From Genes to Jeans II

Grades 6-12

Editor
Mandy Garner

California Foundation for Agriculture in the Classroom
2300 River Plaza Drive
Sacramento, CA 95833
(916) 561-5625 • (800) 700-2482
www.LearnAboutAg.org
California Foundation for Agriculture in the Classroom

Vision: An appreciation of agriculture by all.

Mission: To increase awareness and understanding of agriculture among California’s educators and students.

All or parts of this educational unit may be reproduced for teacher and student classroom use. Permission for reproductions for other purposes must be obtained from the California Foundation for Agriculture in the Classroom.

2nd Edition

December 2014
# Table of Contents

## Table of Contents

Acknowledgments ................................................................. 2

## Getting Started

Introduction ........................................................................ 3

Unit Overview ..................................................................... 5

Background Information on Biotechnology ....................... 9

## Lessons

Introduction to Human Inheritance ..................................... 17

Farming, Food and Heredity .............................................. 25

Applying Heredity Concepts ............................................. 27

Use of Biotechnology in Selecting the Right Plants .......... 49

Enhancing Our World Research Project and Presentation ...... 57

## Teacher Resources

Teacher Resources and References ..................................... 61

Biotechnology and Related Web Sites ............................... 64

Related Literature .......................................................... 66

Common Core and Next Generation Science Standards ...... 67

Glossary ............................................................................ 88
The California Foundation for Agriculture in the Classroom is dedicated to fostering a greater public knowledge of the agriculture industry. The Foundation works with K-12 teachers and community leaders to help young people make informed choices by incorporating agricultural examples into classroom curriculum.

The development of this unit was funded in 2014 by Monsanto Fund to provide teachers with lessons in science and biotechnology that meet California’s Common Core and Next Generation Science Standards.

The Foundation would like to thank the people who helped create, write, revise, and edit From Genes to Jeans II. Their comments and recommendations contributed significantly to the development of this unit. However, their participation does not necessarily imply endorsement of all statements in the document.

**Curriculum Writing Committee**

Lara Alpan
Monsanto

Jason Brennan
Sheldon High School

Haley Clement
Liberty Ranch High School

Shaney Emerson
California Foundation for Agriculture in the Classroom

Dave Menshew
James C. Enochs High School
Introduction

Science education is evolving. With the adoption of the Next Generation Science Standards, a greater emphasis is being placed on the interconnected nature of science as it practiced in the real world. Students are being asked to gather evidence through scientific inquiry to solve real-world problems. This shift in education reflects the skills needed by agriculturalists on a daily basis. Agriculturalists must utilize scientific technology, inquiry, and problem-solving skills every day as they advance the industry in producing a quality product for a growing population.

This unit was designed utilizing themes in the Next Generation Science Standards as well as real world application to the agricultural industry. The lessons may be used independently or as a self-contained unit which covers in depth the concepts of genetics including an introduction to human inheritance, genetic breeding, Punnett squares, the importance of genetic diversity, biotechnology, gene marker selection, and the use of biotechnology for sustainable agriculture.

The activities provided in this unit are a reflection of the current trends in agriculture and allow students to research and explore concepts being discussed, researched, and analyzed on a global level. Students are provided the scientific principles and tools associated with genetics and encouraged to use their knowledge to think critically, creatively, and freely about the viability and ethics associated with biotechnology, genetically modified organisms, and agriculture.
# Unit Overview

## Unit Length

Nine to eleven 50-minute class periods (approximately 2-3 weeks)

## Objectives

*The student will:*

- Compare variations in human traits through data collection both inside and outside of class.
- Describe how traits are inherited and why this results in variation of phenotypes.
- Apply knowledge of heredity as they develop a breeding plan for a scenario in which they inherit a tomato farm that has been suffering from a blight fungus.
- Complete monohybrid and dihybrid Punnett squares and apply these skills in a real world scenario with cotton plants.
- Simulate how a type of biotechnology called Marker Assisted Selection is used to identify crop plants that have desirable traits such as sweet tasting fruit or natural resistance to a pest or disease.
- Utilize genetics concepts from prior lessons to create and promote a potential new agriculture product that uses

## Brief Description

This self-contained science unit of instruction allows students to hone basic genetic concepts and skills through defined vocabulary, and provided explanations all the while applying the terms to agricultural concepts used in the industry.

The unit begins with *Introduction to Human Inheritance*, a lesson exploring heredity and genetic traits. Immediately, students are engaged through an interactive game describing human traits proceeded by an activity that requires the observation, recording, and graphing of recessive phenotypes.

In the second lesson *Farming, Food, and Heredity*, students apply the learned information from the first lesson to develop a breeding plan for a scenario in which they inherit a tomato farm that has been suffering from a blight fungus. In teams, students utilize their knowledge of genetic breeding to save their tomato farm all the while experiencing the importance of genetic diversity within a population.

In the lesson *Applying Heredity Concepts*, students practice the use and understanding of Punnett Squares to predict the outcomes of monohybrid and dihybrid crosses. With that knowledge in hand, students develop a cotton farm growing naturally blue colored cotton, only to discover pests are devouring their fields. Students are introduced to Bt cotton and must discuss the possibility of working with geneticists to genetically enhance their blue and white streaked cotton crop.

In the lesson *Use of Biotechnology in Selecting the Right Plant* students are introduced to nucleotide base pairings and how this allows for scientists to build genetic markers in the lab to identify desired genes.

Finally students apply all genetic concepts in a research project where they assume the responsibility for the creation and promotion of a new agricultural product that matches the need for increased food production with the requirement it must be sustainable for future generations.

## Common Core and Next Generation Science Standards

A concerted effort to improve student achievement in all academic areas has impacted education throughout California. The California Foundation for Agriculture in the Classroom provides educators with numerous resource materials and lessons that can be used to teach and

---

*www.LearnAboutAg.org*
Unit Overview

reinforce Common Core and the Next Generation Science Standards for California Public Schools. The goal of educators is to encourage students to think for themselves, ask questions, and learn problem-solving skills while learning the specific content needed to better understand the world in which they live.

This unit, From Genes to Jeans II, includes lessons that teach standards covered for middle schools and high schools or reinforce many of the educational content standards covered in grades 6-12. It can be used as a self-contained unit, to enhance the lessons already in use, or provide technical information in the areas of genetics and agriculture.

The specific subject matter content standards covered in the lessons are listed on the sidebars of each lesson. A complete listing of Next Generation Science Standards for California Public Schools including Science and Engineering Practices, Disciplinary Core Ideas, Crosscutting Concepts, and ELA/Literacy concepts addressed in each lesson for both middle school and high school for each lesson are identified on page 67.
Unit Overview

Sequence of Events

1. Review the enclosed background information, lessons, and student worksheets. Make appropriate changes to the unit to meet the needs of your students, facilities, time frame, and teaching style.

2. Gather appropriate supplies and resource materials.

3. Complete the activities in the following order:
   - Introduction to Human Inheritance
   - Farming, Food, and Heredity
   - Applying Heredity Concepts
   - Use of Biotechnology in Selecting the Right Plants
   - Enhancing Our World Research Project & Presentation

Evaluation

This unit incorporates numerous activities and questions that can be used as evaluation tools, many of which can be included in student portfolios. The concluding activity, Enhancing Our World Research Project & Presentation requires the students to apply what they have learned to a hypothetical, yet realistic, situation. Other evaluation factors may include active participation in class discussions and general knowledge acquired about the subject matter.

Visual Display Ideas

- Create a collage or free-standing display of products changed through biotechnology. Examples may include tomatoes, cotton, canola oil, papayas, soybeans, corn, and rice.
- Make a display of chromosomes, DNA molecules, genes, and proteins.
- Show the process of protein synthesis using a sequential flow chart.
- Create a display illustrating the sequence of events that occurs to produce a genetically modified plant product.
- Use pictures, graphs or charts to show the specific number of chromosomes in particular plants and animals.
Background Information on Biotechnology

While the study of genetics and biotechnology is complicated, there are many simple components that can be incorporated into the classroom. The following information can help you better understand the subject matter and relay this information to your students.

What is biotechnology?

Biotechnology can be defined as the controlled and deliberate manipulation of biological systems (whether living cells or cell components) for the efficient manufacture or processing of useful products. The fact that living organisms have evolved such an enormous spectrum of biological capabilities means that by choosing appropriate organisms it is possible to obtain a wide variety of substances, many of which are useful to man as food, fuel and medicines. Over the past 30 years, biologists have increasingly applied the methods of physics, chemistry and mathematics in order to gain precise knowledge, at the molecular level, of how living cells make these substances. By combining this newly-gained knowledge with the methods of engineering and science, what has emerged is the concept of biotechnology which embraces all of the above-mentioned disciplines. (Dublin City University)

What is genetic engineering?

Genetic engineering is a process in which genetic material (DNA) is taken from one organism and inserted into the cells of another organism, often of a different species. Genetic engineering can also be a rearrangement of the location of genes. The new “altered” organism then makes new substances or performs new functions based on its new DNA. For example, the protein insulin, used in the treatment of diabetes, can now be produced in large quantities in a laboratory by genetically modified bacteria and yeast. Insulin was formerly extracted from the pancreas of pigs.

What can genetic engineering do?

- It can improve the ability of an organism to do something it already does. For example, an adjustment in the amino acid balance in a particular corn variety improves its storage ability. A genetically enhanced rice variety is resistant to Bacterial Blight due to the insertion of an Xa21 gene that increases its resistance to the disease-causing microbes.

- It can suppress or stop an organism from doing something it already does. For example, the gene that codes for the softening
of tomatoes is “turned-off” in a genetically modified tomato variety. This allows the tomato to stay on the vine longer, producing more flavorful fruit that is firm enough to easily transport.

- It can make an organism do something new that it has never done before. For example, bacteria and yeast have been genetically modified to produce chymosin, an enzyme used to make the milk form curds in cheese production. A new genetically enhanced rice, called “Golden Rice,” has been modified to make beta-carotene, the precursor for Vitamin A. This advancement may end Vitamin A deficiency in children worldwide, one of the leading causes of blindness and other health problems.

**What is a gene?**

A gene is a sequence of DNA, which serves as a blueprint for the production of proteins in all living things. Thousands of genes make up chromosomes. DNA is found in the nuclei of cells with the exception of bacteria and viruses. Bacteria have their DNA in nuclear areas called nucleoids; viruses have their DNA coiled up in the cytoplasm of cells. DNA is made of sugars, phosphates, and four nitrogen-containing bases: adenosine, cytosine, guanine, and thymine. A gene codes for a specific protein or has an assigned function.

**What is a protein?**

Proteins are chains of amino acids that perform the necessary functions of living organisms. When a gene is “expressed” that means it is translated into protein. Proteins are essential chemicals for cell structure and activities such as reproduction, movement, and metabolism or defense (antibiotics). Some proteins perform specific functions themselves (such as insulin and muscle protein); others cause the production of cell components (such as enzyme proteins that assist in making carbohydrates and fats); and others are structural such as flagella and cilia.

**What are some examples of genetically modified products?**

- Human growth hormone, which is produced naturally in the pituitary gland, can now be produced through genetic engineering technology. There are now nearly 500 genetically engineered biopharmaceuticals approved for use in the United States or Europe.
A vaccine for wild animals that protects against the rabies virus.

Oil-eating bacteria that efficiently clean up oil and gasoline spills.

A genetically altered canola (rapeseed) plant, which produces healthier edible oils.

A tomato that delays the onset of softening and rotting.

Plants, such as cotton, that are resistant to herbicides allowing farmers to kill weeds without harming the crop.

Varieties of fruits and vegetables that can be altered to resist plant viruses.

A cheese that can be made using bacterial-fermented rennet (an enzyme formerly taken from calves’ stomachs).

Plants that produce insecticidal proteins called Bt toxin thereby reducing the need for chemical pesticides.

Rice that produces beta-carotene, the precursor of Vitamin A, can be used to reduce blindness and other diseases.

U.S. farmers planted an estimated 169 million acres of GE crops (42% of their total crops) in 2013, including 93% of the soybeans, 90% of the cotton and 90% of the feed corn being genetically engineered.
How do we know that genetically modified plant foods are safe?

The United States has the safest food supply in the world. Advanced technology, as well as standards and regulations set by food producers and governmental agencies, have allowed the United States to maintain its safe food record. The following information will help you better understand the genetic engineering food safety guidelines.

Before any plant food developed through biotechnology is made available to the public, it undergoes a safety evaluation. The United States Food and Drug Administration (FDA), in 1992, issued testing guidelines for genetically modified foods. The specific policies are under the title “Foods Derived From New Plant Varieties.” There are different policies for products other than plants. The genetically modified plant food product guidelines are summarized as follows:

- Genetically modified plant foods shall be regulated the same as traditionally produced foods.

- The food products will be judged on their individual safety, allergenicity, toxicity, etc., rather than on the methods used to produce them.

- Any new food additive produced via biotechnology will be evaluated for safety employing the same guidelines used for a traditional food additive (such as food coloring).

- Any food product that is found to contain material that could render it unsafe will not be allowed to enter commerce.

- If the introduced product contains an allergen or if the production of the food has altered its nutritional value, then the FDA may require informational labels.

In addition to the FDA, the United States Department of Agriculture (USDA) and the Environmental Protection Agency (EPA), are also committed to ensuring the safety of bio-engineered foods.

As is the case for any food product, genetically modified food found to contain substances not in keeping with the safety guidelines may be removed from the marketplace by the FDA. The United Nation's World Health Organization continues to debate the policies revolving around genetically altered food products.
The following information was taken from USDA website: www.usda.gov/wps/portal/usda/usdahome?navid=AGRICULTURE&contentid=BiotechnologyFAQs.xml

The Federal Government developed a Coordinated Framework for the Regulation of Biotechnology in 1986 to provide for the regulatory oversight of organisms derived through genetic engineering. The three principal agencies that have provided primary guidance to the experimental testing, approval, and eventual commercial release of these organisms to date are the USDA’s Animal and Plant Health Inspection Service (APHIS), the Environmental Protection Agency (EPA), and the Department of Health and Human Services’ Food and Drug Administration (FDA). The approach taken in the Coordinated Framework is grounded in the judgment of the National Academy of Sciences that the potential risks associated with these organisms fall into the same general categories as those created by traditionally bred organisms.

Products are regulated according to their intended use, with some products being regulated under more than one agency. All government regulatory agencies have a responsibility to ensure that the implementation of regulatory decisions, including approval of field tests and eventual deregulation of approved biotech crops, does not adversely impact human health or the environment.

The Animal and Plant Health Inspection Service (APHIS) is responsible for protecting U.S. agriculture from pests and diseases. APHIS regulations provide procedures for obtaining a permit or for providing notification prior to “introducing” (the act of introducing includes any movement into or through the U.S., or release into the environment outside an area of physical confinement) a regulated article in the U.S. Regulated articles are organisms and products altered or produced through genetic engineering that are plant pests or for which there is reason to believe are plant pests.

The regulations also provide for a petition process for the determination of non-regulated status. Once a determination of non-regulated status has been made, the organism (and its offspring) no longer requires APHIS review for movement or release in the U.S.

For more information on the regulatory responsibilities of the FDA, the EPA and APHIS please see the following: www.fda.gov, www.epa.gov, www.aphis.usda.gov/biotechnology/regulations.shtml
How do we know if genetically modified plants are safe for the environment?

In order to be sure that genetically modified crop plants are safe, the USDA oversees all field-testing of genetically modified products. Before a new crop can move into commercial production, the USDA reviews the field-testing results. Field-testing results and studies must demonstrate that plants altered using biotechnology react with ecosystems in the same ways as their traditionally produced plant counterparts. Detailed research in this area continues.

What are some risks associated with genetically modified plants?

As with any new technology, risks must be considered. Some criticisms of genetic engineering practices include the possibility that modifications in the genetic make-up of the plant could result in some type of unknown toxin. The odds of that occurring in normal plant breeding and selection are far greater than that occurring in genetic engineering. Genetic engineering involves only the movement of specific genes with specific functions. In traditional plant breeding, crosses between different varieties and wild relatives result in the transfer of many genes.

The potential of gene flow to closely-related plant species is a risk when the gene expressed is in the pollen. That could mean that herbicide resistance genes inserted into beneficial plants could be passed to closely related weed species. New methods are being developed to prevent this from occurring and detailed research continues.

The science of biotechnology is carefully monitored and the risks associated with any products and processes, such as allergens and ecological impacts are constantly addressed. Detailed papers and transcriptions from World Health Organization meetings can be viewed on several of the web sites listed on page 64.

How can genetic engineering benefit agriculture?

With increasing food and fiber needs around the world and the loss of farmland to urbanization, farmers must constantly find ways to increase yields. As farmers continue to look for renewable and safe ways to control pests and fertilize plants, geneticists continue their research to assist agriculture.
Disease resistant plants are being developed through genetic modification. For example, mungbeans, a staple in Asia, can now be grown without the use of pesticides. Strawberry plants have been genetically altered to be resistant to root pests and fungi. The papaya industry in Hawaii was saved by a single gene insertion for viral coat protein. The papaya plants are now resistant to the papaya mosaic virus.

Herbicide tolerant cotton has been developed through genetic engineering. The herbicide bromoxynil is degraded in the cotton plant. This allows the cotton field to be sprayed with bromoxynil to kill weeds without affecting the cotton plant itself. Roundup® resistant cotton has also been developed. These methods of weed control are very efficient and greatly reduce the total amount of herbicide used on cotton while increasing the yield of cotton per acre.

Genetic engineering is helping farmers diversify their crops. For example, ethanol produced from plant oils such as canola and soybeans can be used as a fuel, and starches genetically added to potatoes can be used to produce biodegradable plastics. Uses such as these also reduce the nation's dependence on fossil fuels.

What are the basic procedures for producing a genetically modified plant product?

The actual procedures for producing a genetically engineered product are very complex and vary from product to product. However, most genetically engineered products are produced using the basic steps described below:

1. **Trait Identification**: Traits of organisms are identified.

2. **Gene Discovery**: Genes with a desired function are identified.

3. **Gene Cloning**: The desired gene is placed into a bacterial cell (usually Agrobacterium) and, as the bacteria reproduce, the desired gene is also copied and reproduced.

4. **Gene Verification**: Researchers study the copies of the gene using molecular techniques to verify that the replicated gene is precisely what is wanted.

5. **Gene Implantation**: Using a bacterium or gene gun, the desired DNA (gene) is transferred into the chromosomes of plant cells in nature.
6. **Cell Regeneration**: Researchers select the plant cells that contain the new gene and regenerate whole plants from the selected plant cells.

7. **Testing New Plant**: Laboratory and field-testing occur to verify the function and safety of the new plants.

8. **Seed Production**: Seeds with the desired traits are produced using standards set for specific crop production.

**Why is genetic engineering becoming such a popular science?**

Genetic engineering offers new approaches to the solutions of problems caused by an increasing world population—the increase in demand for food, energy and healthcare. It allows the production of scarce biological substances, new and better pharmaceuticals and more nutritious foods. It can provide new sources of energy through the production of biofuels (fuels produced by plant oils) and improve crop yields. Genetic engineering is another tool available to meet challenges in these areas.

While the study of genetics and biotechnology is complicated, there are many simple components that can be incorporated into the classroom. The following information can help you better understand the subject matter and relay this information to your students.
Introduction to Human Inheritance

**Purpose**

Students will compare variations in human traits through data collection both inside and outside of class. Students will describe how traits are inherited and why this results in variation of phenotypes.

**Time**

Two, 50–minute sessions

**Materials**

*For the teacher:*

- PowerPoint, The Wonderful World of Diversity: Introduction to Human Inheritance found at [www.LearnAboutAg.org/lessonplans](http://www.LearnAboutAg.org/lessonplans)

*For each student:*

- Note paper and pencil
- Student Worksheet if desired

**Standards**

This lesson supports California Standards for Common Core Mathematics, English Language Arts and Next Generation Science Standards for Grades 6-12. See page 67 for a complete listing.

**Background Information**

There are two parts to this lesson.

**Part 1**

Introduce or review concepts of traits and inheritance using the “In the Family Game.”

**Part 2**

Students conduct a survey to explore variation in traits.

**Heredity** is the passing of traits from one generation of organisms to the next. The term trait refers to characteristics such as flower color or hair color.

Geneticists are scientists who study heredity. Gregor Mendel was an Austrian monk who was able to explain how traits are passed from parent to offspring through extensive research with pea plants in the 1800s. Mendel’s work established the basic principles of genetics. As a result of Mendel’s work, we know:

- Every living thing contains deoxyribonucleic acid (DNA) in its cells. DNA consists of base pairs, Adenine (A), Guanine (G), Cytosine (C), and Thymine (T) which are essentially the blueprints for life because our DNA codes for every one of our traits. DNA is coiled up into rod-like structures called chromosomes. Chromosomes carry our genes which are units of heredity that determine our traits.

- Humans and other organisms inherit one gene for each trait from each parent to create a set of genes that code for every single characteristic. For example: a human has 46 chromosomes and inherits 23 from their mother and 23 from their father. Every characteristic is determined by the chromosomes inherited by each parent. Eye color, hair color, and height are all determined by your genetic code inherited from each parent.

- Genes are passed on from parents to offspring in unchanging units.

- When reproductive cells (eggs and sperm) form, gene pairs separate so that each egg or sperm only contains one gene for each trait. Therefore, when a sperm fertilizes an egg, the offspring receive one copy of each gene from each parent for each trait.
Alleles are the name geneticists use to refer to variations of a trait or gene. There are many variations of genes which code for flower color, hair color, eye color and much more.

Pairs of alleles that are alike are called homozygous and pairs that are different are called heterozygous. In the case of heterozygous alleles, one allele usually expresses itself and the other allele remains hidden or masked. The allele that is expressed is referred to as the dominant allele and the allele that is hidden is referred to as the recessive allele. For example: If a curly tail is dominant to a straight tail, a puppy who received a curly tail allele from its mother and a straight tail allele from its father will have a curly tail.

The puppy’s genotype is listed as the alleles that were inherited (Cc) where C = curly tail allele and c = straight tail allele. The puppy’s phenotype is what it looks like, a curly tailed puppy.

Variations in people, other animals, and plants arise because offspring are a combination of characteristics from both parents. Variations can also result from mutations in DNA. Mutations are changes in the genetic code which occurs as DNA replicates and accidently deletes, inverts, or transforms the original code. They are rare and may result in beneficial, neutral or harmful changes to an organism.

Procedure

Part 1: Class Traits

1. Begin the lesson with the PowerPoint titled “The Wonderful World of Diversity: Introduction to Human Inheritance” found at www.LearnAboutAg.org/lessonplans. Generate student interest by playing the “In the Family Game.” Begin by choosing a trait such as hooded sweatshirt (but do not tell students what the trait is). Tell each student who is wearing a hooded sweatshirt, “You are in the family.” Then have students look around the room at the students who are in the family to determine what they have in common. Do a couple of other examples such as students who are wearing blue jeans, students who are right or left handed, and students who are writing with a pencil or pen.

Note: Keep examples non-personal so students don’t feel like they are being singled out for certain traits.
Introduction to Human Inheritance

2. Ask students why people would be interested in how traits are inherited. Discuss class thoughts and how scientific studies in heredity are important in modern medicine and why knowledge of inheritance is also very important to the farmers who produce the food we eat, the flowers we enjoy and the fabric to make our clothes.

3. Click on the PowerPoint slide titled “Talk the Talk” and instruct students to take 15 minutes to turn to a partner and divide up the words. Each student should look up the definition to their word and write it down so they can explain it to their partner. Students can use books or smartphones to access definitions. Let students know that these definitions are important to keep on hand for the next steps in the lesson. Definitions are also found in the glossary on page 88.

4. Project the “Human Traits” slide from the PowerPoint. Students should record their phenotype for the following traits in their journal or on a separate piece of paper. Capital letters are used to represent dominant traits. Remind students that in order to express a recessive trait, they must have received the recessive gene from both parents.

   - Widow’s peak (w) No Widows Peak (W). My phenotype is: __________________
   - Dimples (D) No Dimples (d). My phenotype is: _____________
   - Freckles (F) No Freckles (f). My phenotype is: _____________
   - Hand Cross Right Thumb on Top (R) Left Thumb on Top (r). My phenotype is: _____________
   - Tongue Rolling (T) No Tongue Rolling (t). My phenotype is: _____________
   - Free earlobe (E) Attached Earlobe (e). My phenotype is: _____________

5. Once students have recorded their own phenotypes, project the following on the screen/board and complete as a class.
# Introduction to Human Inheritance

<table>
<thead>
<tr>
<th>Trait</th>
<th>Class Tally</th>
<th>Ratio Students with Trait / Total Students</th>
<th>Percent of Students with each Trait</th>
</tr>
</thead>
<tbody>
<tr>
<td>Widow’s Peak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Widow’s Peak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimples</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Dimples</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freckles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Freckles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Thumb Cross</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Thumb Cross</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tongue Roller</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non Tongue Roller</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free Earlobe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attached Earlobe</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Ask students, “How many classmates matched your trait for earlobes, tongue rolling, thumb crossing, freckles, dimples, and widow’s peak?”

- Instruct students to work with a partner to make a graph of the results for number of students expressing the recessive phenotype. Students should also make a graph for the results of the number of students expressing the dominant phenotype. Students should use a double bar graph to express this information.

## Part 2: Variability in Traits

1. Explain to students that they will be conducting a survey to investigate how the traits they investigated in class vary amongst other groups. Have students work in pairs to determine who they will survey. Survey groups could include friends, family, or other people who agree to participate in the survey. Students should create their own tally sheet and should use the same traits they investigated in class for the survey. The survey can be done as homework.

*Optional: If given permission, students may take photos of people they survey to document evidence.*
2. Once the survey has been conducted, have students examine their data in class. Class discussions should include:

   a. Ask students how many people matched their trait for earlobes, tongue rolling, thumb crossing, freckles, dimples, and widow’s peak?

   b. How are these results different from the survey results from the first part of the lesson that only included your classmates?

   c. In this investigation, we compared 6 traits. Approximately 20,500 traits contribute to the make-up of each human being. All of our genes are called our genome. Each of us shares the same 99.9% of our genes. The .01% that varies is what makes us all different.

3. Instruct students to use key vocabulary in a well written paragraph explaining how traits are inherited and why this results in a wide range of phenotypes.

Extension

In groups of two, have students make a two-sided list of human similarities and differences. On one side, students should list traits that all humans share (two eyes, two ears, etc.) On the opposite side, students should list traits where differences occur (eye color, height, etc.). Remind students that learned traits refer to characteristics we are born with, not habits, or skills that we develop over time. For example, being a fashionable dresser is not an inherited trait.

On PowerPoint Slide . . . Dominant and Recessive Traits

- For each of our traits, we inherit one allele from Mom and one from Dad.

- One allele usually expresses itself (we can see it) and the other remains hidden. The expressed allele is dominant and is represented by a capital letter and the allele we can’t see is recessive and is represented by a lower case letter.

Example: If curly tail is dominant to straight tail, a puppy who received a curly tail allele from its mother and a straight tail allele from its father will have a curly tail.
Genetics

Name: ____________________________

Define these important genetic terms:

Heredity ____________________________________________________________

______________________________________________________________________

Trait ________________________________________________________________

______________________________________________________________________

Gene ________________________________________________________________

______________________________________________________________________

DNA ________________________________________________________________

______________________________________________________________________

Chromosome _________________________________________________________

______________________________________________________________________

Allele ________________________________________________________________

______________________________________________________________________

Genotype ____________________________________________________________

______________________________________________________________________

Phenotype ____________________________________________________________

______________________________________________________________________

Heterozygous _________________________________________________________

______________________________________________________________________

Homozygous _________________________________________________________

______________________________________________________________________
Genetics (continued)

- Widow’s peak (w) No Widow’s Peak (W). My phenotype is: ____________
- Dimples (D) No Dimples (d). My phenotype is: ____________
- Freckles (F) No Freckles (f). My phenotype is: ____________
- Hand Cross Right Thumb on Top (R) Left Thumb on Top (r). My phenotype is: ____________
- Tongue Rolling (T) No Tongue Rolling (t). My phenotype is: ____________
- Free earlobe (E) Attached Earlobe (e). My phenotype is: ____________

Graph your results.
Farming, Food, and Heredity

Purpose

Students will apply their knowledge of heredity as they develop a breeding plan for a scenario in which they inherit a tomato farm that has been suffering from a blight fungus.

Time

50 minutes

Materials

For the teacher:

- PowerPoint: Farming, Food, and Heredity found at www.LearnAboutAg.org/lessonplans

For each student:

- Paper and pencil
- What’s the Difference Between a Strawberry and a Strawberry? www.ars.usda.gov/is/kids/plants/story10/strwbrry.html

Standards

This lesson supports California Standards for Common Core Mathematics, English Language Arts and Next Generation Science Standards for Grades 6-12. See page 67 for a complete listing.

Background Information

For thousands of years, people have been domesticating wild animals and plants for food. In the process, people discovered that they would often improve the quality of future crops if they chose to breed the plants and animals that displayed desired characteristics. For example, we didn’t always have separate breeds of dairy and beef cattle. These breeds resulted after many years of selective breeding by farmers and ranchers who chose to breed cattle for either milk or meat production.

Procedure

1. Begin the lesson by posing the following question to students:

   How does heredity affect agriculture or the food we eat every day? Think just about apples. Have we always had so many varieties of apples to choose from at the grocery store? Is there one variety of apple that you like the best and choose over others? (Teacher could have a variety of apples on display).

2. It is said that we first eat with our eyes and nose and if something doesn’t look or smell good we are unlikely to taste it. Explain that people have been selecting the best tasting, highest producing, and hardiest plants for thousands of years. This was mainly accomplished by saving the seeds of plants that produced fruits or vegetables with a trait that people liked. For example, your great grandmother may have saved seeds from her sweetest tasting tomatoes and passed these down to younger generations in the family who continued to plant them and save seeds.

   Refer to the Farming, Food, and Heredity PowerPoint to discuss the example of Teosinte and modern corn with the class. www.LearnAboutAg.org/lessonplans

3. Either print out, or have students go online to read the article, What’s the Difference Between a Strawberry and a Strawberry? www.ars.usda.gov/is/kids/plants/story10/strwbrry.html

4. Introduce to students the tomato farm challenge. Use the PowerPoint slides to explain the scenario and concept mapping assignment:

   Farmers use genetic breeding to create better tasting and better quality produce. Today, you will need to think like a farmer and use your knowledge of genetics because you have inherited great uncle Hector’s...
Farming, Food, and Heredity

tomato farm and the farm has a problem that you must solve. You go to visit the tomato farm and are told that most of the tomato plants have died after being infected by a fungus. The good news is that there are still a small number of remaining tomato plants that don’t seem to be infected with the fungus. From a breeding standpoint, what could you do to keep next year’s tomato plants from being killed by the fungus?

5. Students may work in groups on their concept maps to determine the best approach to take for breeding fungus resistant tomato plants. After students have completed the assignment you can discuss different approaches that each group took and discuss how some plants are naturally more resistant to certain diseases than other plants.

Disease resistance is a desirable trait for plant breeders and farmers. In developing resistant varieties of tomatoes, breeders may select and cross pollinate tomato plants that survived being exposed to early blight fungus. The seeds from these plants would then be planted and the new plants would be exposed to the blight fungus once again to see which of the plants inherited the disease resistant traits from their parents.

The resistant plants would be selected and the process would be repeated numerous times to develop a variety of tomato that is consistently resistant to early blight fungus.

6. Ask students why they think it is important to maintain genetic diversity in a population.

How can genetic diversity help when a population of tomato plants is exposed to a new type of disease?

A large gene pool usually means that the population will have a better chance of surviving a disturbance in the environment, or a new disease because at least some of the individuals will have inherited a trait that provides them with some resistance to the new disease or an ability to survive new conditions in the environment. Genetic diversity also makes the population less susceptible to inherited disorders which can become a problem with inbreeding.
Applying Heredity
Concepts

Purpose

In this lesson, students will complete monohybrid and dihybrid Punnett squares in preparation for taking on a challenge to breed cotton plants that produce naturally blue colored cotton.

Time

Two to three 45–minute sessions

Materials

For the teacher:

- Understanding Heredity PowerPoint
  www.learnaboutag.org/lessonplans

For each student:

- Vocabulary worksheet
- Background Information About Cotton worksheet
- Punnett Square questions (page 33)

Standards

This lesson supports California Standards for Common Core Mathematics, English Language Arts and Next Generation Science Standards for Grades 6-12. See page 67 for a complete listing.

Background

Students should have some prior knowledge of Gregor Mendel and inheritance but it will be helpful to review the key vocabulary as you begin the lesson. One way to do this would be to give students the list of words without the definitions. Post the definitions around the room on poster paper. Students should make sense of the definitions by drawing an explanation of each on their handout. Handouts and enlarged definitions are available at the end of this lesson.

- DNA: Deoxyribonucleic acid, a double-stranded helical molecule that carries genetic information.
- Chromosomes: Single strands of DNA that are tightly packaged into a concentrated mass. Different species have different numbers of chromosomes. Human cells contain 46 chromosomes in the cell nucleus. Dogs have 78, cats have 38, mosquitoes have 6, and horses have 64 chromosomes. Half of our chromosomes are inherited from our father and half are inherited from our mother.
- Genes: Specific segments of DNA that are like instructions for all of our characteristics such as the shape of our nose and color of our hair.
- Heredity: The transmission of characteristics from parent to offspring through genes.
- Character: A feature that is inherited such as flower color, hair color, and height.
- Trait: Different variations of a character, such as purple flowers, white flowers, red fur, etc.
- Alleles: Variations of a gene. For example, flower color, fur color, and hair color.
- Phenotype: Observable characteristic such as a dog’s fur color.
- Genotype: The alleles that an individual has inherited such as one allele for brown fur and one allele for yellow fur.
- Homozygous: Having two identical alleles for a certain characteristic. For example, inheriting one allele that codes for white flowers from one parent and one allele that also codes for white flowers from the other parent.
Applying Heredity Concepts

Middle School

MS-LS1-5
MS-LS3-2
MS-LS4-5
LS1.B
LS3.A
LS3.B
LS4.B
ELA/Literacy
RST.6-8.7
WHST.6-8.9
6.SP.B.5

High School

HS-LS3-1
HS-LS3-2
HS-LS3-3
LS1.A
LS3.A
LS3.B
ELA/Literacy
RST.11-12.1
RST.11-12.9
WHST.9-12.1

Ag Standards

5.0
5.1
5.3
C2.0
C2.2
C3.0
C3.3
C7.0
C7.1
C7.2
C7.3
D5.0
D5.4
G2.0
G2.5

- **Heterozygous**: Having two different alleles for a certain characteristic. For example, inheriting one allele that codes for purple flowers from one parent and one allele that codes for white flowers from the other parent.

- **Dominant trait**: The trait or allele that is expressed even if an individual has only inherited one copy of that allele.

- **Recessive trait**: Expressed only if an individual has inherited a copy of the recessive allele from both parents.

  *Example:*

  dominant allele + dominant allele = dominant phenotype  
dominant allele + recessive allele = dominant phenotype  
recessive allele + recessive allele = recessive phenotype

- **Incomplete dominance**: Offspring of two true breeding parents does not resemble either parent, but is an intermediate of both parents. For example, if a red flower were crossed with a white flower, the offspring would have pink flowers.

- **Codominance**: Offspring of two true breeding parents resemble both parents and neither trait is completely dominant. For example a blue flower crossed with a yellow flower would produce offspring with blue and yellow striped flowers.

Punnett squares are one tool that scientists, farmers, and ranchers use to predict the outcome of potential crossings of two parents. It is important for students to understand that genetics are very complex and that the Punnett squares in this activity are simplified in order to teach the foundational concepts of inheritance.

Cotton is used as an example in this lesson. Cotton is grown in many states throughout the U.S. including California.

Cotton is the nation's fifth largest crop. Most of the cotton crop goes into clothing apparel and material for home furnishings. Cottonseeds and cottonseed meal are byproducts of cotton production which are used as feed for cattle and poultry. Cottonseed oil is used in salad dressing, margarine and other oils. United States paper money is made of 75% cotton.

The cotton plant grows wild in some places of the world and has been farmed for centuries. Shreds of cotton cloth have been found that date back at least seven thousand years. Wild cotton can be found in shades
Applying Heredity Concepts

of green and brown, as well as white. Most commercial cotton is white due to many years of selective breeding by farmers. White cotton is dyed with fabric dyes in the clothing manufacturing process.

Cotton Production

- Soil is prepared by loosening it, removing weeds, and adding fertilizer.
- When soil reaches about 65 degrees, cotton seeds are planted.
- Depending on the area of the country and the climate, plants may be watered by natural rainfall or in dryer areas, irrigation water must be delivered to the cotton plants.
- A combination of methods are used to remove weeds including cultivator machines, hand hoeing, and herbicides so that weeds don’t outcompete the cotton for water, sunlight, and nutrients.
- Nutrient requirements are monitored and fertilizer may be added as needed.
- Integrated pest management using a combination of insecticides and beneficial insects may be used to control pests that could otherwise destroy the cotton crop.
- When cotton bolls open, harvest aids are applied to help speed up the plant’s maturation. The leaves then dry and fall off making it easier to harvest the cotton bolls which must be gathered before weather damages the cotton. Mechanical cotton pickers harvest the cotton. Cotton is then packed into modules and transported to the cotton gin where the cotton fibers will be separated from the cotton seed.
- The cleaned, raw cotton fiber is called lint and will be baled into large rectangles each weighing 500 pounds to be shipped off to textile mills where it will be woven into fabric.

In the 1980s a scientist named Sally Fox was involved in research for a cotton breeder in Davis, California who was attempting to identify plants with a natural resistance to pests. During her research, Sally came across plants that had brown cotton fiber rather than white.

Although these plants displayed some pest resistant qualities, they were not useful for fabric due to their color and short fibers. Despite this fact, Sally continued to collect and plant seeds from the brown cotton plants. She selected seeds from the plants that produced brown cotton with
Applying Heredity Concepts

the longest fibers. Over time, Sally nurtured a variety of brown cotton plants that had fibers that were long enough to be woven into fabric. She formed FoxFibre® and began to sell various shades of naturally brown and green cotton to major clothing companies.

One of the many challenges of growing cotton involves managing the number of pests that eat cotton, the cost of purchasing and applying pesticides, and pest resistance to some pesticides. Bacillus thuringiensis soil bacteria can be easily cultured by fermentation and is produced as an insecticide permitted for organic farming worldwide. This insecticide has been in use as a spray or ground application for over 40 years. However, this type of application does not protect the plant from pests for long because it can be washed away by water or degraded by the sun.

In searching for solutions to cotton pest problems, scientists developed a strain of genetically modified cotton by inserting genes from the soil bacterium Bacillus thuringiensis into the cotton plant genes. The genes of the soil bacterium produce a protein in the plant’s tissues that protect the plant from being eaten by pests such as the cotton bollworm and corn borers. This variety of cotton is commonly called Bt cotton.

Before Bt cotton could be planted for commercial production, it had to undergo many regulatory tests for toxicity and allergens to humans and other organisms. These tests were carried out by the U.S. Environmental Protection Agency (EPA). Bt is only toxic to specific insects that have receptor sites where the Bt proteins can bind in their guts. Humans, dogs, rats, fish, frogs, guinea pigs, salamanders, birds, honey bees, lady beetles, and most beneficial insects do not have these receptors and are not affected by Bt.

The advantage of Bt cotton is that fewer plants are lost to insect damage and less pesticide needs to be used. Bt cotton first became available in 1996 and as of 2013, approximately 75% of the cotton...
planted in the United States is Bt cotton. This article from the Los Angeles Times provides an interesting perspective on Bt cotton.

http://articles.latimes.com/2013/jun/06/science

**Procedure**

1. Prepare students for this lesson by reviewing the vocabulary (you can use the suggested activity or your own) and have students read the Background Information About Cotton worksheet.

2. Show part one of the Applying Heredity Concepts PowerPoint slides to the class. Take time to pause and allow groups of students to work out the monohybrid and dihybrid problems in the slides and then discuss them together as a class. After you have completed a few examples, distribute the Punnett Squares worksheet on page 33 and have students work in pairs to solve the problems.

3. Inform the class that for part two of the activity, they will be using their knowledge of genetics as they take on the role of a cotton farmer. You may wish to elaborate on how cotton is grown as you show the photos in the PowerPoint slides. America’s Heartland is a PBS broadcast featuring different agricultural crops in each episode. Episode 617 (Found in Season 6, 26 minutes long) provides a thorough overview of growing, harvesting, and processing cotton.

   www.americasheartland.org

4. Work through the Blue Genes Challenge questions by showing the slides. Then, have small groups work out the problems and discuss as a class.

5. For part three, use the corresponding PowerPoint slides to discuss the following with your students.

   *The codominant blue and white streaked cotton has become a sensation and clothing companies from around the world want to buy it because the special colored cotton does not need any acid wash or further processing to give it that cool, worn-in jeans look. This saves the clothing companies a lot of time, labor and money. Your farm is trying to produce enough cotton to meet the demand.*

   *However, there is a problem with pests…they seem to be devouring all of your blue and white streaked cotton. You have heard of a variation of cotton called Bt cotton and you wonder if this could be a solution to your problem.*
Applying Heredity Concepts

Share the background information on Bt cotton with your students and have a class discussion about the possibility of working with geneticists to have Bacillus thuringiensis genes inserted into your blue and white streaked cotton genes to provide protection from hungry insects. Have students write a paragraph explaining how Bt genes could enhance their blue and white streaked cotton crop and explain why or why not they would choose this approach to solve their problem.

Extensions

- Have students create Punnett squares for imaginary plants or animals and show the possible variations of their creatures using illustrations.

- Do a class research project on genetically modified cotton. Organize the class into small groups to research different aspects of the process including research, testing, public relations, pros, and cons. Instruct the class to research information from reputable sources such as the USDA and universities.
Punnett Squares

Name: __________________________

Directions: Work the following problems out in your notebook or on a separate piece of paper.

Monohybrid Crosses (Monohybrid crosses look at one character such as hair color.)

1. If striped squash (S) is dominant to spotted squash (s)
   a. Write the genotype for a homozygous dominant homozygous striped squash.
   b. Write the genotype of a homozygous spotted squash.
   c. Draw a Punnett square and cross the homozygous striped squash with the spotted squash.
   d. What percentage of the offspring are striped? What percentage are spotted?
   e. Draw a Punnett square and cross two offspring from the problem above.
   f. What percentage of this second generation appear striped squash? What percentage appear spotted?

2. In both male and female cattle, hornless or polled (H) is dominant to having horns (h). Perform the following crosses using Punnett squares and list the phenotype and genotype of each offspring.
   a. Heterozygous bull x cow with horns
   b. Homozygous polled bull x cow with horn

3. A calf is born with horns but neither one of its parents had horns. What are genotypes of this calf’s parents?

4. Incomplete dominance occurs when a hybrid cross of two true breeding parents does not resemble either one of the parents but instead resembles a blend of the two. For example, when a homozygous red snap dragon is crossed with a homozygous white snap dragon, all of the heterozygous offspring are pink.
   a. Show this cross in a Punnett square. Use AA for red, aa for white, and Aa for pink.
   b. Draw a Punnett square and cross two of the heterozygous offspring from the F1 generation. What percentage of the F2 generation are white? What percentage are pink? What percentage are red?
Punnett Squares (continued)

5. In the case of codominance, hybrids of two true breeding parents resemble both parents. For example a blue flower crossed with a yellow flower would produce an F1 generation that are all blue and yellow striped.

   a. Show the F1 generation using a Punnett square and BB for blue flowers and YY for yellow flowers.
   b. Now cross two from the F1 generation and show this F2 generation in a Punnett square. How many F2 generation flowers would be yellow? How many would be striped? How many would be blue?
   c. Show the F2 generation with Punnett square.

Dihybrid Crosses (Dihybrid crosses look at two characters such as hair color and tongue rolling.)

1. In rocker guinea pigs, spiky hair (S) is dominant to flat hair (s) and black spotted tongues (B) are dominant to pink tongues (b).

   a. If you cross a homozygous dominant mother (SSBB) with a homozygous recessive father (ssbb), what will the genotype of the offspring be?
   b. What is the phenotype of the offspring?
   c. If you have a parent who is SsBb, it could give SB, Sb, sB, and sb as gametes. Cross two parents who are heterozygous for both traits. Draw the Punnett Square.
   d. How many offspring will have flat hair and black spotted tongues? How many will have flat hair and pink tongues?
Punnett Squares Answer Key

Directions: Work the following problems out in your notebook or on a separate piece of paper.

Monohybrid Crosses *(Monohybrid crosses look at one character such as hair color.)*

1. If striped squash (S) is dominant to spotted squash (s)
   a. Write the genotype for a homozygous dominant striped squash. SS
   b. Write the genotype of a homozygous spotted squash. ss
   c. Draw a Punnett square and cross the homozygous striped squash with the homozygous spotted squash.

\[
\begin{array}{ccc}
S & S \\
s & Ss & Ss \\
s & Ss & Ss \\
\end{array}
\]

d. What percentage of the offspring are striped? 100% What percentage are spotted? 0%

2. In both male and female cattle, hornless or polled (H) is dominant to having horns (h). Perform the following crosses using Punnett squares and list the phenotype and genotype of each offspring.
   a. Heterozygous bull x cow with horns.

\[
\begin{array}{ccc}
H & h \\
h & Hh & hh \\
h & Hh & hh \\
\end{array}
\]

2 Hh = polled
2 hh = horns
b. Homozygous polled bull x cow with horns.

\[
\begin{array}{ccc}
  & H & H \\
 h & Hh & Hh \\
 h & Hh & Hh \\
\end{array}
\]

*All offspring = Hh = polled*

3. A calf is born with horns but neither one of its parents had horns. What are genotypes of this calf’s parents? **Hh**

4. Incomplete dominance occurs when a hybrid cross of two true breeding parents does not resemble either one of the parents but instead resembles a blend of the two. For example, when a homozygous red Snapdragon is crossed with a homozygous white Snapdragon, all of the heterozygous offspring are pink.
   a. Show this cross in a Punnett square. Use AA for red and aa for white.

\[
\begin{array}{ccc}
  A & A \\
  a & Aa & Aa \\
  a & Aa & Aa \\
\end{array}
\]

*Aa = pink*

b. Draw a Punnett square and cross two of the heterozygous offspring from the F1 generation. What percentage of the F2 generation are white? 25% What percentage are pink? 50% What percentage are red? 25%

\[
\begin{array}{ccc}
  A & a \\
  A & AA & Aa \\
  a & Aa & aa \\
\end{array}
\]

5. In the case of codominance, hybrids of two true breeding parents resemble both parents. For example a blue flower crossed with a yellow flower would produce an F1 generation that are all blue and yellow striped.
   a. Show the F1 generation using a Punnett square and BB for blue flowers and YY for yellow flowers.

\[
\begin{array}{ccc}
  B & B \\
  Y & BY & BY \\
  Y & BY & BY \\
\end{array}
\]
b. Now cross two from the F1 generation. Show the F2 generation with Punnett square.

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>BB</td>
<td>BY</td>
</tr>
<tr>
<td>Y</td>
<td>BY</td>
<td>YY</td>
</tr>
</tbody>
</table>

c. How many F2 generation flowers would be yellow? 1 How many would be striped? 2 How many would be blue? 1

Dihybrid Crosses (Dihybrid crosses look at two characters such as hair color and tongue rolling.)

1. In rocker guinea pigs, spiky hair (S) is dominant to flat hair (s) and black spotted tongues (B) are dominant to pink tongues (b).

a. If you cross a homozygous dominant mother (SSBB) with a homozygous recessive father (ssbb), what will the genotype of the offspring be? **The genotype of all offspring will be SsBb.**

b. What is the phenotype of the offspring? **Spikey hair and black spotted tongue.**

c. If you have a parent who is SsBb, it could give SB, Sb, sB, and sb as gametes. Cross two parents who are heterozygous for both traits. Draw the Punnett Square.

<table>
<thead>
<tr>
<th></th>
<th>SB</th>
<th>Sb</th>
<th>sB</th>
<th>sb</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB</td>
<td>SSBB</td>
<td>SSBb</td>
<td>SsBB</td>
<td>SsBb</td>
</tr>
<tr>
<td>Sb</td>
<td>SSBb</td>
<td>SSbb</td>
<td>SsBb</td>
<td>Ssbb</td>
</tr>
<tr>
<td>sB</td>
<td>sSBb</td>
<td>sSbb</td>
<td>ssBB</td>
<td>ssBb</td>
</tr>
<tr>
<td>sb</td>
<td>sSbb</td>
<td>ssBB</td>
<td>ssbB</td>
<td>ssbb</td>
</tr>
</tbody>
</table>

d. How many offspring will have flat hair and black spotted tongues? 3 How many will have flat hair and pink tongues? 1
The Blue Genes Challenge

You made an amazing discovery in your cotton field . . . blue cotton!

- The blue color is probably due to a natural gene mutation or possibly from a wild strain of cotton.
- You plant seeds from the blue cotton plants and they produce more blue cotton.
- You want to know if blue cotton is dominant to white cotton. What should you do?

After crossing a blue cotton plant with a white cotton plant, you find that it produces blue and white streaked cotton. This is a case of ______________ dominance.

How could you market this cotton?

- Run another test cross by crossing two heterozygous plants. B (-) x B (-)
- What percentage of the offspring produce white cotton?
- What percentage of the offspring produce blue cotton?
- What percentage of the offspring produce blue and white striped cotton?

You name your company Blue Genes Incorporated and begin marketing your product. What parent genotypes should you cross to harvest the most blue and white streaked cotton?

___________________________________________________________________________________________

___________________________________________________________________________________________

___________________________________________________________________________________________

___________________________________________________________________________________________

Blue Genes Incorporated has become wildly successful and your farm is trying to meet the demand for blue and white streaked cotton. However, you begin to notice a problem in the cotton fields. The blue and white streaked cotton seems to be especially vulnerable to pests. Your plants are being devoured by insects. You have heard of something called Bt cotton and want to know if this could help you with your insect problem.

What are the facts on Bt cotton?

- Bt cotton was developed to counteract the increasing resistance of insects to pesticides and cost of using them.
- Bt cotton is genetically modified by inserting genes from soil bacterium Bacillus thuringiensis into cotton plant genes.
- Soil bacterium genes produce protein in plant’s tissues that protect plant from pests.
Bt is only toxic to insects that have receptor sites where the Bt proteins can bind in their guts. Humans, dogs, rats, fish, frogs, guinea pigs, salamanders, birds, honey bees, lady beetles, and most beneficial insects are not affected by Bt.

U.S. Environmental Protection Agency (EPA) tested Bt cotton for toxicity and allergens to humans and many organisms.

EPA approved Bt for commercial use in 1995.

The advantage of Bt cotton is that fewer plants are lost to insect damage and less pesticide needs to be used.

As of 2013, approximately 75% of the cotton planted in the United States is Bt cotton.

What do you think? Could this be a solution for your pest problem in your blue and white streaked cotton crop? Explain.
# Vocabulary Review

Name: ________________________________

<table>
<thead>
<tr>
<th>Vocabulary</th>
<th>Draw a Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA</td>
<td></td>
</tr>
<tr>
<td>Chromosomes</td>
<td></td>
</tr>
<tr>
<td>Genes</td>
<td></td>
</tr>
<tr>
<td>Heredity</td>
<td></td>
</tr>
<tr>
<td>Character</td>
<td></td>
</tr>
<tr>
<td>Trait</td>
<td></td>
</tr>
<tr>
<td>Alleles</td>
<td></td>
</tr>
<tr>
<td><strong>Vocabulary Review</strong> (continued)</td>
<td></td>
</tr>
<tr>
<td>----------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Phenotype</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Genotype</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Homozygous</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Heterozygous</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Dominant trait</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Recessive trait</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Incomplete dominance</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Codominance</strong></td>
<td></td>
</tr>
</tbody>
</table>
Vocabulary Definitions

Cut on the dotted lines and post around the room.

Deoxyribonucleic acid, a double-stranded helical molecule that carries genetic information.

Single strands of DNA are tightly packaged into a concentrated mass. Different species have different numbers of chromosomes. Human cells contain 46 chromosomes in the cell nucleus. Dogs have 78, cats have 38, mosquitoes have 6, and horses have 64 chromosomes. Half of our chromosomes are inherited from our father and half are inherited from our mother.
Specific segments of DNA that are like instructions for all of our characteristics such as the shape of our nose and color of our hair.

The transmission of characteristics from parent to offspring through genes.

A feature that is inherited such as flower color, hair color, and height.

Different variations of a character, such as purple flowers, white flowers, red fur, etc.
Variations of a gene. For example, flower color, fur color, and hair color.

Observable characteristic such as a dog’s fur color.

The alleles that an individual has inherited such as one allele for brown fur and one allele for yellow fur.

The trait or allele that is expressed even if an individual has only inherited one copy of that allele.
Having two identical alleles for a certain characteristic. For example, inheriting one allele that codes for white flowers from one parent and one allele that also codes for white flowers from the other parent.

Having two different alleles for a certain characteristic. For example, inheriting one allele that codes for purple flowers from one parent and one allele that codes for white flowers from the other parent.
Expressed only if an individual has inherited a copy of the recessive allele from both parents.

Example:
› dominant allele + dominant allele = dominant phenotype
› dominant allele + recessive allele = dominant phenotype
› recessive allele + recessive allele = recessive phenotype
Offspring of two true breeding parents does not resemble either parent, but is an intermediate of both parents. For example, if a red flower were crossed with a white flower, the offspring would have pink flowers.

Offspring of two true breeding parents resemble both parents and neither trait is completely dominant. For example a blue flower crossed with a yellow flower would produce offspring with blue and yellow striped flowers.
Purpose

Students will simulate how a type of biotechnology called Marker Assisted Selection (MAS) is used to identify crop plants that have desirable traits such as sweet tasting fruit or natural resistance to a pest or disease.

Time

50 minutes

Materials

For each student:

- Super Strawberries activity handout (page 51)

Standards

This lesson supports California Standards for Common Core Mathematics, English Language Arts and Next Generation Science Standards for Grades 6-12. See page 67 for a complete listing.

Middle School

- MS-LS1-5
- MS-LS3-2
- MS-LS4-5
- LS1.B
- LS3.A
- LS3.B
- LS4.B

ELA/Literacy

- RST.6-8.1
- RST.6-8.2

Background Information

You may like to review the following information with students prior to beginning the activity.

Chromosomes are long molecules of DNA that store genetic information. In eukaryotic organisms like humans, chromosomes are stored inside the cell nucleus where the DNA is tightly coiled around proteins called histones. This enables the DNA to fit inside the tiny space of the cell. If removed from the cell nucleus and uncoiled, human DNA would stretch as long as six feet.

Traits are controlled by pieces of DNA called genes. These genes are located on chromosomes. Humans have 46 chromosomes, and scientists have identified which genes are coded for at certain locations on different chromosomes.

Genes are specific sequences of DNA that are located on chromosomes. Genes are similar to instructions that tell a cell how to make one particular protein, when to make it, how much to make, and where it should be made. Proteins are molecules that are involved in every aspect our body’s structure and function. For example, melanin is a pigment which gives skin its color. Melanin is a protein. Insulin is a hormone that regulates blood sugar levels. Insulin is a protein.

DNA is a long molecule made up of units called nucleotides. Each nucleotide is made up of three parts: a 5-carbon sugar called deoxyribose, a phosphate group, and a nitrogenous base (Adenine, Thymine, Cytosine, and Guanine). Adenine always pairs with Thymine.
and Guanine always pairs with Cytosine in DNA. In the genetic code, each group of three bases A,T,G,C (Adenine, Thymine, Guanine, Cytosine) codes for a specific amino acid. Example, AGC codes for the amino acid serine. Chains of amino acids form the structure of proteins.

**Procedure**

1. Ask students to write down 20 nucleotide bases using the symbols A,T,G,C in any order. Next have them switch with a partner and have their partner write the complementary base strand below the original strand.

2. Show YouTube Video to explain the process of genetic markers. [Link](http://www.youtube.com/watch?v=yI8M9z4N4Y8&list=PLl9jG8tIyP3eUMpDwdz3jGx5DRGUTkJ93)

3. Discuss how scientists can build genetic markers in the lab that have complementary base pairs to genes that they are interested identifying in plants. Fluorescent green protein is added to these markers so they light up and glow green when they find and adhere to the gene of interest. Markers can be added to cells on a microscope slide or to extracted DNA on a microscope slide. If the DNA from the cells glows green, then the plant has the gene that the scientist is looking for. This will help scientists quickly identify which plants they want to select for breeding.

4. Distribute the Super Strawberries student activity handout and review each section. Do one example with the class.

5. After students complete the activity, have students draw each strawberry, color, and label its characteristics. Have students circulate through the room in small groups to view the class drawings and discuss why they think MAS technology is important for our future. Have each group share their thoughts with the class.

**Extension**

Super Strawberries

Name: ____________________________

Background

Farmers have been practicing traditional plant breeding for thousands of years. In traditional plant breeding a plant that shows a desired trait is crossed with another plant that also shows that same desired trait or another desired trait. For example, a farmer may have noticed that one of their tomato plants resists mildew and a different tomato plant produces an abundance of fruit. These are two traits that the farmer would like all of her plants to have, so she cross breeds these two plants in hopes of breeding tomato plants that are resistant to mildew and produce an abundance of fruit. Next, the farmer will evaluate the seedlings to determine if they have the desired traits. The best seedlings are selected for breeding and the process is repeated. Plant breeders call this type of selection, direct selection because it is based on plant phenotypes which are the traits that we can observe.

Direct selection can be costly and often takes decades to successfully develop plants with the desired traits. It is also difficult to use this type of plant breeding to select plants for traits that aren't easily observed such as increased levels of nutrients in fruits or a longer shelf life.

Biotechnology is the manipulation (as through genetic engineering) of living organisms or their components to produce useful usually commercial products, for example pest resistant crops. A type of biotechnology called Marker Assisted Selection (MAS) is known as indirect selection because it is not based on a trait that we can observe. Instead it is based on genetic markers that will bind to the genes that code for the trait we are looking for. Genetic markers are sequences of DNA that have been built in the lab to be complementary to a certain gene of interest, such as frost resistance in plants.

Markers are built to include the gene pGLO, which will produce a green fluorescent protein when the marker finds and binds to the gene that codes for the trait we are looking for. Plant cells or DNA can be deposited on a microscope slide along with a few drops of the marker. The plant has the gene you are looking for if its DNA glows green under the microscope. If the plant is found to have the specific gene it can be selected for breeding. MAS is more accurate, less expensive, and much faster than traditional plant breeding.

Here’s a fun analogy for MAS…

Imagine that your class goes on a night hike in a corn maze. You all become separated as you are finding your way through the maze. You see a spaceship overhead and realize aliens are coming to get you. The only way you can be saved is if your teacher finds you before the aliens do. Good thing your teacher gave everyone flare guns before you went into the maze. You shoot off your flare gun so you can be identified and saved by your teacher.

This is a very rough comparison to how MAS works to identify traits of interest. If your teacher had not given everyone a flare gun, the only chance she would have had to find you would be if she happened to wander through the maze in the dark and bumped into you. She might find a few of your classmates this way but she probably wouldn’t find them all and it would take a lot longer. This would be similar to how selection through traditional breeding compares to MAS.
Super Strawberries (continued)

Directions

You work for a plant breeder who grows a variety of strawberries that exhibit an interesting range of traits. You want to find out which strawberry plants have inherited these traits. You are going to speed things up by using Marker Assisted Selection.

1. The following markers will bind to genes for the following traits. Write complementary base pairs of the gene that will bind to each marker.

   Marker A: GGTTGGTTTCGCGA = binds to gene for High Level of Vitamin C

   Marker B: CTAGACCTTAATATTA = binds to gene for Extended Shelf Life

   Marker C: TCTAAAATT = binds to gene for Super Sweet Taste

   Marker D: GTCGTTTCTCT = binds to gene for Fuzziness

   Marker E: ATGCCAGCTAGT = binds to gene for Jumbo Size

   Marker F: GCTTATTACCGTCT = binds to gene for Small Size

   Marker H: GGGCCTGGTT = binds to gene for Pink Flesh

   Marker I: GAAGCCTTCGGTT = binds to gene for Disease Resistance

   Marker J: ATCCCGAGCTAGT = binds to gene for Chocolate Flavor

   Marker K: TTCTAACGGA = binds to gene for Minty Flavor

2. You have a DNA sample from four different strawberry plants. You add the markers to each sample to determine if any of the strawberry plants have the genes you want to select for your breeding program. Search the DNA strands below for complementary regions that match the markers. When you locate an area where the markers will bind, highlight each section of DNA with a fluorescent pen.
Super Strawberries (continued)

Strawberry Single Stranded DNA Sequences

Strawberry Plant 1

AAAACGACTTCGGAAGCCAATTTACGCGAATTACCGAATCCGGCCTCTCGCCC TTCCCGGAATTATTACCGG

Strawberry Plant 2

TTCTCGCCTAATTACGACTTCGACCCAAATTGGAATTAACCAACCAACCAAGCGCTG CTAAAGCTGCTGATGCATGCCTGG

Strawberry Plant 3

TCCCGCTTTTCGCTATTAGGGCTCGATCAGGATATAGCCAACCTTCCGAGCATCGATGAATAGGATCCATGGATTAGAT

Strawberry Plant 4

AAACCGATAGATAGATTTTAAAAAAAAGTTTAGATAGATAGATAGATAGATAGACCGCT ATAGCAGCAAGAGATTATTA

3. Describe the characteristics of each strawberry plant.

4. On a separate piece of paper draw the strawberry plant you would choose for your breeding program. Color your strawberry plant and label the desired characteristics.
Super Strawberry Answer Key

Base Pairings

Marker A: GGTTGGTTCGCGA = binds to gene for High Level of Vitamin C
CCAACCAAGCGCT

Marker B: CTAGACCTTAATATTA = binds to gene for Extended Shelf Life
GATCTGGAATTATAAT

Marker C: TCTAAAATT = binds to gene for Super Sweet Taste
AGATTTTAA

Marker D: GTCGTTTCTCT = binds to gene for Fuzziness
CAGCAAAGAGA

Marker E: ATGCCCAGCTAGT = binds to gene for Jumbo Size
GACGGGTGATCA

Marker F: GCTTATTACCCTCT = binds to gene for Small Size
CGAATAATGGCAGA

Marker H: GGGCCCTGGTT = binds to gene for Pink Flesh
CCCCGACCAA

Marker I: GAAGCCTTCGGTT = binds to gene for Disease Resistance
CTTCCGAAGCCAA

Marker J: ATCCGAGCTAGT = binds to gene for Chocolate Flavor
TAGGGCTCGATCA

Marker K: TTCTAACGGGA = binds to gene for Minty Flavor
AAGATTTGCT

Single Stranded DNA Sequences

Strawberry Plant 1
AAAACGACTTCGGAAGCCAAATTTACGCGCAGATTACCGAATCCGGGCCTCTCGCCCT
TTCCCGGAATTTATTACCGGCT
Disease Resistant

Strawberry Plant 2
TTTCGCGCCTAATTACGACTTCGACCAGGCAATTTGGAATTAACCAAACACCGACGCTG
CTAAAAGCTGTGCTATGCCTGG
High Level of Vitamin C
Super Strawberry Answer Key (continued)

Strawberry Plant 3
TCCCGCTTTTCGCTATTAGGGCTCGATCAGGATATAGCCAACCTTCCGAGCATCGATG
AATAGGATCCATGGATTAGAT
Chocolate Flavor

Strawberry Plant 4
AAACCGATAGATAGATTTTTAAAAAAGTTTAGATAGATAGATAGATAGATAGAACCCT
ATAGCAGCAAAGAGATTATTA
Super Sweet Taste and Fuzziness
Enhancing Our World Research Project

Procedure

Students will combine concepts from prior lessons to create and promote a potential new agriculture product that uses genetic techniques taught in this lesson.

Time

Two to three 45–minute class sessions, plus homework.

Materials

For each student:

- Paper for brochure or posters or computer access with presentation software
- Assignment packet

Standards

This lesson supports California Standards for Common Core Mathematics, English Language Arts and Next Generation Science Standards for Grades 6-12. See page 67 for a complete listing.

Middle School

- MS-LS4-5
- MS-LS2-2
- MS-LS2-5
- LS2.A
- LS4.D
- ETS1.B
- LS4.B

Background

At this point in the unit, students should understand the basic terms and concepts of genetics. This lesson requires students to apply concepts and information from previous lessons in solving a real world situation.

Students will assume responsibility for the creation and promotion of a new agricultural product that uses genetic enhancement. The goal is to help create a future product that matches the need for increased food production with the requirement that it be sustainable for future generations.

It will be helpful to have students complete a reading assignment of sustainable agriculture prior to beginning their project for this lesson.

Resources

- Sustainable Agricultural Research and Education at www.sare.org/Learning-Center/
- Sustainable Agriculture in the Index of the Foundation for Agriculture in the Classroom Teacher Resource Book free for download at www.learnaboutag.org/trg/pdf/trg2013.pdf

Procedure

1. Review the Student Assignment Packet and make any necessary changes to fit the needs of your classroom. You may want to include some or all of the following:
   - Student assignment packet
   - Quality Rubric
   - Reading assignment on sustainable agriculture

2. Provide each student with a copy of the Student Assignment Packet. Discuss the packet and instruct students to work in pairs.

3. Explain the timeline and have them begin the work under your supervision. Use MBWA (manage by wandering around) to monitor their progress, increase focus, and give guidance. It is important that they solve their problems and struggle in the creative process! Refer them to the Rubric for direction.
4. Assign readings on using biotechnology to help develop sustainable agriculture as needed.

5. Allow class time for students to work on projects but make most of the work home work.

6. On due date, if doing brochures or posters, collect and show on document camera while the creator(s) explain their process and meaning. If you have no document cam, you can have students take pictures with their cell phones and send to your email, which you then project and have them present. (If you have no projector, you can just collect and grade each.) PowerPoints can be collected into a period by folder and shown by you while students present. Probing questions will help assure that they can explain their work. Having their classmates keep notes of all presentations helps reinforce the lesson and time on task.

**ELA/Literacy**
RST.6-8.1
RST.6-8.8
RL.8.8
WHST.6-8.2
WHST.6-8.9
SL.8.1
SL.8.4

**High School**
HS-LS2-7
HS-ESS3-3
LS2.C
LS4.D
ETS1.B
ESS3.C
ELA/Literacy
MP.2

**Ag Standards**
2.4
1.1
1.7
2.2
1.8
5.1
5.3
C3.3
C13.2
G11.0
G11.1
G11.3
G11.4
G11.5
**Enhancing Our World Presentation**

Name: ________________________________

---

**The Scenario**

You have just gone to work for a company that promotes sustainable agriculture. You do some research and learn that this is a farming practice that makes use of the principles of ecology. This means that the farmer understands and respects the relationship between living things and their environments and does his or her best to preserve the environment for future generations while producing food to feed people. Your job has two parts:

- Develop a new and creative way to help feed people in a sustainable way.
- Explain this to your supervisors through a brochure, poster, or computer presentation that will help to sell them on your idea and put it into practice.

**Directions**

1. Create a catchy, fun company name and write it on your draft brochure sheet. (If doing a PowerPoint, fold the paper in half twice to give you eight boxes for eight slides.)

2. Brainstorm, perhaps with others in your class, something you want your product to change. Some suggested topics are drought resistant corn, insect resistant apples, pollution consuming plants, vegetables with increased shelf life, broccoli that tastes like cheese, faster growing trees or plants, plants that make medicines directly, and much more. Write a paragraph that explains a current problem and how your product will work towards solving it.

3. Have a section called “Before and After” showing a plant or situation without your product, and one after using your product. It should be clear to the reader that your proposed product is worth the money you want them to spend.

4. Contact someone with some expertise or interest in your product (a stakeholder). Explain the benefits of your product to them. Stakeholders could include a farmer, a parent, a school nurse, shoppers at the grocery store, a grocery store manager, an environmentalist, and so on. Get their input on your product and include their comments in your brochure. If they like it, good, if they are opposed, deal with that in your “Concerns” section.

5. Come up with a list of benefits to society of the plant or process you are promoting. Put these on your paper in a section titled “Benefits: Then anticipate the negatives/downsides to what you are promoting and address these in your “Concerns.”

6. Explain how your product will be created using genetic enhancement. Use the terminology you have learned in prior lessons.

7. Use appropriate formatting to complete your brochure, PowerPoint or poster. Your final product should be visually appealing and you should be able to defend it when you present it. Did you address all the concerns?

8. Display guidelines - Using the rubric, compare your work to the expectations. What score do you expect? Should any parts be done over or modified?
<table>
<thead>
<tr>
<th>Component</th>
<th>5 Points</th>
<th>4 Points</th>
<th>3 Points</th>
<th>2 Points</th>
<th>1 Point</th>
<th>0 Points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product Name</strong></td>
<td>Catchy, entertains, fun, smile maker, clever</td>
<td>Less catchy, but still good</td>
<td>OK, but not outstanding</td>
<td>Passable, but descriptive</td>
<td>Not descriptive</td>
<td>No title</td>
</tr>
<tr>
<td><strong>Before and After Section</strong></td>
<td>Has both pictures with descriptive labeling</td>
<td>Has both pictures but not labeled</td>
<td>Has both pictures, labels incomplete</td>
<td>Has both pictures, no labels</td>
<td>Has only one picture</td>
<td>No picture</td>
</tr>
<tr>
<td><strong>Description of How Product is Created</strong></td>
<td>Interesting, clear and concise explanation using genetic terminology to explain how product is created</td>
<td>Concise explanation of product creation with genetic terminology used appropriately</td>
<td>Complete explanation of product creation using some genetic terminology</td>
<td>Incomplete description of product creation, little genetic terminology used or not used correctly</td>
<td>Confusing description of product creation, no genetic terminology used</td>
<td>No explanation of how product is created</td>
</tr>
<tr>
<td><strong>Benefits Section</strong></td>
<td>Has at least five benefits</td>
<td>Has four benefits</td>
<td>Has three benefits</td>
<td>Has two benefits</td>
<td>Has one benefit</td>
<td>No benefits listed</td>
</tr>
<tr>
<td><strong>Concerns Section</strong></td>
<td>Has at least five concerns</td>
<td>Has four concerns</td>
<td>Has three concerns</td>
<td>Has two concerns</td>
<td>Has one concern</td>
<td>No concerns listed</td>
</tr>
<tr>
<td><strong>Expert or Stakeholder Input Section</strong></td>
<td>Has quality quote, well written, attributed</td>
<td>Has quote but needs work, attributed</td>
<td>Has quote but not attributed</td>
<td>Has quote but meaning unclear</td>
<td>Has quote but not relevant</td>
<td>Has no quote</td>
</tr>
<tr>
<td><strong>Overall Visual Appeal</strong></td>
<td>One of two or three best in class</td>
<td>One of few superior ones in class</td>
<td>Above average</td>
<td>Average</td>
<td>Below average</td>
<td>Poor visual appeal</td>
</tr>
</tbody>
</table>
Teacher Resources
and References

Agricultural Research Service Magazine
Published monthly by the Agricultural Research Service, United States Department of Agriculture, this magazine reports on current research in the agricultural industry. Free one-year subscription to schools and libraries.

Agricultural Research Magazine
5601 Sunnyside Avenue, 1-2232C
Beltsville, MD  20705-5130
(301) 504-1660
Fax: (301) 504-1641
Web Site: www.ars.usda.gov/is/AR

Biotechnology Industry Organization
A variety of basic and detailed information on biotechnology including genetic engineering is available.

Biotechnology Industry Organization
1201 Maryland Avenue SW, Suite 900
Washington, DC 20024
(202) 962-9200
Fax: (202) 488-6301
Web Site: www.bio.org

California Foundation for Agriculture in the Classroom
Provides a variety of programs and resources, which can increase the understanding of agriculture and its impact in today's world. Commodity and natural resource fact and activity sheets, lesson plans, and teacher and student programs are available. Request a free Teacher Packet.

California Foundation for Agriculture in the Classroom
2300 River Plaza Drive
Sacramento, CA  95833
(800) 700-2482
Fax: (916) 561-5697
Web Site: www.LearnAboutAg.org

Biotechnology—Careers for the 21st Century Video
This video shares interviews of people who have a career in biotechnology.

Biotechnology—Careers for the 21st Century Video

National Association of Biology Teachers
12100 Sunset Hills Road, Suite 130
Reston, VA 20190
(703) 435-4390
(888) 501-NABT
E-mail: office@nabt.org
Fax: (703) 435-4390

If you have questions, call the National Association of Biology Teachers toll-free at (888) 501-NABT or (703) 264-9696.

California Science Teachers Association
This association provides newsletters, journals, and conferences for California science educators about ideas, issues, and trends in science education.

California Science Teachers Association
CSTA
3880 Watt Avenue, #175
Sacramento, CA  95821-2666
(916) 979-7004
Fax: (916) 979-7023
Web Site: www.cascience.org

Bio-Rad Laboratories
This company provides many biotechnological classroom kits and supplies. Request a free catalog.

Bio-Rad Laboratories
2000 Alfred Nobel Drive
Hercules, CA 94547
(800) 424-6723
Fax: (800) 879-2289
Web Site: www.bio-rad.com

California Science Teachers Association
This association provides newsletters, journals, and conferences for California science educators about ideas, issues, and trends in science education.

National Association of Biology Teachers
12100 Sunset Hills Road, Suite 130
Reston, VA 20190
(703) 435-4390
(888) 501-NABT
E-mail: office@nabt.org
Fax: (703) 435-4390

If you have questions, call the National Association of Biology Teachers toll-free at (888) 501-NABT or (703) 264-9696.
### Teacher Resources and References

<table>
<thead>
<tr>
<th>California Strawberry Commission</th>
<th>Center for Engineering Plants for Resistance Against Pathogens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free strawberry lessons and fact sheets are available.</td>
<td>This organization has a variety of free STEMWare Modules, Lab Protocols, Lab Intros, How To Lab Videos and other resources and programs for educators including those described below.</td>
</tr>
<tr>
<td>California Strawberry Commission Post Office Box 269 Watsonville, CA 95077-0269 (831) 724-1301 Fax: (831) 724-5973 Web Site: calstrawberry.com</td>
<td><strong>Germ Wars</strong> is a sixth through ninth grade interactive computer program that describes how people and plants defend themselves against microbes and how biotechnology can help prevent and treat disease.</td>
</tr>
<tr>
<td><strong>CDE Press</strong> The Content Standards for California Public Schools and subject matter frameworks are available through this company. They are also available on the listed California Department of Education Web site.</td>
<td><strong>Virtual Plant Biotechnology and Genomics Laboratory</strong> immerses students in five different scenarios. In each case, students research and isolate a gene of interest, transform a virtual plant, and explore the controversial issues surrounding transgenic crops. In addition to gaining familiarity with equipment and techniques in the virtual lab, students are provided with topical readings, and background information.</td>
</tr>
<tr>
<td>CDE Press <em>Sales Office:</em> California Department of Education Post Office Box 271 Sacramento, CA 95812-0271 (916) 445-1260 Fax: (916) 323-0823 Web Site: <a href="http://www.cde.ca.gov">www.cde.ca.gov</a></td>
<td><strong>The Virtual DNA Fingerprinting Lab</strong> is software that involves high school students in solving a forensic mystery. Over the course of seven episodes, students collect evidence, extract DNA, perform a southern blot, use PCR, and finally solve a crime.</td>
</tr>
<tr>
<td><strong>Center for Consumer Research</strong> This organization has a free video and brochures available on food biotechnology. They educate consumers about food biotechnology and address current issues.</td>
<td>Center for Engineering Plants for Resistance Against Pathogens University of California, Davis One Shields Avenue Davis, CA 95616 (530) 752-6552 Fax: (530) 752-6523 Web Site: <a href="http://ppge.ucdavis.edu/">http://ppge.ucdavis.edu/</a></td>
</tr>
<tr>
<td>Center for Consumer Research University of California One Shields Avenue Davis, CA 95616 (530) 752-2774 Fax: (530) 752-3975 E-Mail: <a href="mailto:ccr@ucdavis.edu">ccr@ucdavis.edu</a></td>
<td></td>
</tr>
</tbody>
</table>
### Teacher Resources and References

<table>
<thead>
<tr>
<th>Resource</th>
<th>Description</th>
<th>Contact Information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cottonseed and Its Products</strong></td>
<td>This free 24-page pamphlet describes the history of cotton and cottonseed production as well as its many products.</td>
<td>National Cottonseed Products Association, Inc. 866 Willow Tree Circle Cordova, TN 38018 (901) 682-0800 Fax: (901) 682-2856 Web Site: <a href="http://www.cottonseed.com">www.cottonseed.com</a> E-mail: <a href="mailto:info@cottonseed.com">info@cottonseed.com</a></td>
</tr>
<tr>
<td><strong>Lab-Aids, Inc.</strong></td>
<td>Numerous genetics and heredity hands-on modules are available. Request a free catalog.</td>
<td>Lab-Aids, Inc. 17 Colt Court Ronkonkoma, NY 11779 (800) 381-8003 (631) 737-1133 Fax: (631) 737-1286 Web Site: <a href="http://www.sepup.com">www.sepup.com</a></td>
</tr>
<tr>
<td><strong>Council for Biotechnology Information</strong></td>
<td>This organization's purpose is to share information about biotechnology, relying on scientific research, expert opinion, and published reports. Free information is available including a brochure, Biotechnology: Good Ideas Are Growing.</td>
<td>Council for Biotechnology Information 1201 Maryland Avenue SW Ste0900 Washington, DC 20024 (202) 962-9200 Web Site: <a href="http://www.whybiotech.com">www.whybiotech.com</a></td>
</tr>
<tr>
<td><strong>National Cotton Council</strong></td>
<td>A variety of resources including brochures, stories, teaching packets and posters are available. Request a free catalog.</td>
<td>National Cotton Council Communications Service Department 7193 Goodlett Farms Parkway Cordova, TN 38016 (901) 274-9030 Fax: (901) 725-0510 Web Site: <a href="http://www.cotton.org">www.cotton.org</a></td>
</tr>
<tr>
<td><strong>National 4-H Council</strong></td>
<td>This organization has a variety of biotechnology materials available in their catalog. Most relate to careers in biotechnology.</td>
<td>National 4-H Council 7100 Connecticut Avenue Chevy Chase, MD 20815-4999 (301) 961-2800 Fax: (301) 961-2937 Web Site: <a href="http://www.fourhcouncil.org">www.fourhcouncil.org</a> Catalog Web Site: <a href="http://www.4-h.org/resource-library/curriculum/">http://www.4-h.org/resource-library/curriculum/</a></td>
</tr>
<tr>
<td><strong>National FFA Organization</strong></td>
<td>This organization has a variety of biotechnology materials available in their catalog. Most relate to careers in biotechnology.</td>
<td>National FFA Center 6060 FFA Drive Post Office Box 68960 Indianapolis, IN 46268-0960 (317) 802-4334 Fax: (317) 802-5334 Web Site: <a href="http://www.ffa.org">www.ffa.org</a></td>
</tr>
</tbody>
</table>
Biotechnology and Related Web Sites

This list is offered as an information resource only. It contains Web sites established by various entities and, at the time of printing, included information on biotechnology or a subject matter related to the instructional materials unit From Genes to Jeans. The list is not considered to be all-inclusive. The entities or contents of the sites on this list are not necessarily endorsed by the California Foundation for Agriculture or by the authors or editors of From Genes to Jeans.

Ag-West Biotech Inc.
www.agwest.sk.ca

The Alliance for Better Foods
www.betterfoods.org

American Farm Bureau Federation

Biotechnology Industry Organization
https://www.bio.org/category/food-agriculture

Biotechnology Information Center, National Agricultural Library
http://www.nal.usda.gov/biotechnology

California Farm Bureau Federation
www.cfbf.com

California Foundation for Agriculture in the Classroom
www.LearnAboutAg.org

Food and Drug Administration
  Center for Food Safety and Applied Nutrition
http://www.fda.gov/Food/default.htm

Genetic Engineering & Biotechnology News
http://www.genengnews.com/best-of-the-web

United States Department of Agriculture-Animal and Plant Health Inspection Service (APHIS)

University of California Biotechnology Program
www.biotech.ucdavis.edu
Biotechnology and Related Web Sites

University of California Center for Consumer Research

University of Utah Health Sciences
http://learn.genetics.utah.edu/

United States National Library of Medicine- Genetics Home Reference
Related Literature


Fine, Edith Hope. *Barbara McClintock: Nobel Geneticist*. Enslow Publishers, Inc., 1998. Presents the life and career of the geneticist who spent many years studying cells of maize and, in 1983, was awarded the Nobel Prize in physiology and medicine.

Fussell, Betty. *The Story of Corn*. Alfred A. Knopf, 1992. The story of corn: the myths and history, the culture and agriculture, the art and science of this crop.


Viola, Herman J. and Carolyn Margolis. *Seeds of Change*. Smithsonian, 1991. Words and photographs explain the encounter and exchange of plants and animals between the Old and New Worlds and the transformation of people and land in the 500 years since Columbus.

Common Core and Next Generation Science Standards

Introduction to Human Inheritance

Middle School

MS-LS3-1. Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism.

MS-LS3-2. Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation.

Science and Engineering Practices

Developing and Using Models

- Develop and use a model to describe phenomena. (MSLS3-1), (MS-LS3-2)

Disciplinary Core Ideas

LS1.B: Growth and Development of Organisms

- Organisms reproduce, either sexually or asexually, and transfer their genetic information to their offspring. (secondary to MS-LS3-2)

LS3.A: Inheritance of Traits

- Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited. (MS-LS3-2)

LS3.B: Variation of Traits

- In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other. (MS-LS3-2)
- In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations. Though rare, mutations may result in changes to the structure and function of proteins. Some changes are beneficial, others harmful, and some neutral to the organism. (MS-LS3-1)

Crosscutting Concepts

Cause and Effect

- Cause and effect relationships may be used to predict phenomena in natural systems. (MSLS3-2)
- Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability. (MS-LS1-4), (MS-LS1-5), (MS-LS4-5)

Structure and Function

- Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the shapes, composition, and relationships among its parts, therefore complex natural structures/systems can be analyzed to determine how they function. (MS-LS3-1)
Common Core and Next Generation Science Standards

Introduction to Human Inheritance (continued)

ELA/Literacy
RST.6-8.4 Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 6-8 texts and topics. (MS-LS3-1), (MS-LS3-2)
6.SP.B.5 Summarize numerical data sets in relation to their context. (MS-LS3-2)

High School

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.

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.

HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.

Science and Engineering Practices
Asking Questions and Defining Problems
- Ask questions that arise from examining models or a theory to clarify relationships. (HS-LS3-1)

Analyzing and Interpreting 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. (HS-LS3-3)

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 to HS-LS3-1)

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. (HS-LS3-1)
Introduction to Human Inheritance (continued)

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. (HS-LS3-2)

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). (HSLS3-3)

ELA/Literacy

RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (HS-LS3-1)

HSF-IF.C.7 Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases. (HSLS1-4)

Ag Standards

C7.1 Differentiate between genotype and phenotype, and describe how dominant and recessive genes function.

D5.0 Students understand animal inheritance and selection principles, including the structure and role of DNA.

D5.4 Understand how to predict phenotypic and genotypic results of a dominant and recessive gene pair.
Common Core and Next Generation Science Standards

Farming, Food, and Heredity

Middle School

MS-LS1-4. Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants respectively.

MS-LS1-5. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.

MS-LS3-2. Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation.

MS-LS4-5. Gather and synthesize information about the technologies that have changed the way humans influence the inheritance of desired traits in organisms.

MS-LS4-4. Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals’ probability of surviving and reproducing in a specific environment.

Science and Engineering Practices

Constructing Explanations and Designing Solutions

- Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students’ own experiments) 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. (MS-LS1-5)

Engaging in Argument from Evidence

- Use an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. (MS-LS1-4)

Disciplinary Core Ideas

LS4.B: Natural Selection

- In artificial selection, humans have the capacity to influence certain characteristics of organisms by selective breeding. One can choose desired parental traits determined by genes, which are then passed on to offspring. (MS-LS4-5)

- Natural selection leads to the predominance of certain traits in a population, and the suppression of others. (MS-LS4-4)
Common Core and Next Generation Science Standards

Farming, Food, and Heredity (continued)

Crosscutting Concepts
Cause and Effect

- Cause and effect relationships may be used to predict phenomena in natural systems. (MS-LS3-2)
- Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability. (MS-LS1-4),(MS-LS1-5),(MS-LS4-5)

Connections to Engineering, Technology, and Applications of Science
Interdependence of Science, Engineering, and Technology

- Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems. (MS-LS4-5)

Connections to Nature of Science
Science Addresses Questions About the Natural and Material World

- Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes. (MS-LS4-5)

ELA/Literacy

WHST.6-8.1 Write arguments focused on discipline content. (MS-LS1-4)

WHST.6-8.2 Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content. (MS-LS1-5)

WHST.6-8.9 Draw evidence from informational texts to support analysis, reflection, and research. (MS-LS4-2),(MS-LS4-4)

RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions (MS-LS4-1),(MS-LS4-2),(MS-LS4-3),(MS-LS4-4)

RST.6-8.9 Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. (MS-LS4-3),(MS-LS4-4)

SL.8.1 Engage effectively in a range of collaborative discussions (one-on-one, in groups, teacher-led) with diverse partners on grade 6 topics, texts, and issues, building on others’ ideas and expressing their own clearly. (MS-LS4-2),(MS-LS4-4)

SL.8.4 Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. (MS-LS4-2),(MS-LS4-4)

High School

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.

HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.
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.

Science and Engineering Practices

Asking Questions and Defining Problems

- Ask questions that arise from examining models or a theory to clarify relationships. (HS-LS3-1)

Analyzing and Interpreting 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. (HS-LS3-3)

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 to HS-LS3-1)

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. (HS-LS3-1)

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. (HS-LS3-2), (HS-LS3-3)

LS4.B: Natural Selection

- The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. (HS-LS4-3)

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS3-1), (HS-LS3-2)

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. (HS-LS4-1),(HS-LS4-3) specific causes and effects. (HS-LS3-1), (HS-LS3-2)
Farming, Food, and Heredity (continued)

ELA/Literacy
WHST.9-12.1 Write arguments focused on discipline-specific content. (HS-LS3-2)
MP.2 Reason abstractly and quantitatively. (HS-LS3-2), (HS-LS3-3)

Ag Standards
C7.1 Differentiate between genotype and phenotype, and describe how dominant and recessive genes function.
G2.0 Students understand cell biology.
G2.4 Understand the part of the cell that is responsible for the genetic information that controls plant growth and development.
G2.5 Understand plant inheritance principles, including the structure and role of DNA.
G5.0 Students understand pest problems and management:
G5.3 Know conventional, sustainable, and organic management methods to prevent or treat plant disease symptoms.
G5.5 Understand how biotechnology can be used to manage pests.
Applying Heredity Concepts

Middle School

MS-LS1-5. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.

MS-LS3-2. Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation.

MS-LS4-5. Gather and synthesize information about the technologies that have changed the way humans influence the inheritance of desired traits in organisms.

Science and Engineering Practices

Developing and Using Models

Develop and use a model to describe phenomena. (MSLS3-1),(MS-LS3-2)

Obtaining, Evaluating, and Communicating

Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence. (MS-LS4-5)

Disciplinary Core Ideas

LS1.B: Growth and Development of Organisms

Organisms reproduce, either sexually or asexually, and transfer their genetic information to their offspring.

LS3.A: Inheritance of Traits

Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited. (MS-LS3-2)

LS3.B: Variation of Traits

In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other. (MS-LS3-2)

LS4.B: Natural Selection

In artificial selection, humans have the capacity to influence certain characteristics of organisms by selective breeding. One can choose desired parental traits determined by genes, which are then passed on to offspring. (MS-LS4-5)
Applying Heredity Concepts (continued)

Crosscutting Concepts
Cause and Effect
- Cause and effect relationships may be used to predict phenomena in natural systems. (MS-LS3-2)
- Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability. (MS-LS1-4), (MS-LS1-5), (MS-LS4-5)

Connections to Engineering, Technology, and Applications of Science
Interdependence of Science, Engineering, and Technology
- Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems. (MS-LS4-5)

Connections to Nature of Science
Science Addresses Questions About the Natural and Material World
- Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes. (MS-LS4-5)

ELA/Literacy
RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). (MS-LS3-1),(MS-LS3-2)
WHST. 6-8.9 Draw evidence from informational texts to support analysis, reflection, and research. (MS-LS1-5),
6.SP.B.5 Summarize numerical data sets in relation to their context. (MS-LS3-2)

High School

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.

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.

HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.

Asking Questions and Defining Problems
- Ask questions that arise from examining models or a theory to clarify relationships. (HS-LS3-1)
Analyzing and Interpreting 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. (HS-LS3-3)

Engaging in Argument from Evidence

- Make and defend a claim based on evidence about the natural world that reflects scientific knowledge, and student-generated evidence. (HS-LS3-2)

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 to HS-LS3-1)

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. (HS-LS3-1)

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. (HS-LS3-2)

- 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. (HS-LS3-2),(HS-LS3-3)

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS3-1),(HS-LS3-2)

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). (HS-LS3-3)
Applying Heredity Concepts (continued)

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. (HS-LS3-3)
- Science and engineering are influenced by society and society is influenced by science and engineering. (HS-LS3-3)

ELA/Literacy
RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-LS3-1),(HS-LS3-2)

RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (HS-LS3-1)

WHST.9-12.1 Write arguments focused on discipline-specific content. (HS-LS3-2)

Ag Standards
5.0 Problem Solving and Critical Thinking: Students understand how to create alternative solutions by using critical and creative thinking skills, such as logical reasoning, analytical thinking, and problem-solving techniques.

5.1 Apply appropriate problem-solving strategies and critical thinking skills to work-related issues and tasks.

5.3 Use critical thinking skills to make informed decisions and solve problems.

C2.0 Students understand the interrelationship between agriculture and the environment.

C2.2 Understand current agricultural environmental challenges.

C3.0 Students understand the effects of technology on agriculture.

C3.3 Understand public concern for technological advancements in agriculture, such as genetically modified organisms.

C7.0 Students understand basic animal genetics.

C7.1 Differentiate between genotype and phenotype, and describe how dominant and recessive genes function.

C7.2 Compare genetic characteristics among cattle, sheep, swine, and horse breeds.

C7.3 Understand how to display phenotype and genotype ratios (e.g., by using a Punnett Square).

D5.0 Students understand animal inheritance and selection principles, including the structure and role of DNA.

D5.4 Understand how to predict phenotypic and genotypic results of a dominant and recessive gene pair.
Applying Heredity Concepts (continued)

G2.0 Students understand cell biology.
G2.5 Understand plant inheritance principles, including the structure and role of DNA.
G11.0 Students understand plant biotechnology.
G11.1 Understand how changing technology—such as micropropagation, biological pest controls, and genetic engineering (including DNA extraction and gel electrophoresis)—affects plant production, yields, and management.
G11.3 Know how herbicide-resistant plant genes can affect the environment.
G11.4 Understand how genetic engineering techniques have been used to improve crop yields.
G11.5 Understand the effects of agricultural biotechnology, including genetically modified organisms, on the agriculture industry and the larger society and the pros and cons of such use.
Use of Biotechnology in Selecting the Right Plants

Middle School

MS-LS1-5. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.

MS-LS3-2. Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation.

MS-LS4-5. Gather and synthesize information about the technologies that have changed the way humans influence the inheritance of desired traits in organisms.

Science and Engineering Practices

Developing and Using Models

- Develop and use a model to describe phenomena. (MS-LS3-1), (MS-LS3-2)

Constructing Explanations and Designing Solutions

- Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students’ own experiments) 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. (MS-LS1-5)

Obtaining, Evaluating, and Communicating Information

- Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence. (MS-LS4-5)

Disciplinary Core Ideas

LS1.B: Growth and Development of Organisms

- Organisms reproduce, either sexually or asexually, and transfer their genetic information to their offspring. (secondary to MS-LS3-2)

- Genetic factors as well as local conditions affect the growth of the adult plant. (MS-LS1-5)

LS3.A: Inheritance of Traits

- Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited. (MS-LS3-2)

LS3.B: Variation of Traits

- In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other. (MS-LS3-2)
Use of Biotechnology in Selecting the Right Plants (continued)

LS4.B: Natural Selection
- In artificial selection, humans have the capacity to influence certain characteristics of organisms by selective breeding. One can choose desired parental traits determined by genes, which are then passed on to offspring. (MS-LS4-5)

Crosscutting Concepts
Cause and Effect
- Cause and effect relationships may be used to predict phenomena in natural systems. (MS-LS3-2)
- Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability. (MS-LS1-4), (MS-LS1-5), (MS-LS4-5)

Connections to Engineering, Technology, and Applications of Science
Interdependence of Science, Engineering, and Technology
- Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems. (MS-LS4-5)

Connections to Nature of Science
Science Addresses Questions About the Natural and Material World
- Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes. (MS-LS4-5)

ELA/Literacy
RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts. (MS-LS1-4), (MS-LS1-5), (MS-LS3-1), (MS-LS3-2), (MS-LS4-5)
RST.6-8.2 Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. (MS-LS1-5)
RST.6-8.4 Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 6-8 texts and topics. (MS-LS3-1), (MS-LS3-2)
RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). (MS-LS3-1), (MS-LS3-2)
WHST.6-8.2 Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content. (MS-LS1-5)
WHST.6-8.9 Draw evidence from informational texts to support analysis, reflection, and research. (MS-LS1-5)
Use of Biotechnology in Selecting the Right Plants (continued)

High School

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.

Science and Engineering Practices

- Ask questions that arise from examining models or a theory to clarify relationships. (HS-LS3-1)

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 to HS-LS3-1)

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. (HS-LS3-1)

Crosscutting Concepts

Cause and Effect
- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS3-1), (HS-LS3-2)

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. (HS-LS3-3)
- Science and engineering are influenced by society and society is influenced by science and engineering. (HS-LS3-3)

ELA/Literacy

RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-LS3-1), (HS-LS3-2)

RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (HS-LS3-1)
Use of Biotechnology in Selecting the Right Plants (continued)

Ag Standards
4.1 Understand past, present, and future technological advances as they relate to a chosen pathway.
4.2 Understand the use of technological resources to gain access to, manipulate, and produce information, products, and services.
C3.0 Students understand the effects of technology on agriculture:
C3.2 Understand how technology influences factors such as labor, efficiency, diversity, availability, mechanization, communication, and so forth.
G11.0 Students understand plant biotechnology.
G11.1 Understand how changing technology—such as micropropagation, biological pest controls, and genetic engineering (including DNA extraction and gel electrophoresis)—affects plant production, yields, and management.
G11.4 Understand how genetic engineering techniques have been used to improve crop yields.
G11.5 Understand the effects of agricultural biotechnology, including genetically modified organisms, on the agriculture industry and the larger society and the pros and cons of such use.
MS-LS4-5. Gather and synthesize information about the technologies that have changed the way humans influence the inheritance of desired traits in organisms.

MS-LS2-2. Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.

MS-LS2-5. Evaluate competing design solutions for maintaining biodiversity and ecosystem services.

Science and Engineering Practices
Constructing Explanations and Designing Solutions
- Construct an explanation that includes qualitative or quantitative relationships between variables that predict phenomena. (MS-LS2-2)

Engaging in Argument from Evidence
- Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MS-LS2-5)

Obtaining, Evaluating, and Communicating Information
- Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence. (MS-LS4-5)

Disciplinary Core Ideas
LS2.A: Interdependent Relationships in Ecosystems
- Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared. (MS-LS2-2)

LS4.D: Biodiversity and Humans
- Changes in biodiversity can influence humans’ resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling. (secondary to MS-LS2-5)

ETS1.B: Developing Possible Solutions
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (secondary to MS-LS2-5)
LS4.B: Natural Selection

- In artificial selection, humans have the capacity to influence certain characteristics of organisms by selective breeding. One can choose desired parental traits determined by genes, which are then passed on to offspring. (MS-LS4-5)

Crosscutting Concepts

Patterns

- Patterns can be used to identify cause and effect relationships. (MS-LS2-2)

Stability and Change

- Small changes in one part of a system might cause large changes in another part. (MS-LS2-5)

Connections to Engineering, Technology, and Applications of Science

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

- The use of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time. (MS-LS2-5)

Interdependence of Science, Engineering, and Technology

- Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems. (MS-LS4-5)

Connections to Nature of Science

Science Addresses Questions About the Natural and Material World

- Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes. (MS-LS2-5, MS-LS4-5)

ELA/Literacy

RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts. (MS-LS2-2, MS-LS4-5)

RST.6-8.8 Distinguish among facts, reasoned judgment based on research findings, and speculation in a text. (MS-LS2-5)

RI.8.8 Trace and evaluate the argument and specific claims in a text, assessing whether the reasoning is sound and the evidence is relevant and sufficient to support the claims. (MS-LS2-5)

WHST.6-8.2 Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content. (MS-LS2-2)

WHST.6-8.9 Draw evidence from literary or informational texts to support analysis, reflection, and research. (MS-LS2-2)
Enhancing Our World Research Project & Presentation (continued)

SL.8.1 Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 8 topics, texts, and issues, building on others’ ideas and expressing their own clearly. (MS-LS2-2)

SL.8.4 Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. (MS-LS2-2)

High School

HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

HS-ESS3-3. Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.

Science and Engineering Practices
Using Mathematics and Computational Thinking
- Create a computational model or simulation of a phenomenon, designed device, process, or system. (HS-ESS3-3)

Constructing Explanations and Designing Solutions
- Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-LS2-7)

Disciplinary Core Ideas
LS2.C: Ecosystem Dynamics, Functioning, and Resilience
- Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. (HS-LS2-7)

LS4.D: Biodiversity and Humans
- Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). (secondary to HS-LS2-7)

- Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. (secondary to HS-LS2-7),(HS-LS4-6)
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. (secondary to HS-LS2-7),(secondary to HS-LS4-6)

ESS3.C: Human Impacts on Earth Systems
- The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources. (HS-ESS3-3)

Crosscutting Concepts
Stability and Change
- Much of science deals with constructing explanations of how things change and how they remain stable. (HS-LS2-6),(HS-LS2-7)
- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS3-3)

Connections to Engineering, Technology, and Applications of Science
Influence of Engineering, Technology, and Science on Society and the Natural World
- Modern civilization depends on major technological systems. (HS-ESS3-1),(HS-ESS3-3)
- New technologies can have deep impacts on society and the environment, including some that were not anticipated. (HS-ESS3-3)

Connections to Nature of Science
Science is a Human Endeavor
- Scientific knowledge is a result of human endeavors, imagination, and creativity. (HS-ESS3-3)

ELA/Literacy
MP.2 Reason abstractly and quantitatively. (HS-ESS3-1),(HS-ESS3-2),(HS-ESS3-3),(HS-ESS3-4), (HS-ESS3-6)

Ag Standards
2.4 Listening and Speaking: Specific applications of Listening and Speaking Strategies and Applications standards (grades nine and ten):
1.1 Formulate judgments about the ideas under discussion and support those judgments with convincing evidence.
1.7 Use props, visual aids, graphs, and electronic media to enhance the appeal and accuracy of presentations.
2.2 Deliver expository presentations.
2.4 Listening and Speaking: Specific applications of Listening and Speaking Strategies and Applications standards (grades eleven and twelve):
1.8 Use effective and interesting language.
Common Core and Next Generation Science Standards

Enhancing Our World Research Project & Presentation (continued)

2.4 Deliver multimedia presentations.

5.1 Apply appropriate problem-solving strategies and critical thinking skills to work-related issues and tasks.

5.3 Use critical thinking skills to make informed decisions and solve problems.

C3.3 Understand public concern for technological advancements in agriculture, such as genetically modified organisms.

C13.2 Analyze an animal or plant problem and devise a solution based on the scientific method.

G11.0 Students understand plant biotechnology:

G11.1 Understand how changing technology—such as micropropagation, biological pest controls, and genetic engineering (including DNA extraction and gel electrophoresis)—affects plant production, yields, and management.

G11.3 Know how herbicide-resistant plant genes can affect the environment.

G11.4 Understand how genetic engineering techniques have been used to improve crop yields.

G11.5 Understand the effects of agricultural biotechnology, including genetically modified organisms, on the agriculture industry and the larger society and the pros and cons of such use.
### Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alleles</strong></td>
<td>The name geneticists use to refer to variations of a trait or gene.</td>
</tr>
<tr>
<td><strong>Amino Acid</strong></td>
<td>The biochemical units from which all proteins are made. There are twenty different amino acids that occur most commonly in the proteins of all life forms.</td>
</tr>
<tr>
<td><strong>Antibiotic</strong></td>
<td>A substance that kills or prevents the growth of microorganisms; often produced by other microbes.</td>
</tr>
<tr>
<td><strong>Antigen</strong></td>
<td>A substance (often a protein) which triggers the production of antibodies.</td>
</tr>
<tr>
<td><strong>Bacterium</strong></td>
<td>A simple organism consisting of one cell or short chain of cells in which there is no nucleus. The chromosomal DNA is free within the cytoplasm as a singular circular strand.</td>
</tr>
<tr>
<td><strong>Base</strong></td>
<td>One of four different chemical units comprises DNA or RNA. The sequence of DNA bases codes for the amino acid sequence of proteins. These four bases are adenine, cytosine, guanine, and thymine. In RNA, uracil substitutes for thymine.</td>
</tr>
<tr>
<td><strong>Base Pair</strong></td>
<td>Two complementary bases on opposing strands of the sugar-phosphate ladder structure of DNA. These bases can form hydrogen bonds in only one way: adenine with thymine and cytosine with guanine. In RNA, adenine pairs with uracil.</td>
</tr>
<tr>
<td><strong>Biotechnology</strong></td>
<td>The development of a product or products using biological agents. In the past, these agents have been yeasts, molds, enzymes and bacteria used in such processes as wine-making and in bread and cheese production. Recently, biotechnology is identified with techniques that collectively allow the precise identification, isolation, alteration, and re-introduction of heritable traits to living organisms for specific purposes.</td>
</tr>
<tr>
<td><strong>Chromosome</strong></td>
<td>Rod or thread-like structures found in cell nuclei; contains the DNA molecules that make up the chromosome’s genes.</td>
</tr>
<tr>
<td><strong>Clone</strong></td>
<td>A group of cells or an entire organism generated from one ancestor; all cloned cells or organisms are genetically identical to the parent.</td>
</tr>
<tr>
<td><strong>Co-dominance</strong></td>
<td>A circumstance where the two alleles (or genes) for a specific trait are equally strong; a mixture of the two phenotypes results; e.g. pink snapdragons from a red and white cross.</td>
</tr>
</tbody>
</table>
**Glossary**

**Codon:** A three-nucleotide sequence of bases on RNA that specifies an amino acid. ACG would be a codon on RNA; its counterpart along the DNA strand would be TGC and is called an anti-codon. The three-base group may also act as a signal to stop or start gene translation (protein synthesis) or perform some other function of gene regulation.

**Crossing Over:** A natural process occurring during meiosis in sexually-reproducing organisms in which sections of similar chromosome pairs are exchanged, often resulting in new traits.

**Darwin, Charles:** Co-credited with the theory of evolution.

**Deoxyribonucleic Acid (DNA):** The chemical that makes up genes (the information molecules for the cell); looks like a spiral ladder, with sugar and phosphate groups the ladder sides and the four bases (adenine, cytosine, guanine and thymine) as the rungs.

**Dominant:** A gene or allele that is expressed or “shown” in the phenotype regardless of the nature of the other gene or allele.

**Enzyme:** A protein catalyst, which speeds up a specific chemical reaction.

**Evolution:** Theory that life forms change over long periods of time; the mechanism of change in natural selection.

**Expression:** The manifestation of a particular characteristic specified by a gene.

**Gene:** The basic unit of informational inheritance consisting of a sequence of DNA and generally occupying a specific position within a genome. Genes may be structural, which encode for particular proteins; regulatory, which control the expression of the other genes; or genes for transfer RNA.

**Gene Expression:** The physical manifestation of a genetic trait (phenotype). The DNA message is translated to make a protein, which ultimately gives rise to the phenotype of the cell.

**Genetic Code:** The groups of three nucleotide bases (codons) which specify a particular amino acid.

**Genetic Engineering:** The process whereby the DNA of living organisms is altered so that new traits are produced in the organism.
### Glossary

**Genetics**: The study of DNA and heredity.

**Genome**: The total hereditary material of a cell’s nucleus.

**Genotype**: The kinds of genes an individual carries for a trait or traits.

**Heredity**: The passing of genetic traits, based on the DNA code, from parents to offspring.

**Heterozygous**: Two different genes for the same trait [for example (Ww)].

**Homozygous**: Two identical genes for the same trait [for example (ww) or (WW)].

**Hybridization**: Used in cross-breeding to produce offspring from genetically different parents; in plant production, two genetically dissimilar parents are crossed to produce a hybrid offspring.

**Incomplete Dominance**: Offspring of two true breeding parents does not resemble either parent because one allele does not completely dominate over another allele, but is an intermediate between both parents. For example, if a red flower were crossed with a white flower, the offspring would have pink flowers.

**Ligase**: An enzyme used to join segments of DNA together.

**Marker Assisted Selection**: An indirect selection process that is not selected based on the trait we observe but rather on the genetic markers that will bind to the genes that code for the trait we are looking for.

**Meiosis**: Reproduction in sex cells where the daughter cells produced have half the number of parent chromosomes.

**Mendel, Gregor**: So-called “father of modern genetics”; Austrian monk who discovered how genetic “factors” were passed down; his experiments with pea plants are well-documented.

**Mitosis**: The process of division of the nucleus of a cell in which the chromosomes duplicate and divide to yield two identical nuclei. Nuclear division is usually followed by cell division.

**Mutant**: A cell or an organism that expresses traits due to a change in its genetic material.
**Glossary**

**Mutation**: A random or directed change in the structure of DNA or the chromosomes.

**Natural Selection**: The mechanism by which evolution operates; says that individuals who are best adapted to their environment will have a better chance to pass on their genes to their offspring; “survival of the fittest.”

**Nucleic Acids**: DNA and RNA; large molecules made up of nucleotides in base pairings.

**Nucleotides**: The basic units of nucleic acids; each nucleotide consists of a base, a sugar and a phosphate group. The order in which the nucleotides are arranged determines what proteins are made by the cell.

**Nucleus**: The control center of a cell; the membrane-bound structure within eukaryotic cells that contains the chromosomes.

**Phenotype**: The physical expression of a genotype.

**Plasmid**: A small ring of DNA found in many bacteria and some yeast. Plasmids are able to replicate independently of the chromosome and may pass from one cell to another. They are principal agents used in genetic engineering for cloning and transformation.

**Polymerase**: An enzyme which catalyses the synthesis of nucleic acid molecules.

**Protein**: A molecule composed of a chain of many amino acids that acquires a particular folded shape due to the amino acid sequence; both the amino acid sequences and the pattern of folding are involved in the specific functions of the protein.

**Punnett Square**: One tool that scientists, farmers, and ranchers use to predict the outcome of potential crossings of two parents.

**Recessive**: An allele or gene that is not expressed or “shown” in the phenotypes. This is usually “hidden” by a dominant gene.

**Recombination**: Inserting new genetic information into another living organism.

**Restriction Enzyme**: An enzyme that will cut DNA molecules only at sites where particular sequences of base pairs occur.
**Glossary**

**Ribonucleic Acid (RNA):** Similar to DNA, but with the sugar ribose instead of deoxyribose in its structure, and with the base uracil in place of thymine; there are several forms of RNA.

**Selective Breeding:** Continuous breeding of particular organisms to obtain a desired trait or traits.

**Sustainability:** An integrated system of plant and animal production practices having a site-specific application that will over the long-term satisfy human food and fiber needs.

**Tissue Culture** (in plant biotechnology): The process of regeneration of a plant from single cells, isolated embryos, or small bits of plant tissue on liquid or solid media. The media is supplemented with a customized balance of nutrients and plant hormones known to induce the formulation of roots, shoots, or both from plant tissue, called callus.

**Trait:** A specific inherited characteristic.

**Transcription:** The synthesis of a strand of RNA by cellular enzymes using the sequence of bases present in a single strand of the DNA molecule as a template.

**Transformation:** A change in the genetic composition of a cell or organism brought about by the integration and expression of purified DNA.

**Transgenic Organism:** The living thing that results from inserting foreign genetic material into another living organism.

**Translation:** Synthesis of a protein directed by the DNA sequence information encoded in an mRNA molecule.

**Variations:** A deviation from the norm occurring in people, animals, and plants which arise because offspring are a combination of characteristics from both parents.

**Vector:** The vehicle by which external genetic information is spliced into another living organism.

**Virus:** A submicroscopic infectious agent that contains genetic material but must invade a cell in order to replicate itself.