 e). ● Synthetic biology combines many different science disciplines to design and build new biological parts, devices, and systems. Synthetic biology has many different applications (BIO.5 e). ● Tools and techniques are used in genetic engineering, such as polymerase chain reaction, restriction enzymes, gel electrophoresis, DNA ligase, bacterial plasmids, and CRISPR have improved our ability to genetically alter the DNA or organisms for a specific purpose. Synthetic biology employs different tools, depending on the desired product (BIO.5 e).	

BIO.6 The student will investigate and understand that modern classification systems can be used as organizational tools for scientists in the study of organisms. Key ideas include

a) organisms have structural and biochemical similarities and differences;
b) fossil record interpretation can be used to classify organisms;
c) developmental stages in different organisms can be used to classify organisms;
d) Archaea, Bacteria, and Eukarya are domains based on characteristics of organisms;

e) **the functions and processes of protists, fungi, plants, and animals allow for comparisons and differentiation within the Eukarya kingdoms; and**
f) **systems of classification are adaptable to new scientific discoveries.**

Central Idea: Taxonomic classification is a hierarchal system for classifying organisms. Organisms are classified based on physiological structures, embryology and ontogeny, and phylogenetic relationships. Evidence shows how species can change over time. Species are related to varying degrees, which can be determined through evolutionary relationships.

Vertical Alignment: Students are introduced to the concept of classification in elementary science and the concept is expanded in Life Science. Students learn characteristics of the domains and kingdoms and use this knowledge to classify organisms. Students are also introduced to the major phyla of the plant and animal kingdoms (LS.3). In Biology, students will build on their classification and taxonomy knowledge as they compare organisms using biochemical, cellular, and embryologic properties and fossil evidence.

Enduring Understandings	**Essential Knowledge and Processes**
Classification relies on careful observation of patterns of similarities and differences. Classification is useful in explaining relationships and organizing objects or processes into groups. ● Organisms that live on Earth today, or once lived on Earth, are classified into a hierarchy of groups and subgroups based on similarities of physiological structures, embryology and ontogeny (development), and phylogenetic (evolutionary) relationships (BIO.6 f). ● The organisms that live on Earth today share many physiologic structures and metabolic processes, including cellular organization; common molecular mechanisms for energy transformation, utilization, and maintenance of life processes; common genetic code; and mechanisms for the transmission of traits from one generation to the next (BIO.6 a, b, c). ● Evolutionary relationships can be represented using a branching diagram called a *cladogram* or *phylogenetic tree,* on which they	In order to meet this standard, it is expected that students will ● arrange organisms in a hierarchy according to similarities and differences in structural and biochemical characteristics (BIO.6 a) ● recognize scientific names as part of a binomial nomenclature (BIO.6 a) ● compare structural characteristics of an extinct organism, as evidenced by its fossil record, with present, familiar organisms (BIO.6 b) ● analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth (under the assumption that natural laws operate today as in the past) (BIO.6 b)

are organized by shared, derived characteristics (BIO.6 a, b, c, f). ● Biological classification (*taxonomy*) uses a systematic method to name, organize, and show how organisms are related (BIO.6 d, e, f). ● Binomial nomenclature is a standard way of identifying a species with a scientific two-word name. The first word is the genus name and the second is the species name. Species is the basic unit of classification (BIO.6 f). ● Similarities among organisms on the structural and metabolic levels are reflected in the large degree of similarity in proteins and nucleic acids of different organisms. Diversity is the product of variations in these molecules (BIO.6 a). ● Information about relationships among living organisms and those that inhabited Earth in the past is gained by examining and interpreting the fossil record. Fossils provide a time-ordered record of the unique characteristics of organisms over millions of years. Data from fossils can be used to infer phylogenetic relationships among existing and extinct organisms (BIO.6 b). A cladogram is a model (diagram) used to show relationships among organisms. A cladogram uses lines that branch off in different directions, ending at a group of organisms with a common ancestor (*clade*) (BIO.6 b). ● Embryology is the study of an organism's embryological development and may reveal that there are features present in early stages that that are absent in the adult form of the organism (BIO.6 c).	● interpret a cladogram or phylogenetic tree to make inferences about the evolutionary relationships among organisms (BIO.6 b) ● recognize similarities in embryonic stages in diverse organisms in the animal kingdom, from zygote through embryo, and infer relationships (BIO.6 c) ● apply classification criteria to categorize examples of organisms as representatives of the three domains: Archaea, Bacteria, and Eukarya (BIO.6 d) ● apply classification criteria to categorize examples of organisms as representatives of the six kingdoms: archaebacteria, eubacteria, protista, fungi, plantae, and animalia (BIO.6 e) ● recognize new attributes (physical and chemical) that affect the taxonomic group into which an organism is (or was) placed (BIO.6 f).

● Information about the physical features and activities of living things are organized into a hierarchy of increasing specificity (BIO.6). ● Characteristics used to classify organisms into domains include, but are not limited to, whether the organism is prokaryotic vs. eukaryotic, differences in sequences of nucleic acids (RNA), and the cell membrane and/or cell wall structure (BIO.6 d). Characteristics used to group organisms into kingdoms include, but are not limited to, prokaryote vs. eukaryote, unicellular vs. multicellular, cell wall vs. no cell wall, level of organization of cells into tissues, autotroph vs. heterotroph, and within heterotrophs, decomposer vs. ingestion (BIO.6 e). ● Protists are simple, predominately unicellular, eukaryotic organisms (BIO.6 e). ● Fungi are unicellular or multicellular, eukaryotic organisms. The cells of fungi have cell walls but are not organized into tissues. They are heterotrophs and obtain nutrients through absorption (BIO.6 e). ● Plants are multicellular, eukaryotic organisms. The cells of plants have cell walls and are organized into tissues. Plants are autotrophs and obtain nutrients through photosynthesis and absorption. Plant divisions include mosses, ferns, conifers, and flowering plants (BIO.6 e). ● Animals are multicellular, eukaryotic organisms. The cells of animals do not have a cell wall. Animals are heterotrophs and are mobile for at least a part of their life cycles (BIO.6 e).	

BIO.7 The student will investigate and understand that populations change through time. Key ideas include
- **a) evidence is found in fossil records and through DNA analysis;**
- **b) genetic variation, reproductive strategies, and environmental pressures affect the survival of populations;**
- **c) natural selection is a mechanism that leads to adaptations and may lead to the emergence of new species; and**
- **d) biological evolution has scientific evidence and explanations.**

Central Idea: Similarities and differences in inherited characteristics of organisms alive today or in the past can be used to infer the relatedness of any two species, changes in species over time, and lines of evolutionary descent. Speciation, extinction, and changes in population genetics result from evolution.

Vertical Alignment: Students learn about change over time as it relates to mutations that may lead to adaptations within a population in Life Science. Natural selection, leading to the evolution of a population, is evidenced through fossil records, genetic information, and anatomical comparisons (LS.11).

Enduring Understandings	**Essential Knowledge and Skills**
Genetic variation, reproductive strategies, and environmental pressures affect the survival of populations ● A fossil is any evidence of an organism that lived long ago. Scientists have used the fossil record to construct a history of life on Earth. Although there is not a complete record of ancient life for the past 3.5 billion years, a great deal of modern knowledge about the history of life comes from the fossil record (BIO.7 a). ● Having similar DNA is a strong indicator that organisms share a common ancestor. Identifying DNA sequences through comparative genomics has helped to identify and better understand similarities in DNA sequences across species (BIO.7 a). ● Variations within a population for a given trait can arise through mutations, gene flow, and sexual reproduction.	In order to meet this standard, it is expected that students will ● determine the relative age of a fossil, given information about its position in the rock and absolute dating by radioactive decay (BIO.7 a) ● differentiate between relative and absolute dating based on fossils in biological evolution (BIO.7 a) ● explain how advancements in our understanding of DNA and its function contribute to the understanding that species change over time (BIO.7 a) ● provide evidence to support the argument that variations for a given trait within a population may be helpful or harmful to the survival of a population when environmental pressures arise (BIO.7 b)

Mutations are changes in the sequence of DNA nitrogenous bases. The accumulation of mutations within a population over time can result in changes to the gene pool. The movement of genes from one population to another also provides greater genetic variation. The genetic shuffling that takes place during meiosis and sexual reproduction introduces new gene combinations within a population (BIO.7 b). ● Organisms possess reproductive strategies and rates that maximize the probability that their offspring, and thus the population, can survive (BIO.7 b). ● Populations produce more offspring than the environment can support. Organisms with certain genetic variations will be favored to survive and pass their variations on to the next generation (BIO.7 b). ● Variations within populations sometimes arise abruptly in response to strong environmental selective pressures (BIO.7 b). Natural selection is a mechanism that leads to adaptations and may lead to the emergence of new species. ● Natural selection occurs only if there is both variation in the genetic information among organisms in a population and variation in the expression of that genetic information that leads to differences in performance among individuals (BIO.7 c). ● The unequal ability of individuals to survive and reproduce leads to the gradual change in a population, generation after generation, over many generations (BIO.7 b).	● discuss sources of genetic variation within a population (BIO.7 b) ● describe the effect of reproductive strategies and rates on a population's survival (BIO.7 b) ● predict the effects of environmental pressures on populations (BIO.7 b) ● explain how natural selection leads to changes in gene frequency in a population over time (BIO.7 c) ● compare punctuated equilibrium with gradual change over time (BIO.7 d) ● construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships (BIO.7 d) ● explain how advancements in genetic technology contribute to the understanding that species change over time (BIO.7 a) ● construct an explanation based on evidence that the process of evolution primarily results from o the potential for a species to increase in number o the heritable genetic variation of individuals in a species due to mutation and sexual reproduction o competition for limited resources o the proliferation of those organisms that are better able to survive and reproduce in the environment (BIO.7 a, b, c, d) ● evaluate evidence supporting the claim that changes in environmental conditions may result in an increased number

● Traits that positively affect survival are more likely to be reproduced and are more common in the population (BIO.7 c). ● Natural selection leads a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment (BIO.7 c). ● Depending on the selective pressure, these changes can be rapid over few generations (i.e., antibiotic resistance) or may take millions of years to develop (BIO.7 d). ● Speciation, the emergence of new species, occurs when a lineage has split into groups that can no longer naturally interbreed and produce fertile offspring and/or are no longer genetically aligned (BIO.7 d). ● If a population is not able to respond to environmental pressures, it may become extinct (BIO.7 c). Biological evolution is supported by scientific evidence from many disciplines. ● Natural selection may lead to the permanent change in the frequency of a gene in a given population. This is called *biological evolution* (BIO.7 c). ● Biological evolution is supported by scientific evidence from many disciplines such as, but not limited to, paleontology, geology, embryology, anatomy, biology, genetics, and biochemistry (BIO.7 d).	of some species, the emergence of new species over time, and/or the extinction of other species (BIO.7 b, c, d).

BIO.8 The student will investigate and understand that there are dynamic equilibria within populations, communities, and ecosystems. Key ideas include

a) interactions within and among populations include carrying capacities, limiting factors, and growth curves;
b) nutrients cycle with energy flow through ecosystems;
c) ecosystems have succession patterns; and
d) natural events and human activities influence local and global ecosystems and may affect the flora and fauna of Virginia.

Central Idea: Organisms are part of living systems and demonstrate interdependence with other organisms and the environment.

Vertical Alignment: Students study both the biotic and abiotic factors that affect an ecosystem, to include the movement of matter and energy through the ecosystem (including both biochemical cycles and organism interactions) in Life Science. Interactions of organisms, populations, communities, and ecosystems are emphasized, including human interactions and the impact of these interactions on ecosystem dynamics (LS.8, LS.9).

Enduring Understandings	**Essential Knowledge and Practices**
All biological systems from cells and organisms to populations, communities, and ecosystems are affected by complex biotic and abiotic interactions involving exchange in matter and energy. ● *Carrying capacity* is the number of organisms that can be supported by the resources in an ecosystem (BIO.8 a). ● Ecosystems have carrying capacities, which refer to the limits to the numbers of organisms and populations ecosystems can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem (BIO.8 a).	In order to meet this standard, it is expected that students will ● use mathematical representations such as charts, graphs, histograms, and population change data, to support explanations of factors that affect carrying capacity of ecosystems (BIO.8 a) ● make predictions about changes that could occur in population numbers as the result of population interactions (BIO.8 a) ● graph and interpret a population growth curve and identify the carrying capacity of the populations (BIO.8 a) ● interpret how the flow of energy occurs between trophic levels in all ecosystems in a o food chain o food web o pyramid of energy o pyramid of biomass (BIO.8 b)

● Populations are groups of interbreeding individuals that live in the same place at the same time and compete for food, water, shelter, and mates (BIO.8 a). ● Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives (BIO.8 a). ● As any population of organisms grows, it is held in check by interactions among a variety of biotic and abiotic factors (BIO.8 a). ● Abiotic factors are the nonliving elements in an ecosystem, such as temperature, moisture, air, salinity, and pH. Biotic factors are all the living organisms that inhabit the environment, including predators, food sources, and competitors (BIO.8 a). ● Communities are composed of populations of organisms that interact in complex ways. Members of a population interact with other populations in a community. These organisms compete to obtain the matter and energy they need for basic resources, mates, and territory. They also cooperate to meet basic needs and carry out life processes (BIO.8 a). ● Population growth curves exhibit many characteristics, such as initial growth stage, exponential growth, steady state, decline, and extinction. Limiting factors are the components of the environment that restrict the growth of populations (BIO.8 a). Systems are dynamic and change in response to inputs and outflows of energy and matter. A healthy ecosystem has a state of dynamic equilibrium, when the inflow and outflow of energy and matter is	● develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere (BIO.8 b) ● evaluate 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 BIO.8 c) ● recognize and understand the cause-and-effect relationship between changes in the abiotic and biotic conditions in an ecosystem and succession (BIO.8 c) ● describe the patterns of succession found in aquatic and terrestrial ecosystems of Virginia (BIO.8 c) ● identify factors leading to primary and secondary succession (BIO.8 c) ● describe the characteristics of a climax community (BIO.8 c) ● provide examples to illustrate and explain how habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change can disrupt an ecosystem and threaten the survival of species (BIO.8 d) ● design, evaluate, and refine a solution for reducing the negative effects of human activity on a Virginia watershed or ecosystem (BIO.8 d).

steady. When one of the variables is out of balance, the health of the ecosystem changes. • Ecosystems demonstrate an exchange of energy and nutrients among inhabiting organisms (BIO.8 b). • An ecosystem consists of all the interacting species and the abiotic environment in a given geographic area. All matter, including essential nutrients, cycle through an ecosystem. The most common examples of such matter and nutrients include carbon, nitrogen, and water (BIO.8 b). • Photosynthesis and cellular respiration are important components for the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes (BIO.8 b). • The main components of the nitrogen cycle include nitrogen fixation, nitrification, assimilation, ammonification, and de-nitrification (BIO.8 b). • The main components of the carbon cycle include photosynthesis, respiration, combustion, and decomposition (BIO.8 b). Ecological succession is the process by which the structure of a biological community evolves over time. • Ecological succession is a predictable change in the sequence of species that establish in an area over time (BIO.8 c). • A *climax community* occurs when succession slows and a stable community is established. The climax community in most of Virginia is a deciduous oak-hickory (hardwood) forest (BIO.8 c).	

Human and natural activities affect ecosystems on local, regional, and global scales. ● As the human population increases, so does the human impact on the environment. Human activities, such as reducing the amount of forest cover, increasing the amount and variety of chemicals released into the environment, and intensive farming, have changed Earth’s land, oceans, and atmosphere. Some of these changes have decreased the capacity of the environment to support some life forms (BIO.8 d). ● Large-scale changes that influence ecosystems include the addition of excess nutrients to the system (eutrophication), which alters environmental balance; dramatic changes in climate; and catastrophic events, such as fire, drought, flood, and earthquakes (BIO.8 d).	