High School Conceptual Progressions Model Course II – Bundle 5
Inheritance of Genetic Variation

This is the fifth bundle of the High School Conceptual Progressions Model Course II. Each bundle has connections to the other bundles in the course, as shown in the Course Flowchart.

Bundle 5 Question: This bundle is assembled to address the question "how can individuals of the same species have different characteristics?"

Summary

The bundle organizes performance expectations around helping students understand the role of DNA in living systems. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards, but recognize that instruction is not limited to the practices and concepts directly linked with any of the bundle performance expectations.

Connections between bundle DCIs

Systems of specialized cells within organisms help them perform the essential functions of life (LS1.A as in HS-LS1-1). These systems and their functions are controlled by the genetic information within all cells that forms DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells (LS1.A and HS-LS1-1 and HS-LS3-1). These ideas connect to the concepts that all cells in an organism have the same genetic content, but the genes expressed by the cell may be regulated in different ways, and that 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 (LS3.A as in HS-LS3-1).

The idea that there is variation and distribution of traits that depends on both genetic and environmental factors (LS3.B as in HS-LS3-2 and HS-LS3-3) connects to the idea although DNA replication is tightly regulated and remarkable accurate, errors do occur and result in mutations, which are also a source of variation. It also connects to the idea that environmental factors can cause mutations in genes (LS3.B as in HS-LS3-2) and hence affect the probability of occurrences of traits in a population (LS3.B as in HS-LS3-2 and HS-LS3-3).

Bundle Science and Engineering Practices

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of asking questions (HS-LS3-1), analyzing and interpreting data (HS-LS3-3), constructing explanations (HS-LS1-1), and engaging in argument (HS-LS3-2). Many other practice elements can be used in instruction.

Bundle Crosscutting Concepts

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the crosscutting concepts of Cause and Effect (HS-LS3-1 and HS-LS3-2), Scale, Proportion, and Quantity (HS-LS3-3), and Structure and Function (HS-LS1-1). Many other crosscutting concept elements can be used in instruction.

All instruction should be three-dimensional.

Performance Expectations	**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-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.]
Example Phenomena	The DNA code only has four letters. DNA sequencing can be done from any part of a plant, even though the different parts all look very different.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information. Students could *ask questions that arise from careful observation to clarify* [how] ***genetic and environmental factors both affect expression of traits***. HS-LS3-2 and HS-LS3-3 **Developing and Using Models** • Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or design criteria. Students could *evaluate merits and limitations of two different models* [of how] ***genetic and environmental factors both affect expression of traits, and hence affect the probability of occurrences of traits in a population*** *in order to select a model that best fits the evidence*. HS-LS3-2 and HS-LS3-3 **Planning and Carrying Out Investigations** • Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of supporting explanations for phenomena. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. Students could *plan an investigation to produce data to serve as the basis for evidence* [for how] ***genetic and environmental factors both affect expression of traits***. HS-LS3-2 and HS-LS3-3

Additional Practices Building to the PEs (Continued)	**Analyzing and Interpreting Data** • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Students could *analyze data using mathematical models in order to make valid and reliable scientific claims* [about how] ***genetic and environmental factors both affect the probability of occurrences of traits in a population***. HS-LS3-2 and HS-LS3-3 **Using Mathematical and Computational Thinking** • Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. Students could *use computational representations of phenomena to describe* [that] ***each chromosome consists of a single very long DNA molecule, each gene on the chromosome is a particular segment of that DNA, and the instructions for forming species' characteristics are carried in DNA***. HS-LS3-1 **Constructing Explanations and Designing Solutions** • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. Students could *assess the extent to which data support an explanation* [for how] ***genetic and environmental factors both affect expression of traits, and hence affect the probability of occurrences of traits in a population***. HS-LS3-2 and HS-LS3-3 **Engaging in Argument from Evidence** • Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining what additional information is required to resolve contradictions. Students could *respectfully provide critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions* [about how] ***all cells contain genetic information in the form of DNA molecules***. HS-LS1-1 **Obtaining, Evaluating, and Communicating Information** • Compare, integrate, and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem. Students could *compare and evaluate sources of information* [about how] ***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***. HS-LS3-1

Additional Crosscutting Concepts Building to the PEs	**Patterns** • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. Students could identify *different patterns at each of the scales at which* [the effect of] ***DNA*** [on organisms and] ***populations*** *is studied*. HS-LS3-1, HS-LS3-2, and HS-LS3-3 **Scale, Proportion, and Quantity** • Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. Students could construct an argument for why [the effects of] ***DNA on trait expression*** *can be studied indirectly* [in the classroom because the effects of DNA are] *too small and too fast to observe directly*. HS-LS3-1 and HS-LS3-2 **Stability and Change** • Much of science deals with constructing explanations of how things change and how they remain stable. Students could construct an argument for how *much of science deals with constructing explanations of how things change and how they remain stable,* [using as evidence] ***systems of specialized cells within organisms help them perform the essential functions of life.*** HS-LS1-1
Additional Connections to Nature of Science	**Scientific Investigations Use a Variety of Methods (SEP):** • Science investigations use diverse methods and do not always use the same set of procedures to obtain data. Students could obtain, evaluate, and communicate information for how *science investigations* [about the role of] ***genes on chromosomes*** *use diverse methods and do not always use the same set of procedures to obtain data*. HS-LS1-1 and HS-LS3-1 **Science is a Way of Knowing (CCC):** • Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time. Students could construct an argument from evidence for how *science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time* [about the role of] ***DNA in coding for the formation of proteins***. HS-LS1-1 and HS-LS3-1

HS-LS1-1

Students who demonstrate understanding can:

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.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

Disciplinary Core Ideas

LS1.A: Structure and Function

- Systems of specialized cells within organisms help them perform the essential functions of life.
- 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, which carry out most of the work of cells. *(Note: This Disciplinary Core Idea is also addressed by HS-LS3-1.)*

Crosscutting Concepts

Structure and Function

- Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.

Observable features of the student performance by the end of the course:		
1	Articulating the explanation of phenomena	
	a	Students construct an explanation that includes the idea that regions of DNA called genes determine the structure of proteins, which carry out the essential functions of life through systems of specialized cells.
2	Evidence	
	a	Students identify and describe* the evidence to construct their explanation, including that:
		i. All cells contain DNA;
		ii. DNA contains regions that are called genes;
		iii. The sequence of genes contains instructions that code for proteins; and
		iv. Groups of specialized cells (tissues) use proteins to carry out functions that are essential to the organism.
	b	Students use a variety of valid and reliable sources for the evidence (e.g., theories, simulations, peer review, students' own investigations).
3	Reasoning	
	a	Students use reasoning to connect evidence, along with the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future, to construct the explanation. Students describe* the following chain of reasoning in their explanation:
		i. Because all cells contain DNA, all cells contain genes that can code for the formation of proteins.
		ii. Body tissues are systems of specialized cells with similar structures and functions, each of whose functions are mainly carried out by the proteins they produce.
		iii. Proper function of many proteins is necessary for the proper functioning of the cells.
		iv. Gene sequence affects protein function, which in turn affects the function of body tissues.

HS-LS3-1

Students who demonstrate understanding can:

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.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Asking Questions and Defining Problems

Asking questions and defining problems in 9-12 builds on K-8 experiences and progresses to formulating, refining and evaluating empirically testable questions and design problems using models and simulations.

- Ask questions that arise from examining models or a theory to clarify relationships.

Disciplinary Core Ideas

LS1.A: Structure and Function

- 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. *(secondary) (Note: This Disciplinary Core Idea is also addressed by HS-LS1-1.)*

LS3.A: Inheritance of Traits

- 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.

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:			
1	Addressing phenomena or scientific theories		
	a	Students use models of DNA to formulate questions, the answers to which would clarify:	
		i.	The cause and effect relationships (including distinguishing between causal and correlational relationships) between DNA, the proteins it codes for, and the resulting traits observed in an organism;
		ii.	That the DNA and chromosomes that are used by the cell can be regulated in multiple ways; and
		iii.	The relationship between the non-protein coding sections of DNA and their functions (e.g., regulatory functions) in an organism.
2	Evaluating empirical testability		
	a	Students' questions are empirically testable by scientists.	

HS-LS3-2

Students who demonstrate understanding can:

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.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Engaging in Argument from Evidence

Engaging in argument from evidence in 9-12 builds on K-8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Make and defend a claim based on evidence about the natural world that reflects scientific knowledge and student-generated evidence.

Disciplinary Core Ideas

LS3.B: Variation of Traits

- In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited.
- Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depends on both genetic and environmental factors.

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:		
1	Developing a claim	
	a	Students make a claim that includes the idea that inheritable genetic variations may result from:
		i. New genetic combinations through meiosis;
		ii. Viable errors occurring during replication; and
		iii. Mutations caused by environmental factors.
2	Identifying scientific evidence	
	a	Students identify and describe* evidence that supports the claim, including:
		i. Variations in genetic material naturally result during meiosis when corresponding sections of chromosome pairs exchange places.
		ii. Genetic mutations can occur due to:
		a) errors during replication; and/or
		b) environmental factors.
		iii. Genetic material is inheritable.
	b	Students use scientific knowledge, literature, student-generated data, simulations and/or other sources for evidence.
3	Evaluating and critiquing evidence	
	a	Students identify the following strengths and weaknesses of the evidence used to support the claim:

		i. Types and numbers of sources;
		ii. Sufficiency to make and defend the claim, and to distinguish between causal and correlational relationships; and
		iii. Validity and reliability of the evidence.
4	Reasoning and synthesis	
	a	Students use reasoning to describe* links between the evidence and claim, such as:
		i. Genetic mutations produce genetic variations between cells or organisms.
		ii. Genetic variations produced by mutation and meiosis can be inherited.
	b	Students use reasoning and valid evidence to describe* that new combinations of DNA can arise from several sources, including meiosis, errors during replication, and mutations caused by environmental factors.
	c	Students defend a claim against counter-claims and critique by evaluating counter-claims and by describing* the connections between the relevant and appropriate evidence and the strongest claim.

HS-LS3-3

Students who demonstrate understanding can:

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.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 9-12 builds on K-8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible.

Disciplinary Core Ideas

LS3.B: Variation of Traits

- Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus, the variation and distribution of traits observed depends on both genetic and environmental factors.

Crosscutting Concepts

Scale, Proportion, and Quantity
Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).

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Connections to Nature of Science

Science is a Human Endeavor

- Technological advances have influenced the progress of science and science has influenced advances in technology.
- Science and engineering are influenced by society and society is influenced by science and engineering.

Observable features of the student performance by the end of the course:		
1	Organizing data	
	a	Students organize the given data by the frequency, distribution, and variation of expressed traits in the population.
2	Identifying relationships	
	a	Students perform and use appropriate statistical analyses of data, including probability measures, to determine the relationship between a trait's occurrence within a population and environmental factors.
3	Interpreting data	
	a	Students analyze and interpret data to explain the distribution of expressed traits, including:
		i. Recognition and use of patterns in the statistical analysis to predict changes in trait distribution within a population if environmental variables change; and
		ii. Description* of the expression of a chosen trait and its variations as causative or correlational to some environmental factor based on reliable evidence.