Hardy Weinberg Population Genetics

Purpose
Students will learn about the Hardy Weinberg Theory of genetic equilibrium. The students will study the relationship between evolution and changes in allele frequency of a population by using the Net Logo Hardy Weinberg computer modeling simulation.

Overview
Biology students will use the Hardy Weinberg Classroom Model Net Logo program created by Kenneth Letendre. They will use the computer simulation to analyze how variables such as the proportion of alleles, population size, and selection against alleles can influence the genetics of a population. The Hardy Weinberg principle predicts the genotype and phenotype frequencies given that five assumptions (large population size, mating is random, no mutations, no migration, and no selection) hold true in a population.

Learner Objectives of the lesson:
1. Understand how natural selection can alter allelic frequencies in a population.
2. Apply the Hardy Weinberg equation and its use in determining the frequency of alleles in a population.
3. Analyze the effects on allelic frequencies of selection against the homozygous recessive population or other genotypes.
4. Explain natural selection and other causes of microevolution as deviations from the conditions required to maintain Hardy Weinberg equilibrium.

Illinois State Science Standards
11.A. Know and apply the concepts, principles and
processes of scientific inquiry

11.A.4c Collect, organize and analyze data accurately and precisely

12.B. Know and apply concepts that describe how living things interact with each other and with their environment

12.B.4a Compare physical, ecological and behavioral factors that influence interactions and interdependence of organism

12.B.5b Compare and predict how life forms can adapt to changes in the environment by applying concepts of change and constancy (e.g., variations within a population increase the likelihood of survival under new conditions)

**Time**

2 class periods (84 minutes) will be needed to explain the program and for students to complete the activity.

**Level**

High School/ AP Biology

**Materials and Tools**

Supplementary documents or handouts- found at the end of this lesson plan.

NetLogo Home Page  [http://ccl.northwestern.edu/netlogo/](http://ccl.northwestern.edu/netlogo/)

Net Logo Hardy Weinberg Simulation (found under “Community Model” link, Jan. 2009)
[http://ccl.northwestern.edu/netlogo/models/community/Hardy%20Weinberg%20Classroom%20Model](http://ccl.northwestern.edu/netlogo/models/community/Hardy%20Weinberg%20Classroom%20Model)
Preparation

NetLogo is a programmable modeling environment for simulating natural and social phenomena. It was authored by Uri Wilensky in 1999 and has been in continuous development ever since at the Center for Connected Learning and Computer-Based Modeling. NetLogo is particularly well suited for modeling complex systems developing over time. Modelers can give instructions to hundreds or thousands of "agents" all operating independently. This makes it possible to explore the connection between the micro-level behavior of individuals and the macro-level patterns that emerge from the interaction of many individuals.

Teachers should review the system requirements to run the NetLogo programs. The requirements can be found at http://ccl.northwestern.edu/netlogo/docs. Students do not need to download the program on to the computer. They may run the program with the internet browser.

Prerequisites
Students should review the Hardy Weinberg principle. An alternative activity would be to complete “Activity 23.1 A Quick Review of Hardy Weinberg Population Genetics” worksheet.

Background

The background below can be found on the NetLogo Hardy Weinberg Model website.

WHAT IS IT?
This is a model of the Hardy-Weinberg (HW) equilibrium.
The HW principle predicts the genotypic frequencies that will be observed in a population over the course of generations given particular allele frequencies, and given that five assumptions (discussed below) hold true in the population. Given two alleles, A and a, and the frequencies of each allele in the population, freq(A)=p and freq(a)=q, the HW principle predicts:

1) \( p + q = 1 \).
That is, since A and a are the only alleles at this locus in the model population, the allelic frequencies of A and a must add up to 1.

2) The genotypic frequency of AA homozygotes in the population is \( p^2 \).
The frequency of aa homozygotes is \( q^2 \). The probability that any given member of the population will inherit two A alleles is \( p \times p \).

The frequency of heterozygotes is \( 2pq \). The probability that any given member of the population will inherit one A and one a allele is \( p \times q \times 2 \), since a heterozygote can inherit allele A from its mother and allele a from its father, OR allele a from its mother and A from its father.
\[ p^2 + 2pq + q^2 = 1 \] . That is, the frequencies of both types of homozygotes and the frequency of heterozygotes must add up to 1, since these are the only possible combinations.

These predictions hold true given these five assumptions:
1) Large (infinite) population size. In small populations, chance differences in reproductive success and mating choices can produce deviations from the predictions of HW.
2) No selection. There is no systematic difference in the survival or reproductive success of organisms with different genotypes.
3) No mutation. The alleles are inherited from one generation to the next without being changed by mutation.
4) No migration. No organisms leave the population, and no new ones come in.
5) Random mating. Organisms choose mates at random with respect to the alleles of interest in the model.

If any of these assumptions do not hold true in a population, the observed genotypic frequencies will deviate from the predictions of HW in particular ways depending on the assumption(s) that is (are) violated.

**HOW IT WORKS**
The model is initialized with a randomly distributed population of blue (the dominant trait) and yellow (the recessive trait) organisms. Organisms are randomly assigned alleles according to the selected frequency of the A allele (the frequency of the a allele is determined as \( q = p - 1 \)).

As the model runs, organisms move around the world in a correlated random walk at a dispersal rate determined by the user. On each tick, organisms select a mate, either by mating with another organism chosen at random anywhere in the world, or by choosing a nearby organism to mate with. An offspring is produced adjacent to the reproducing organism, which randomly inherits either the a or A alleles from each of its parents. The organisms are diploid, but are essentially hermaphroditic, as every organism is capable of producing offspring and may mate with any other organism without the need to locate a mate of the opposite sex.

Following reproduction, the population decreases to bring the population size back down to the carrying capacity determined by the user. During each population decrease, each organism is subject to a probability of death determined by the degree to which the current population size exceeds the carrying capacity. As a result, an organism may live for
several generations, or it may not survive to first reproduction. There is no maturation time, so that any organism that survives the first drop in population size following its birth can reproduce during the next reproduction cycle.

The model ends when it reaches a specified number of generations ("ticks"), or when one allele becomes fixed in the population (that is, the other allele goes extinct), or when the entire population of organisms goes extinct (e.g. due to high selection against both phenotypes).

HOW TO USE IT
The "proportion-allele-A" slider bar determines the initial frequency of the allele A. The frequency of allele a is determined by calculating \( \text{freq}(a) = 1 - \text{freq}(A) \). The "population-size" slider determines the carrying capacity of the system. The "species" chooser allows the user to select from a list of possible icons to represent the organism as they move around the world.

Clicking the "setup" button initializes the world with a population of organisms of the selected species, with the specified allele frequencies. The "go" button starts the model.

The "Population size" monitor displays the current population size. Note that this population size will not always match exactly the value selected by the "population-size" slider. In fact, during each reproduction cycle, the population size will rise well above this value, and then fall back roughly to the specified population size at the end of the culling cycle. However because mortality for each organism is determined by a certain probability, the final population size will not be exactly the specified value, although it will be close.

Graphs track the genotypic frequencies, phenotypic
frequencies, and allele frequencies over time as the model runs. Monitors display the current values for each of these. As the model runs, the user may change the settings of any slider, chooser or input -- with the exception of the "proportion-allele-A" slider -- and the model will reflect these newly selected values. The value of the "proportion-allele-A" slider is used only at model setup; allele frequencies are determined only by the behavior of the organisms after the model begins running.

**Teaching Notes**

Before the activity teachers should read the background information about population genetics and the Hardy Weinberg principle. Below is a summary of the model written by Kenneth Letendre, Department of Biology and Computer Science, University of New Mexico.

**THINGS TO NOTICE**

Note that the genotypic and phenotypic frequencies approximate the values predicted by the HW formulas. Try calculating the predicted values based on the allele frequencies you have specified (or the current allele frequencies obtained by the current A and a alleles present in the population) and compare these to the actual values produced by the model as it runs. The model itself does not make use of the HW formulas, but produces values similar to those predicted by HW by the interactions of the model organisms.

Note the random changes in the genotypic, phenotypic, and allelic frequencies over time. These changes are more apparent with smaller population sizes, but can still be observed even with populations in the thousands. These
random changes result from random differences in the survival and reproductive success of individuals each generation, and are called genetic drift. Genetic drift has a bigger effect on the makeup of small populations than larger ones. Theoretically, the HW assumption of "large population" actually requires an infinitely large population in order to completely eliminate the effect of drift.

THINGS TO TRY
Experiment with the settings of the model to create violations of the five assumptions described above. The Hardy-Weinberg equilibrium describes a theoretical population that cannot exist in the real world; perhaps its greatest value is in describing a population where no evolution is occurring, in order to better understand real populations where one or more of the five assumptions are violated, and evolution is occurring.
1) Large (infinite) population size. Try running the model with populations of different sizes in order to observe differences in the strength of genetic drift.
2) No selection. Try experimenting with different degrees of selection against (increased mortality of) the blue and yellow phenotypes. You will observe that selection against the recessive phenotype (yellow color) takes much longer to completely remove the a allele from the population, even with heavy selection against the yellow phenotype. Why is this? What does this tell us about the persistence of recessive genetic disorders in the population?
3) No mutation. Experiment with different mutation rates from dominant to recessive, or recessive to dominant. What happens if there is a large rate of mutation in both directions?
4) No migration. Experiment with different rates of immigration of blue and yellow individuals. How does immigration of individuals of a particular color effect the
overall genetic makeup of the population?
5) Random mating. The "mate-with" chooser can cause the organisms in the model to choose mates completely at random, selecting any other organism in the world as a mate. You can also cause organisms to mate with a neighbor, so that organisms must be adjacent in order to mate with each other. Note what happens to the frequency of heterozygotes when organisms are mating with their neighbors. Also note that increasing the dispersal rate (the distance the organisms move each time step) decreases the effect of mating with neighbors on the phenotypic makeup of the population. Why does this happen?

EXTENDING THE MODEL
Other methods for violating the assumptions of the HW equilibrium could be added. For example, selection in this model is caused by increasing the mortality rate of one or both of the phenotypes. Selection could also result from differential reproductive output, or from differential success in finding mates (sexual selection).
The model could also be extended to multiple genes to, for example, examine the effect of linkage on inheritance.

RELATED MODELS
NetLogo Library Models:
- GenDrift (T reproduce)
- Simple Birth Rates
NetLogo Community Models:
- PopGen Fishbowl 1
- Genetics and Cellular Automata

CREDITS AND REFERENCES
Hardy-Weinberg Classroom Model (2009)
Kenneth Letendre
Departments of Biology and Computer Science
Assessment
Students will complete the lab worksheet. The objectives of the lesson will be assessed by reviewing student answers on the lab worksheet.
Appendix Standards

I. Data and Information Skills
1a. Collecting Data

<table>
<thead>
<tr>
<th>Students will understand that…</th>
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<tbody>
<tr>
<td>· Collecting data includes questions of accuracy, precision, validity, and data storage.</td>
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<tr>
<td>· Data can take different forms including numbers, text, images, and audio or video formats. Each of these forms comes with a different set of computational tools for collection and storage.</td>
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<tr>
<td>· Computational devices can assist in data collection. They are especially useful when collecting large data sets and when a high degree of precision is desired. By precision we are referring to the specificity of the result of a measurement.</td>
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<tr>
<td>· Computers can automate the process of data collection to increase the efficiency and validity of the collected data. By validity we are referring to the trustworthiness of the data – whether the data represent what we believe they do.</td>
</tr>
<tr>
<td>· Using a computational device to conduct data collection procedures can increase the accuracy of the measurement as well as remove human error from the process. By accuracy we are referring to the closeness of the measurement to the true value of what is being measured.</td>
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<tr>
<td>· Underlying randomness can produce different results from the same initial configuration. Thus, it is important to conduct data collection procedures multiple times to identify potential sources of error inherent in the data collection process.</td>
</tr>
<tr>
<td>· The validity and accuracy of data can be affected by the procedures followed in the data collection process. When using a computational device to assist in these processes, the problem can be magnified due to repetition, thus it is important to regularly review the data that have been collected and the procedure being followed to ensure the data collection process is proceeding as expected.</td>
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<table>
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<tr>
<th>Students will be able to…</th>
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<tr>
<td>· Collect data using a variety of computational tools, e.g. digital sensors, computer simulations or models, and spreadsheets.</td>
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<tr>
<td>· Decompose a large data collection strategy into a systematic set of sub-tasks that can be carried out to achieve the larger data-collection goal.</td>
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<tr>
<td>· Describe what types of data collection activities are best done using a computer and what types of data collection tasks require, or are more easily accomplished by a human (e.g. classification of visual characteristics vs. specific repeated steps).</td>
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1b. Generating Data

Students will understand that…
- Computers are powerful tools for creating data sets given a generative data description that can be executed. Computers often rely on iterative logic to create data sets.
- Randomness plays an important role in creating realistic data sets and must be explicitly included in computationally executable generative descriptions of data.
- When writing a program to create a data set, you can control all aspects of the data set including its size, distribution and the range of values it includes. Moreover, you can define what form the data is output in and how/where it will be stored.
- When using a computational tool to generate data, the output of the procedure will be the data you wish to investigate, so questions of format and storage must consider future uses of the data.

Students will be able to…
- Assess and critique data creation practices with respect to the desired characteristics of the data set needed to investigate the initial question.
- Define an automated procedure that a computer could carry out to gather a particular set of data or produce a data set that matches a set of pre-defined criteria.
- Introduce randomness into a computational generative description of data and discuss the role it plays in the data generation process.
- Discuss the role iterative logic plays in generating a set of data using a computer.

1d Manipulating Data

Students will understand that…
- By rearranging or reorganizing data new insights can be found. Computational tools can assist in the data manipulation process.
- Computers can help improve the accuracy and precision of a data manipulation task, especially when working with a large data set.

Students will be able to…
Use computational tools (such as Microsoft Excel) to manipulate a set of data.
Manipulate a dataset as a whole rather than each of the data points.

### 1e. Analyzing Data

Students will understand that...
- Data analysis is a prerequisite for drawing conclusions or making hypotheses.
- During the data analysis process, individual data points might shift, change, or otherwise be altered, but the underlying information should not change.
- Computational tools can help us with analyzing large amounts of data.
- Data analysis often includes looking for patterns and underlying structures in a data set.
- To study a data set, it can be described in many forms including mathematical equations, spreadsheet formulas, computer programs, or as collections of individual data points. One potential output of data analysis is a generative description of the data that can be used to create similar data sets.
- One dataset can be interpreted and analyzed in many different ways, depending on the question that is being investigated.
- Conclusions drawn from data analysis are only as reliable as the data from which they were drawn.
- Many computational tools offer functionality to assist in analysis of data, in tools for graphing, charting, filtering and conditionally displaying data.
- Creating visualizations of data can be a useful strategy when conducting an analysis.
- Data analysis and data manipulation often proceed hand-in-hand. Manipulation helps analysis, analysis informs manipulations.

Students will be able to...
- Suggest and implement a successful data analysis strategy for the question being investigated.
- Select and use an appropriate dataset to be analyzed for a specific problem.
- Search through a dataset to find patterns and anomalies in the data using computational tools.
- Leverage computational tools to assist in data analysis.
- Produce a data visualization and discuss how the chosen visualization can assist them in conducting their data analysis.
If. Visualizing Data

Students will understand that...
- Data visualizations can be used to highlight interesting or important characteristics of data that can be useful for analysis or for presenting your data to others.
- Computers can be used to create many different types of data visualizations including graphs, charts, plots, diagrams, movies, and figures.
- Computers make it possible to generate interactive and dynamic data visualizations that can be an effective and engaging way to explore a set of data.
- Interactive visualizations can be rendered in one, two, or three dimensions. When studying a phenomenon that occurs in nature, it is often powerful to render it in three dimensions as it creates a more realistic representation of how the phenomena actually occurs.
- When using a computer to visualize a set of data, you need to give the computer explicit instructions for what data to include and how it should be displayed. There are many characteristics that can be manipulated to highlight certain aspects of the data; including size, color, shape, position, and text labels.
- When creating a visualization, you often only display a subset of the entire set. Which data and how much of it you include depends on the information you trying to convey and the type of visualization you are creating.

Students will be able to...
- Use computational tools to design and implement data visualizations that highlight interesting aspects of a provided data set. This includes an accompanying write-up that articulates what the visualization is showing.
- Define a set of parameters so that only a subset of a larger data set is included in a visualization. These parameters might require using conditional logic, developing bucketing strategies, or defining upper and lower bounds for inclusion.
- Articulate the process followed in creating a visualization so that others can create similar products.
- Specify conditions to have data points display differently based on specific characteristics of the data.
- Assess the strengths and weaknesses of different visualizations for the same set of data.

2. Problem Solving Skills

2a. Decomposing Problems into Subproblems /
Developing Modular Solutions

Students will understand that…
- An effective, and sometimes necessary, approach to solve a complex problem is to break it down into smaller problems.
- Decomposing a problem into smaller pieces allows the large problems to be solved faster, as the subproblems can be solved in parallel.

Students will be able to…
- Decompose a problem into a set of subproblems that are easier to solve and result in a global solution for the initial problem.
- Use the solutions from subproblems to answer, or make progress, on the larger problem.
- Design and implement modular solutions in such a way that they can be reused in future solutions.
- Discuss how each module of a solution works individually and how the modules work together to generate the global solution to the problem.
- Explain the advantages of modularly designed computer programs.

2b. Reframing Problems into Known/Familiar Problems

Students will understand that…
- There are frequently commonalities across problems, even if they appear at first glance. Once the commonalities are recognized, they can be leveraged to apply approaches/solutions from a solved problem to the unknown problem.
- Similarities in the underlying principles or concepts involved in the solution problem are more important than surface similarities when deciding if a known solution will be applicable in a novel context.

Students will be able to…
- Discuss strategies that can be used to identify commonalities across problems.
- Identify and then background unimportant features of related problems when searching for common approaches to solve the problems.
- Solve a problem by reframing it into a similar problem that is already understood.

2c. Simplifying Complex Problems

Students will understand that…
- Problems are sometimes less complex than they seem; identifying the par
problem that are relevant and focusing on those can make a large, complex problem simpler.

- One effective strategy to solve a complex problem is to first find a solution to a simplified version of the problem by temporarily ignoring some details of the problem at hand. Upon solving the simplified problem, you can then reintroduce the aspects of the problem you had initially ignored.

Students will be able to:
- Identify the source(s) of complexity in a problem.
- Recognize what makes solving a problem easier or harder, such as the amount of detail provided, the number of unknowns, the parts that can be automated, and existence of software designed to help solve the problem.
- Determine if and how the most complex parts of a problem can be circumvented to solve a simplified version of the problem that yields insights into the initial problem.

2d. Generating Algorithmic Solutions

Students will understand that:
- Algorithm design involves outlining the steps that should be followed to solve a problem or accomplish a task.
- Algorithms can include conditional logic, recursion, iteration, and other principles from computer science.
- A successful algorithm is the one that is clear and unambiguous at each step and achieves the desired result.
- Writing pseudo-code is an effective way to outline an algorithm before implementing it on a computer or communicating it to team members.
- The specificity of an algorithm depends on who or what is going to carry the algorithm out. Computers require very explicit steps.
- Algorithms can be expressed in a number of different ways including pseudo-code, executable computer code and flow charts.

Students will be able to:
- Propose an algorithmic solution to a problem.
- Leverage constructs such as conditional logic and iteration when defining an algorithm.
- Express algorithmic solutions using representational systems that can be executed by a computer.
- Leverage visual representations, like flowcharts, to define and share a proposed algorithmic solution.
3. Computational Modeling Skills

3a. Using Computational Models to Understand a Concept

Students will be able to…
· Use a computational model to gain an understanding of the phenomena or concept the model simulates.
· Understand and explain the role different inputs into a computational model play in its overall behavior and functioning.
· Explain the relationship between different modalities and representations provided by the model’s interface.
· Interpret results of a given run of a simulation in context of concept being investigated.

3b. Understanding How and Why a Computational Model Works

Students will understand that…
· Computational models are not the real world; therefore, to make a better sense of the model, you must be aware of how it differs from the real world.
· Computational models usually simplify the real world phenomena by highlighting the key features and backgrounding the unnecessary details.
· The observed behavior of a computational model is a result of the collective underlying rules and behaviors. This information either comes from accompanying descriptive text to the model, from studying the actual code, or through exploring using the model itself.
· Although the computational models generally simulate complex behaviors, underlying rules can sometimes be quite simple.
· By understanding the rules underlying the observed behavior of a model, you are better able to interpret and apply insights gleaned from the model.

Students will be able to…
· Identify and discuss the underlying rules of a computational model as well
roles they play in the model. This can result from studying accompanying
documentation or the code that drives the model.
· Explain how different sets of configurations of the parameters a model infl
ts its resulting behaviors.
· Identify what states a model can be in and discuss what causes the model element of that model) to change from one state to another during a single ru
model.
· Make sense of multiple runs of a simulation and discuss the cause or lack variation in the resulting output. When randomness is present in the model, s will be able to identify the source of this randomness and the role it plays in t model.

4. Systemic Thinking Skills

4a. Understanding the Relationships within a System

Students will understand that…
· Systems can be composed of a variety of elements that can play similar or different roles.
· Sometimes different types of elements play complimentary roles, helping e other; while other times elements can play adversarial roles and compete witl system.
· A change to one element of the system can result in a change into the out\ the system or possibly to other elements of the system.
· Sometimes, a small change in a system can result in a big change in the c other parts of the system.
· Computational tools (such as simulations of phenomena) can provide cont environments with which to study and investigate the different elements of a $s and the roles that each play.
· The characteristics and properties of a system (as a whole entity) are diffe from those of the sum of the interrelated elements of the system.

Students will be able to…
· Identify constituent elements of a given system.
· Describe how different components of a system interact with each other.
· Propose approaches one can take to identify what role a given element pla within a system.
• Predict how a change in one part of the system will propagate and what effect it will have on other parts of the system.

4b. Thinking in Levels

Students will understand that...
• Different views of a system have different strengths and weaknesses. Some information about a system only makes sense from a macro (or aggregate) view, while others are unique to a finer, more micro view.
• An effective strategy for understanding a system or solving a problem is to view them from multiple levels as different levels may yield different insights.

Students will be able to...
• Propose ways of measuring aspects of the system at different levels.
• Identify different levels within a system and discuss their properties/qualities.
• Associate characteristics/measures of a system with the appropriate level.
• Discuss how different levels of a system are related.
• Switch between different levels when viewing a system to solve a problem.

4c. Investigating a Problem/Phenomenon by Viewing It as a System

Students will understand that...
• One approach in solving a problem (or investigating a phenomenon) that involves many interactions is to view it as a system. Investigating a system is often easier than investigating a problem by itself; you can make sense of a system by focusing on its elements and the way that these elements work together.
• Systems have inputs and outputs. When investigating a system, varying the inputs and measuring changes in output is one mechanism for developing an understanding of how the system works. Computational tools are especially useful for systematically testing combinations and variations of system inputs.
• Systems can take more than one input and produce more than one output.
• Systems can be composed of small self-contained subsystems that operate within the larger system. These systems can be investigated independently of the larger system, with the findings being used to understand the larger system as a whole.

Students will be able to...
• Transform a complex problem into a systemic representation to solve it.
• Identify the details of a problem or phenomena that can be transformed as elements and determine the relationships between these elements.
• Identify the full set of inputs and outputs of a given system.
• Design a series of tests to measure different outputs from a single system how they relate to the inputs to that system.
• Isolate different subsystems of a larger system and test them individually.

Next Generation Science Standards (NGSS draft)
Developing and Using Models
• Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and constructing models to predict and explain relationships between systems and their components in the natural and designed world.
• Use multiple types of models to represent and explain phenomena and move flexibly between model types based on merits and limitations. (a)

Planning and Carrying Out Investigations
• Evaluate various methods of collecting data (e.g., field study, experimental design, simulations) and analyze components of the design in terms of various aspects of the study. Decide types, how much, and accuracy of data needed to produce reliable measurement and consider any limitations on the precision of the data (e.g., number of trials, cost, risk, time). (f)

Analyzing and Interpreting Data
• Use tools, technologies, and/or models (e.g., computational, mathematical) to generate and analyze data in order to make valid and reliable scientific claims or determine an optimal design solution. (c)
• Consider limitations (e.g., measurement error, sample selection) when analyzing and interpreting data. (c)
• Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations. (c)

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. (a),(c)
• The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. (b),(c),(d),(f)

LS4.C: Adaptation
• Natural selection is the result 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. (a)
• 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. (b),(c),(f)

• Adaptation also means that the distribution of traits in a population can change when conditions change. (d)

Common Core State Standards Connections: [Note: these connections will be made more explicit and complete in future draft releases]

ELA –
RI.9-10.1 Cite strong and thorough textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text.
RI.9-10-8 Delineate and evaluate the argument and specific claims in a text, assessing whether the reasoning is valid and the evidence is relevant and sufficient identify false statements and fallacious reasoning.
SL.9-10.2 Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each source.
SL.11-12.2 Integrate multiple sources of information presented in diverse formats and media (e.g., visually, quantitatively, orally) in order to make informed decisions and solve problems, evaluating the credibility and accuracy of each source and noting any discrepancies among the data.

Mathematics –
MP.3 Construct viable arguments and critique the reasoning of
others.
N-Q Reason quantitatively and use units to solve problems
S.ID Summarize, represent, and interpret data on a single count or measurement variable
S.IC Make inferences and justify conclusions from sample surveys, experiments, and observational studies