High School Modified Domains Model Course III – Life Sciences
Bundle 4: Life Diversifies Over Time

This is the fourth bundle of the High School Domains Model Course III – Life Sciences. Each bundle has connections to the other bundles in the course, as shown in the Course Flowchart.

Bundle 4 Question: This bundle is assembled to address the question "how can populations change over time?"

Summary
The bundle organizes performance expectations with a focus on helping students build understanding of how genetic variation among organisms affects survival and reproduction. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards, and recognize that instruction is not limited to the practices and concepts directly linked with any of the bundle performance expectations.

Connections between bundle DCIs
Evolution is a consequence of the interaction of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment (LS4.C as in HS-LS4-2).

Evolution can be a result of natural selection, which occurs only if there is both variation in the genetic information between organisms in a population and variation in the expression of that genetic information that leads to differences in performance among individuals (LS4.B as in HS-LS4-2 and HS-LS4-3). Natural selection leads to adaptation, in other words, to the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not (LS4.C as in HS-LS4-3 and HS-LS4-4). Adaptation also means that the distribution of traits in a population can change when conditions change (LS4.C as in HS-LS4-3). Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline—and sometimes the extinction—of some species (LS4.C as in HS-LS4-5).

The engineering design idea that when evaluating solutions, it is important to take into account a range of constraints, including cost safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts (ETS1.B as in HS-ETS1-3) could connect to many different science ideas, including how species become extinct because they can no longer survive and reproduce in their altered environment (LS4.C as in HS-LS4-5). Connections could be made through engineering design tasks such as evaluating solutions for how to stop the extinction of a local endangered organism by minimizing the negative effects of roads, housing construction, or pollution.

Bundle Science and Engineering Practices
Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of analyzing and interpreting data (HS-LS4-3), constructing explanations and designing solutions (HS-LS4-2, HS-LS4-4, and HS-ETS1-3), and engaging in argument from evidence (HS-LS4-5). 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 Patterns (HS-LS4-3) and Cause and Effect (HS-LS4-2, HS-LS4-4, and HS-LS4-5). Many other crosscutting concept elements can be used in instruction.

All instruction should be three-dimensional.	
Performance Expectations HS-LS4-3 and HS-LS4-5 are partially assessable.	HS-LS4-2. **Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.** [Clarification Statement: Emphasis is on using evidence to explain the influence each of the four factors has on number of organisms, behaviors, morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models such as simple distribution graphs and proportional reasoning.] [Assessment Boundary: Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and co-evolution.] HS-LS4-3. **Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.** [Clarification Statement: Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations.] [Assessment Boundary: Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.] HS-LS4-4. **Construct an explanation based on evidence for how natural selection leads to adaptation of populations.** [Clarification Statement: Emphasis is on using data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or evolution of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations.] HS-LS4-5. **Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.** [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.] HS-ETS1-3. **Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.**
Example Phenomena	The fly orchid looks a lot like an insect. The golden toad was last seen in 1989, and is now extinct.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations. Students could *define a design problem* [related to] ***the extinction of species*** [when] ***they can no longer survive and reproduce in their altered environment***. HS-LS4-5 **Developing and Using Models** • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. Students could *develop, revise, and/or use a model based on evidence to illustrate* [how] ***natural selection occurs only if there is both variation in the genetic information between organisms in a population and variation in the expression of that genetic information***. HS-LS4-2 and HS-LS4-3

Additional Practices Building to the PEs (Continued)	**Planning and Carrying Out Investigations** • Select appropriate tools to collect, record, analyze, and evaluate data. Students could *select appropriate tools to record, analyze, and evaluate data on* ***variation in traits that leads to differences in performance among individuals***. HS-LS4-2 **Analyzing and Interpreting Data** • Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. Students could *evaluate the impact of new data on a working model* [of how] ***competition for an environment's limited supply of resources*** [contributes to] ***evolution***. HS-LS4-2 **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 support claims* [for how] ***natural selection leads to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment***. HS-LS4-3 and HS-LS4-4 **Constructing Explanations and Designing Solutions** • Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables. Students could *make a qualitative claim regarding the relationship between* ***the changes in the physical environment and the expansion of some species***. HS-LS4-5 **Engaging in Argument from Evidence** • Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. Students could *compare and evaluate competing arguments* [about how] ***natural selection leads to adaptation***. HS-LS4-3 and HS-LS4-4 **Obtaining, Evaluating, and Communicating Information** • Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. Students could *critically read scientific literature* [about how] ***evolution is a consequence of the interaction of four factors*** *to determine the conclusions and paraphrase them in simpler but still accurate terms*. HS-LS4-5

Additional Crosscutting Concepts Building to the PEs	**Cause and Effect** • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. Students could *predict cause and effect relationships between t**raits that positively affect survival and traits that are common in populations** by examining what is known about smaller scale mechanisms within the system*. HS-LS4-3 **Scale, Proportion, and Quantity** • The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. Students could evaluate information about how the *significance of an **advantageous heritable trait** depends on* [its] *scale, proportion, and quantity **in a population***. HS-LS4-3 and HS-LS4-4 **Stability and Change** • Much of science deals with constructing explanations of how things change and how they remain stable. Students could communicate how *science deals with constructing explanations of how things change*, [using as an example explanations of] ***changes in the physical environment contributing to the expansion of some species, the emergence of new distinct species, or the decline or extinction of some species***. HS-LS4-5
Additional Connections to Nature of Science	**Scientific Investigations Use a Variety of Methods** • Science investigations use diverse methods and do not always use the same set of procedures to obtain data. Students could communicate how *science investigations use diverse methods and procedures to obtain data*, [including data on how] ***changes in the physical environment have contributed to the expansion of some species, the emergence of new distinct species, or the decline or extinction of some species***. HS-LS4-5 **Science Addresses Questions About the Natural and Material World** • Science knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. Students could construct an argument that *science knowledge indicates what can happen in natural systems and not what should happen* [when] ***evaluating solutions*** [for the] ***extinction of some species***. HS-LS4-5 and HS-ETS1-3

HS-LS4-2

Students who demonstrate understanding can:

HS-LS4-2. **Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.** [Clarification Statement: Emphasis is on using evidence to explain the influence each of the four factors has on the number of organisms, behaviors, morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models such as simple distribution graphs and proportional reasoning.] [*Assessment Boundary: Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and co-evolution.*]

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

LS4.B: Natural Selection

- Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information — that is, trait variation — that leads to differences in performance among individuals.

LS4.C: Adaptation

- Evolution is a consequence of the interaction of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment.

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	Articulating the explanation of phenomena	
	a	Students construct an explanation that includes a description* that evolution is caused primarily by one or more of the four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
2	Evidence	
	a	Students identify and describe* evidence to construct their explanation, including that:
		i. As a species grows in number, competition for limited resources can arise.

		ii. Individuals in a species have genetic variation (through mutations and sexual reproduction) that is passed on to their offspring.
		iii. Individuals can have specific traits that give them a competitive advantage relative to other individuals in the species.
	b	Students use a variety of valid and reliable sources for the evidence (e.g., data from investigations, theories, simulations, peer review).
3	Reasoning	
	a	Students use reasoning to connect the 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 for their explanation:
		i. Genetic variation can lead to variation of expressed traits in individuals in a population.
		ii. Individuals with traits that give competitive advantages can survive and reproduce at higher rates than individuals without the traits because of the competition for limited resources.
		iii. Individuals that survive and reproduce at a higher rate will provide their specific genetic variations to a greater proportion of individuals in the next generation.
		iv. Over many generations, groups of individuals with particular traits that enable them to survive and reproduce in distinct environments using distinct resources can evolve into a different species.
	b	Students use the evidence to describe* the following in their explanation:
		i. The difference between natural selection and biological evolution (natural selection is a process, and biological evolution can result from that process); and
		ii. The cause and effect relationship between genetic variation, the selection of traits that provide comparative advantages, and the evolution of populations that all express the trait.

HS-LS4-3

Students who demonstrate understanding can:

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

The 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

LS4.B: Natural Selection

- Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information — that is, trait variation — that leads to differences in performance among individuals.
- The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population.

LS4.C: Adaptation

- Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not.
- Adaptation also means that the distribution of traits in a population can change when conditions change.

Crosscutting Concepts

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.

Observable features of the student performance by the end of the course:		
1	Organizing data	
	a	Students organize data (e.g., using tables, graphs and charts) by the distribution of genetic traits over time.
	b	Students describe* what each dataset represents
2	Identifying relationships	

	a	Students perform and use appropriate statistical analyses of data, including probability measures, to determine patterns of change in numerical distribution of traits over various time and population scales.
3	Interpreting data	
	a	Students use the data analyses as evidence to support explanations about the following:
		i. Positive or negative effects on survival and reproduction of individuals as relating to their expression of a variable trait in a population;
		ii. Natural selection as the cause of increases and decreases in heritable traits over time in a population, but only if it affects reproductive success; and
		iii. The changes in distribution of adaptations of anatomical, behavioral, and physiological traits in a population.

HS-LS4-4

Students who demonstrate understanding can:

HS-LS4-4. **Construct an explanation based on evidence for how natural selection leads to adaptation of populations.** [Clarification Statement: Emphasis is on using data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or evolution of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations.]

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

LS4.C: Adaptation

- Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not.

Crosscutting Concepts

Cause and Effect

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

Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future.

Observable features of the student performance by the end of the course:		
1	Articulating the explanation of phenomena	
	a	Students construct an explanation that identifies the cause and effect relationship between natural selection and adaptation.
2	Evidence	
	a	Students identify and describe* the evidence to construct their explanation, including:
		i. Changes in a population when some feature of the environment changes;
		ii. Relative survival rates of organisms with different traits in a specific environment;
		iii. The fact that individuals in a species have genetic variation (through mutations and sexual reproduction) that is passed on to their offspring; and
		iv. The fact that individuals can have specific traits that give them a competitive advantage relative to other individuals in the species.
	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 synthesize the valid and reliable evidence to distinguish between cause and correlation to construct the explanation about how natural selection provides a mechanism for species to adapt to changes in their environment, including the following elements:
		i. Biotic and abiotic differences in ecosystems contribute to changes in gene frequency over time through natural selection.

		ii.	Increasing gene frequency in a population results in an increasing fraction of the population in each successive generation that carries a particular gene and expresses a particular trait.
		iii.	Over time, this process leads to a population that is adapted to a particular environment by the widespread expression of a trait that confers a competitive advantage in that environment.

HS-LS4-5

Students who demonstrate understanding can:

HS-LS4-5. **Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.** [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.]

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 or historical episodes in science.

- Evaluate the evidence behind currently accepted explanations or solutions to determine the merits of arguments.

Disciplinary Core Ideas

LS4.C: Adaptation

- Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline — and sometimes the extinction — of some species.
- Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or drastic, the opportunity for the species' evolution is lost.

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	Identifying the given claims and evidence to be evaluated	
	a	Students identify the given claims, which include the idea that changes in environmental conditions may result in:
		i. Increases in the number of individuals of some species;
		ii. The emergence of new species over time; and
		iii. The extinction of other species.
	b	Students identify the given evidence to be evaluated.
2	Identifying any potential additional evidence that is relevant to the evaluation	
	a	Students identify and describe* additional evidence (in the form of data, information, models, or other appropriate forms) that was not provided but is relevant to the claims and to evaluating the given evidence, including:
		i. Data indicating the change over time in:
		a) The number of individuals in each species;
		b) The number of species in an environment; and
		c) The environmental conditions.
		ii. Environmental factors that can determine the ability of individuals in a species to survive and reproduce.

3	Evaluating and critiquing	
	a	Students use their additional evidence to assess the validity, reliability, strengths, and weaknesses of the given evidence, along with its ability to support logical and reasonable arguments about the outcomes of group behavior.
	b	Students assess the ability of the given evidence to be used to determine causal or correlational effects between environmental changes, the changes in the number of individuals in each species, the number of species in an environment, and/or the emergence or extinction of species.
4	Reasoning and synthesis	
	a	Students evaluate the degree to which the given empirical evidence can be used to construct logical arguments that identify causal links between environmental changes and changes in the number of individuals or species based on environmental factors that can determine the ability of individuals in a species to survive and reproduce.

HS-ETS1-3

Students who demonstrate understanding can:

HS-ETS1-3. **Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.**

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.

- Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Disciplinary Core Ideas

ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.

Crosscutting Concepts

Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

Observable features of the student performance by the end of the course:			
1	Evaluating potential solutions		
	a	In their evaluation of a complex real-world problem, students:	
		i.	Generate a list of three or more realistic criteria and two or more constraints, including such relevant factors as cost, safety, reliability, and aesthetics that specifies an acceptable solution to a complex real-world problem;
		ii.	Assign priorities for each criterion and constraint that allows for a logical and systematic evaluation of alternative solution proposals;
		iii.	Analyze (quantitatively where appropriate) and describe* the strengths and weaknesses of the solution with respect to each criterion and constraint, as well as social and cultural acceptability and environmental impacts;
		iv.	Describe* possible barriers to implementing each solution, such as cultural, economic, or other sources of resistance to potential solutions; and
		v.	Provide an evidence-based decision of which solution is optimum, based on prioritized criteria, analysis of the strengths and weaknesses (costs and benefits) of each solution, and barriers to be overcome.
2	Refining and/or optimizing the design solution		
	a	In their evaluation, students describe* which parts of the complex real-world problem may remain even if the proposed solution is implemented.	