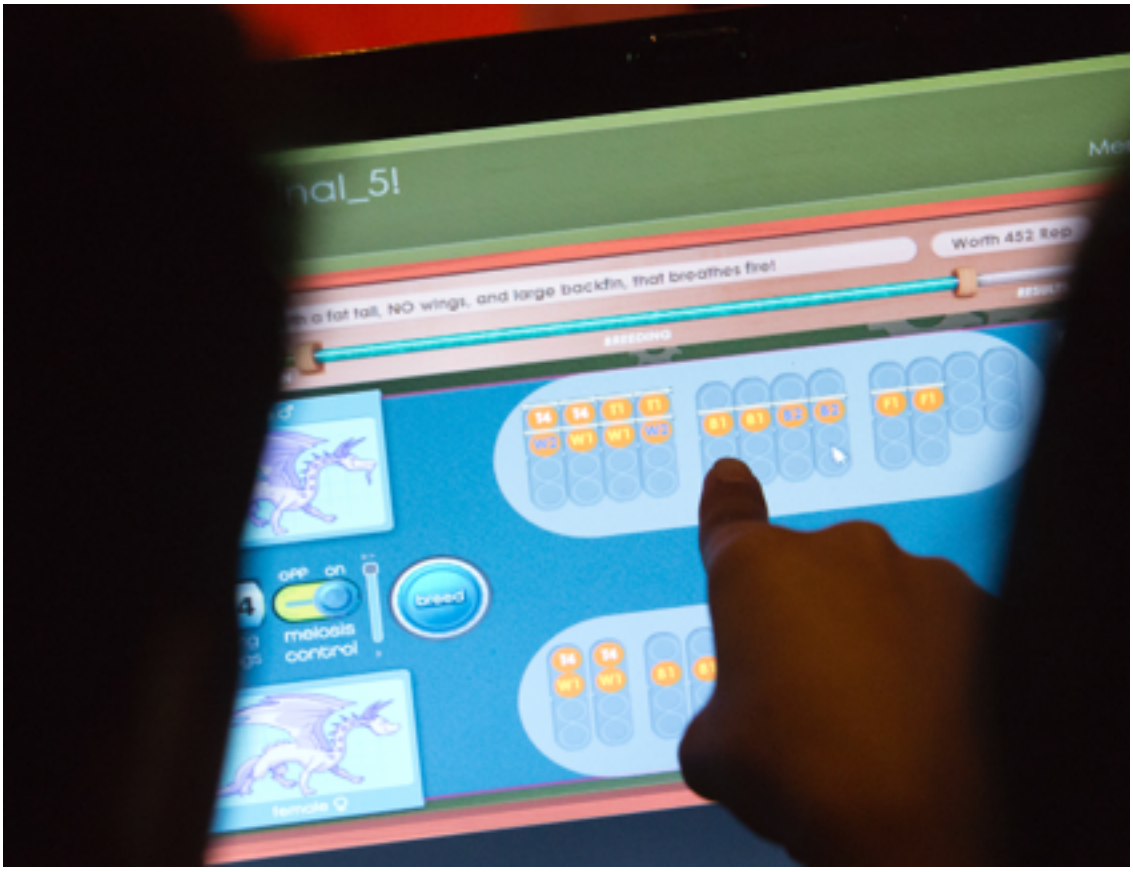
Welcome to GeniGames!

WHAT IS GENIGAMES?

The New York Hall of Science and Concord Consortium have designed, developed and produced GeniGames, a web-based application that supports the teaching and learning of genetics in high school *Living Environment* classes. GeniGames aims to increase student engagement, motivation, affect and learning.



sciplay

The Sara Lee Schupf Family Center for Play, Science, and Technology Learning (SciPlay) is a community-based, hands-on approach to teaching science, technology, engineering and mathematics (STEM). SciPlay's mission is to enhance students' understanding of and engagement in science by harnessing the potential of play for science learning.

Standard 4: Students will understand and apply scientific concepts, principles and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

KEY IDEA	PERFORMANCE INDICATOR	MAJOR UNDERSTANDING
2: Organisms inherit genetic information in a variety of ways that result in continuity of structure and function between parents and offspring.	2.1: Explain how the structure and replication of genetic material result in offspring that resemble their parents.	2.1b: Every organism requires a set of coded instructions for specifying its traits. For offspring to resemble their parents, there must be a reliable way to transfer information from one generation to the next. Heredity is the passage of these instructions from one generation to another.
		2.1c: Hereditary information is contained in genes, located in the chromosomes of each cell. An inherited trait of an individual can be determined by one or by many genes, and a single gene can influence more than one trait. A human cell contains many thousands of different genes in its nucleus.
		2.1e: In sexually reproducing organisms, the new individual receives half of the genetic information from its mother (via the egg) and half from its father (via the sperm). Sexually produced offspring often resemble, but are not identical to, either of their parents.
3: Individual organisms and species change over time.	3.1: Explain the mechanisms and patterns of evolution.	3.1c: Mutations and the sorting and recombining of genes during meiosis and fertilization result in a great variety of possible gene combinations
4: The continuity of life is sustained through reproduction and development.	4.1: Explain how organisms, including humans, reproduce their own kind.	4.1c: The processes of meiosis and fertilization are key to sexual reproduction in a wide variety of organisms. The process of meiosis results in the production of eggs and sperm which each contain half of the genetic information. During fertilization, gametes unite to form a zygote, which contains the complete genetic information for the offspring.

Next Generation Science Standards

HS. Inheritance and Variation of Traits

LS3-a. Ask questions to obtain information about the role of DNA and chromosomes in coding the instructions for forming the characteristic traits of species passed from parents to offspring.

LS3-b. Synthesize, communicate, and evaluate the validity and reliability of the claim 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.

LS3-c. Evaluate the merits of competing ethical arguments for the research, development, and growth of industries based on the development of technologies that modify the genetic make-up of an organism.

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

Student Aims

Students will use this unit to connect to what they already know about cells, DNA and sexual reproduction. Students will develop their understanding of how genetic information results in the production of phenotypically and genotypically unique individuals. Students will incorporate their knowledge of meiosis and patterns of inheritance to answer the Driving Questions: "*How are traits distributed to offspring?*" and "*How does [selective] breeding produce unique individuals with specific traits?*"

Enduring Understandings and Learning Objectives

Essential Understanding: An organism's genetic makeup determines the physical expression of traits.

- *Learning Objective:* Students will know that a genotype is the combination of genes for one or more specific traits.
- *Learning Objective:* Students will know that an allele is one of a pair of genes that exists at the same location on a pair of homologous chromosomes and codes for a particular trait.
- *Learning Objective:* Students will know that an organism's genes (genotype) result in differences in phenotypes.
- *Learning Objective:* Students will be able to describe and discuss the relationship between genotypes and phenotypes of organisms.

Essential Understanding: Meiosis is essential for sexual reproduction.

- *Learning Objective:* Students will understand that meiosis is a process in cell division during which the number of chromosomes decreases to half the original number.
- *Learning Objective:* Students will know that meiosis results in the production of 4 gametes (sperm for males and egg cells for females) with random allelic combinations.
- *Learning Objective:* Students will understand how meiosis and sexual reproduction transfer genetic information from parent to offspring.
- *Learning Objective:* Students will be able to explain, and predict the effects of meiosis, including crossing over, on gamete production and chromosomal numbers.

Essential Understanding: The genetic outcomes of meiosis can vary greatly, even within an individual.

- *Learning Objective:* Students will be able to explain how crossing-over and independent assortment increase genetic variation in offspring.
- *Learning Objective:* Students will be able to explain why offspring from the same parents will differ genotypically and phenotypically.

Essential Understanding: Traits are inherited through probabilistic patterns.

- *Learning Objective:* Students will know about the following inheritance patterns: dominant/recessive, x-linked, incomplete dominance, polyallelic and multigenic.
- *Learning Objective:* Students will understand that genetic transference is probabilistic.
- *Learning Objective:* Students will be able to predict breeding outcomes using Punnett squares and Pedigree charts.
- *Learning Objective:* Students will be able to use their understanding of inheritance patterns to identify, interpret, and explain probabilistic data.

Lessons at a Glance

Part 1: Phenotypes & Genotypes

Driving Questions: *What are traits and can you measure them?*

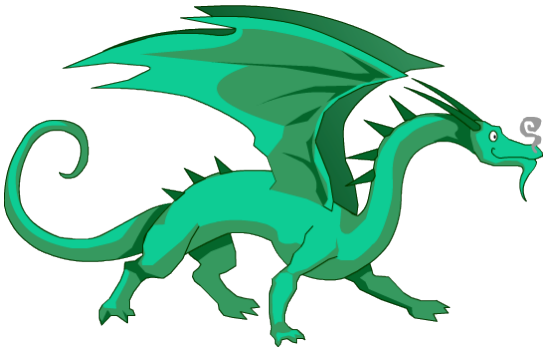
- Determining Differences Among Classmates
- Genes, alleles and chromosomes discussion
- Optional Extension Activity: Vocabulary study guide

Part II: GeniGames Towns

Driving Questions: *How do two parents produce a unique individual? Why are there similarities and differences between parents and offspring? How do different alleles determine a drake's phenotype? Are drake traits all inherited in the same way?*

Town 1: Lullen

- Wings vs No Wings
- Meiosis Discussion
  - Think-pair-share about meiosis
  - Meiosis Models Lab
- aFor Understanding
- Punnett Squares
- Metallic vs Nonmetallic



- Discussion about dominant/recessive traits
- Optional Extension Activity: Meiosis vs Mitosis comparison

Town 2: Angeral

- Backward vs Forward Horns
- Fire vs No Fire
- aFor Understanding
- Discussion about X-linked traits
- Pedigree Charts
- The Case of the Calico Cat

Town 3: Tarrin's Crag

- Green vs Purple Color
- aFor Understanding
- Wide vs Medium vs Narrow Spikes
- Discussion about incomplete dominant traits
- Homework: Incomplete Dominance

Town 4: Narran

- Long vs Kinked vs Short Tail
- aFor Understanding
- Armor vs No Armor
- Discussion about polyallelic traits

Town 5: Luxceros

- Red vs Blue Color
- Discussion about multigenic traits

Part III: GeniGames Towns

Assimilating concepts

- The Impacts of Breeding
- Concept Map

Part 1: Introduction to Phenotypes & Genotypes

Lesson Goal/Aim

Students will begin this lesson by considering what makes individuals unique. They will be asked the questions: *What are traits and can you measure them?* By the end of the lesson, students will have an understanding of phenotypes; genotypes; and the role of chromosomes, genes, and alleles.

Time: 2-3 class periods

Materials

- Pens/pencils
- Worksheet Packet
  - Determining Differences worksheet
  - Computer paper and construction paper for Vocabulary Study Guide (optional)

Procedure

1. *Determining Differences Among Classmates*

- Begin by asking students what it means to be unique. Students should brainstorm possible ways that they are different from their classmates. List out their answers.
- What makes individuals physically diverse? What words can be used to describes these physical similarities and differences?
- Discuss ***traits***-- what they are and why they are important.

Teacher Talking Points

A ***character*** refers to a heritable feature that can vary among individuals. An example of a character is eye color.

A ***trait*** is a variant of this character, such as blue or green eyes. Traits are usually observable, physical characters.

A ***physical trait or phenotype*** is a characteristic of an individual's physical makeup. Examples include height, hair color, eye color etc.

Focus Questions

Are some traits more common than others?
Did any group members have exactly the same combination of traits?
How are the group data and the class data similar/different? Is there more or less variation between groups members or the class? Why?

- Working in groups of 2-3 individuals, students should complete the *Determining Differences* worksheet. Have groups discuss their results.
- Tally the results of the class data and review Focus Questions.
- Discuss how these traits are also called ***phenotypes***.

II. *Genes, alleles and chromosomes*

- Begin by discussing *how* offspring acquire physical traits, focusing on genes, alleles and chromosomes. If students are struggling with the concept of genes, what they are and where they are located, take this time to review the content areas below in the Teacher Talking Points.

Teacher Talking Points

A cell contains many organelles, each with different functions. The nucleus, a prominent organelle, contains the genetic information of that cell. Deoxyribonucleic acid, or DNA, exists as two long, paired strands spiraled into a double helix. Each strand is made up of millions of chemical building blocks called bases. There are four different bases in DNA (adenine, thymine, cytosine, and guanine). DNA is organized, along with proteins, into material called chromatin. Chromatin is a collection of separate structures called chromosomes that are visible as separate units only when a cell is dividing.

Genes are segments of DNA that code for specific proteins that will be expressed in a certain way. Some genes enable cells to make proteins needed for basic functions. Some genes play a role in early development of the embryo. Some genes encode proteins that are unique to a particular kind of cell and that give the cell its character.

Focus Questions

How do genes determine an organism's appearance? What are some different examples of alleles (eye color, hair color, strait/curly hair)?

How many variations of a particular gene exist? Do all genes have the same number of alleles?

- Using the Focus Questions, guide students to the conclusion that there exists great variations in traits because there are actually variations within a particular gene. These variations are called **alleles**.

Teacher Talking Points

Alleles are alternative forms of genes.

An organism's ***genotype*** is its genetic makeup, or the combination of alleles that it possesses. The genotype will determine the organism's phenotype.

An individual who is ***homozygous*** for a particular trait will have two of the same alleles on their chromosomes.

An individual who is ***heterozygous*** will have two different alleles for that particular trait.

- Discuss how knowing the allelic combinations of an individual will lead to knowing the **genotype**. Introduce students to the terms **heterozygous** and **homozygous**.

STOP
Check for Understanding

- Following the Two Minute Paper FACT format (Appendix I), give students the following prompt: *Explain what is passed along to offspring--genes or traits? Why? What is the difference?*

At this time, introduce students to the genetics project that they will be focusing on over the next several days. Explain that through the use of drakes (dragons) they will learn about different traits and approaches to breeding.

Each day they will be incorporating new ideas, facts and concepts into their understanding of different breeding mechanisms. The breeding process and concepts learned will lead to an understanding of how one can selectively choose traits and manipulate the genotype and phenotype of organisms.

Optional Extension Activity

Vocabulary Study Guide

As new words are introduced throughout the unit, students can create a study guide that will allow them to learn and review the variety of genetics vocabulary. Using colored and white construction paper, students should fold, cut and weave together the different papers (Smith, n.d.). See Appendix II. Students should write down the newly learned vocabulary words and their definitions. This will help to reinforce learned concepts. *Throughout this unit, students will continue to add new vocabulary words to the guide.* Ultimately this will serve as a comprehensive tool to review genetics material.

Part II: GeniGames Towns

Lesson Goal/Aim

Students will investigate the different ways that traits are inherited. They will explore aspects of dominant/recessive, incomplete dominance, X-linked, polyallelic and multigenic--relating this knowledge back to the physical features of drakes. Students will ask: *How do different alleles determine a drake's phenotype? Are drake traits all inherited in the same way? How do two parents produce a unique individual?* and *Why are there similarities and differences between parents and offspring?*

Time: 7-10 class periods

Materials

Town 1: Lullen

- Computers with internet
- Pens/pencils
- Worksheet Packet
  - Cheat Sheets
  - Meiosis: Understanding the Drake's Genome
  - Punnett Square Worksheet
- Meiosis Models Lab
  - Clay or Pop-beads (4 different colors) for groups of students
- Meiosis Prompt

Town 2: Angeral

- Computers with internet
- Pens/pencils
- Worksheet Packet
  - Double Punnett Square
  - Pedigree Chart Worksheet
  - The Case of the Calico Cat

Town 3: Tarrin's Crag

- Computers with internet
- Pens/pencils
- Worksheet Pack
  - Incomplete Dominance Homework

Materials Continued

Town 4: Narran

- Computers with internet
- Pens/pencils
- Project Worksheet Pack
    - Polyallelic Traits and Pets Worksheet

Town 5: Luxceros

- Computers with internet
- Pens/pencils

Procedure

Students will work through a series of different inheritance patterns. The goal is to have students figure out the pattern and the associated rules prior to actually being taught the pattern. For this reason, allow students to struggle through the tasks before stopping them to discuss what they are seeing.

With each new trait, have students try to identify what rule they are experiencing. Encourage students to use their own annotations and Punnett squares to work through the tasks. After completing each set of tasks, come back as a group and discuss. At that time, make sure that students have the correct understanding of the rule, as well as recognize and know how to use the more traditional genotype annotations (ex. Ww). Have students record all information on their *Track Sheets*. For particularly difficult tasks, have students work together in small groups sharing breeding mechanisms. **Remember to take timeouts as needed to assess student understanding throughout**.

Town 1: Lullen (Dominant/Recessive Traits)

Students should begin by logging into GeniGames and going into the first town, Lullen.

Genetics Hints

Wing alleles:

- W1 (wings) is dominant to W2 (no wings)

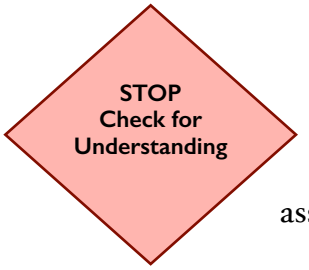
Wing genotypes and phenotypes

- W1 W1 or W1 W2 = wings
- W2W2= no wings

Wings vs. No Wings

- Complete Drake 1.1 and 1.2 in Lullen.

Drake	Features	Outcomes
1.1: Wings	A new allele is revealed: W1 for wings	Students will learn to use the GeniGames interface.
1.2: Wings	A new allele is revealed: W2 for wingless	Students will discover that the W1 allele is dominant to the W2 allele.



Using the information from these tasks, have students pose a claim for the rules of how wing alleles interact. Pick a FACT from the list and follow the format to assess for student understanding (See Appendix I).

- Continue on to Drake 1.3. Discuss how long it took everyone to breed their target drake.

Drake	Features	Outcomes
1.3: Wingless	Students will be working with heterozygous and homozygous recessive parents to breed a recessive drake.	There is a 50% chance that students will achieve the target drake on any attempt. Have students tally the number of times it took them to reach the target. Compare results. Why did it take longer for some students than others?

Think-Pair-Share: Meiosis

- Since 1.3 is the first time that students can get different offspring, stop and contemplate why this might happen. Think about a litter of puppies, kittens or even siblings. Are they exact copies of each other? Should they be? Why or why not?

- Using the Focus Questions as prompts, give students several minutes to write down their own thoughts, followed by several minutes to discuss these ideas with their neighbors. Then come together as a whole class to discuss. Connect gamete production to fertilization.

Focus Questions: Meiosis

What would you tell someone about the process and/or purpose of meiosis?

How are egg cells and sperm cells different from other body cells?

Why are their similarities and differences between parents and offspring?

- It is important that students understand that the game simulates what actually happens during meiosis. Compare meiosis during the game to real clips of meiosis happening in humans. Use YouTube or another source to find appropriate videos. Have students answer questions in the *Meiosis: Understanding the Drake's Genome* worksheet.

Meiosis Manipulation Lab

- To help students think about how meiosis increases genetic variation, complete the *Meiosis Models Lab* or a meiosis lab of your choosing.

By the end of this activity students should know:

- why gametes contain the haploid number of chromosomes (as compared to diploid somatic cells)
- that the combination of gametes results in the creation of a unique individual
- offspring get half of the genes from their mother and half from their father
- crossover and random assortment of chromosomes (Law of Independent Assortment) result in increased variation.

*For steps and concepts associated with meiosis, see Appendix III.

At this point...

As either an Entrance or Exit Ticket, have students answer the following prompt:
Thinking as a breeder, how would the process of meiosis affect your breeding decisions?

Optional Extension:

Meiosis vs. Mitosis

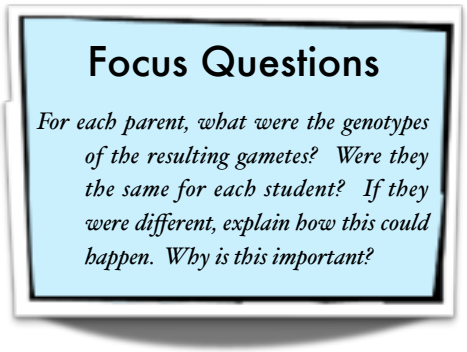
Although mitosis is not specifically discussed in this unit, if you have previously covered this topic, have students compare and contrast the two different mechanisms of cell division. Be sure to note the similarities and differences; a Venn diagram might be useful to organize thoughts.

MITOSIS	MEIOSIS
Start with diploid number (2n) of chromosomes	Start with diploid number (2n) of chromosomes
Chromosomes replicate	Chromosomes replicate
Chromosome pairs (two sister chromatids)	Tetrads are formed between homologous chromosome pairs
Chromosomes align at the center (metaphase plate)	Tetrads align at the center (metaphase plate)
Sister chromatids separate resulting in daughter cells with diploid number (2n)	Homologous chromosome separate, but sister chromatids remain together
Produces 2 somatic (body) cells	Sister chromatids separate, resulting in daughter cells with a haploid number (n)
Only one phase of mitosis	Produces either 4 sperm cells or 4 egg cells
	Two phases of meiosis

Punnett Squares

- Introduce students to the Punnett square to help them better predict genotype and phenotype breeding outcomes. Model how to predict the probable outcome of offspring by using such a tool.
- Discuss the P1, F1 and F2 generations as well as the ratios observed while using a Punnett square.
- Work through the first question in the *Punnett Square Worksheets*. Assign the remaining questions for homework.

Drake	Features	Outcomes
1.4: Wingless	Students can choose between 2 different mothers and 2 different fathers.	The set of parents that will lead to successful results are heterozygous. Using these parents, there will be a 25% chance of breeding the target drake. Have students tally the number of breeds it takes them to achieve the target.



- Use students' results from Drake 1.4 to discuss probabilities. Help students uncover, based on their own results, how likely they were to achieve their target drake from two heterozygous parents. Then compare this with the combined class probability (taken from all of the student data). Is it closer to the predicted probability from a Punnett square. Why or why not?

Drake	Features	Outcomes
1.5: Wingless	**Chromosome selection** becomes active for the first time during this task. This allows users to choose which chromosomes, and therefore alleles, they wish to end up with in a parent's gamete.	This is essentially the same drake as 1.4, except that students are now able to bypass the randomization of gamete formation. Students will want to breed an offspring with two W2 alleles.

Metallic vs Nonmetallic and X/Y Chromosomes

- Review Punnett Square homework. Then continue on with Drakes 1.6-1.7.

Genetics Hints

Metallic alleles:

- M1 (metallic) is dominant to M2 (nonmetallic)

Metallic genotypes and phenotypes

- M1M1 or M1M2 = metallic
- M2M2 = nonmetallic

Drake	Features	Outcomes
1.6: Metallic	New alleles are revealed. M1 for metallic and M2 for nonmetallic skin coloring	Students will acquire a deeper understanding of dominant/recessive traits.
1.7: Nonmetallic & Male	A new game features is introduced: the ability to control of **Meiosis Speed** level. This is also the first time that students will need to breed for a particular gender.	Guide students to recognize that the male offspring inherit a Y chromosome from the father while female offspring inherit the X chromosome.

This is the first task where students will need to breed for a gender-specific drake. After Drake 1.7 review the differences between X and Y chromosomes. Understanding how these chromosomes interact to produce males and females will be important moving forward.

Drake	Features	Outcomes
1.8: Female, Nonmetallic & Wings	Students will be breeding for two separate traits, one dominant and one recessive, and gender.	Students will want to make sure to select a chromosome with M2 and W1 to pair with a chromosome with M2 and W2/W1 to be successful. They shouldn't forget about needing two X chromosomes.

Dominant and recessive traits discussion

- After students have completed all of the tasks in the first town, have a class discussion about what they encountered, how difficult the tasks were, and any new information they have learned.

- Take this time to officially decide upon the rule for this pattern of inheritance. Students might be using words like 'stronger' or 'weaker'. Guide them to use the words dominant and recessive, understanding that in the presence of a dominant allele, a recessive allele has no noticeable affect on an organism's phenotype.

Teacher Talking Points

Dominant and Recessive traits: when the alleles for a specific trait are different (heterozygous) and one allele is fully expressed while the other has no noticeable effect on the phenotype of that organism, then the allele that is expressed is known as the **dominant allele** while the allele that is not expressed is known as the **recessive allele**.

Focus Questions

How do you determine if a certain trait is masked by another trait?

For each trait, how many genes are there, and how many copies of each gene does each drake have? Are the copies always the same? Is this similar or different to alleles for all of the traits?

Are there some traits for which you need two copies of that allele in order for your drake to show that type of trait? Which ones?

Are there some traits for which you only need one copy of that allele in order for your drake to show that type of trait? Which ones?

Were there any combinations that you knew for sure would not give you offspring with certain traits? Any combinations that you knew would give you offspring with certain traits? Give some examples.

What strategies did you use to create your target drakes?

If you didn't know the parents' genes and could only look at the ratios of offspring traits, could you say with certainty what the parents' genes were? Could you say what they probably were? Give an example.

- Make sure students are recording this information on their Cheat Sheets for future use. Have students update their TAC charts based on what they discovered and share new thoughts with the class.

Test Crosses and Dogs

- Following a Think-Pair-Share format, prompt students with: *In dogs, shorthaired alleles are dominant to longhaired alleles. With this in mind, is there a way to determine the genotype of a shorthaired dog without knowing the dog's alleles?*

- Allow students several minutes to suggest a possible way to determine a dog's genotype that is displaying the dominant phenotype for hair length. If needed, guide students to focus their thinking

Teacher Talking Points

A **test cross** is a cross between an organism with an unknown dominant genotype and an organism that is homozygous recessive for the trait in question.

Town 2: Angeral (X-linked traits)

Town 2, **Angeral**, introduces students to traits that follow an X-linked (sex-linked) pattern of inheritance, in addition to dominant/recessive traits.

Genetics Hints

Horn alleles:

- H_1 (backward pointing horns) is dominant to H_2 (forward pointing horns)

Horn genotypes and phenotypes

- H_1H_1 or H_1H_2 = backward pointing horns
- H_2H_2 = forward pointing horns

Forward vs Backward Horns and Backcrossing

- Students should begin by completing the first task (2.1) in Angeral.

Drake	Features	Outcomes
2.1: Forward Horns	Two new alleles are revealed: H1 (backward horns) and H2 (forward horns)	This dominant/recessive trait does not display the typical presence/absence phenotype.

STOP
Check for Understanding

Using the information from these tasks, have students pose a claim for the rules of how horn alleles interact. Pick a FACT from the list and follow the format to assess for student understanding (See Appendix I).

Drake	Features	Outcomes
2.2: Forward Horns	The **backcrossing** feature is unlocked for the first time. Students will need to save an offspring and use as a parent to complete this task.	Students will need to create a heterozygous female to use in a backcross with a heterozygous male.

- After students complete this task, discuss how they did this. Did they save an offspring to use as a parent (backcross) or did they pick two parents and wait for the odds of getting the correct allelic combination? Which decision is better and why?
- Have students defend their position citing the differences in probability. Help them get from their reasoning in the game to formal understanding.

Teacher Talking Points

With a **backcross,** an offspring from the F_1 generation is crossed with a parent from the P_1 generation.

Drake	Features	Outcomes
2.3: Male & Reverse Horns	Breeding for the dominant trait and gender.	Students will learn to make strategic choices.
2.4: Forward Horns & Wings	Breeding for two separate traits: one recessive and one dominant. The easiest way to breed for the target is to use meiosis control to create a male W1W2/H1H2 drake to use for backcrossing.	Students acquire a deeper understanding of backcrossing and will be able to complete a double Punnett square.

Fire-Breathing vs. Non Fire-Breathing

- Continue on to Drakes 2.5-2.8 to learn about the X-linked trait, fire-breathing.
- If students struggle with these drakes, help them come to the understanding that the gene for fire is found on the X chromosome only.

Genetics Hints

Fire alleles:

- F_1 = no fire
- F_2 = fire

Fire genotypes and phenotypes:

- F_1F_1 or F_1F_2 = female drake that does *not* breath fire
- F_1 Y = male drake that does *not* breath fire
- F_2F_2 = female drake that breathes fire
- F_2Y = male drake that breathes fire

Drake	Features	Outcomes
2.5: Fire-Breathing	Two new alleles are revealed: F1 (no fire-breathing) and F2 (fire-breathing).	Students will discover how X-linked traits are passed on.

STOP
Check for Understanding

Using the information from this task, have students pose a claim for the rules of how fire alleles interact. Pick a FACT from the list and follow the format to assess for student understanding (See Appendix I).

Drake	Features	Outcomes
2.6: Male & No Fire-Breathing	The heterozygosity of the female drake is the key to accomplishing the target.	Without meiosis control, student will have a 25% chance of achieving the target. Ask students if there is the same probability of getting a target male as there is for a female.
2.7: Female & Fire-Breathing	Students will need to save and backcross a male (F2Y) drake.	Students will further their understanding of X-linked traits and backcrossing.
2.8 Fire-Breathing & Forward Horns	Breeding for two recessive traits. Will need to use meiosis control and backcross multiple times.	Students will work on breeding for multiple traits.

X-linked Traits Discussion

- After completing these tasks, have students work in groups to determine the rule to this inheritance pattern. Remind students that they must choose evidence that addresses their claims and that their reasoning must use scientific principals.

Teacher Talking Points

X-linked (or sex-linked): X-linked genes tend to follow the typical dominant/recessive pattern, except with a twist. This type of gene is only located on the X chromosome. In cats/dogs/drakes, as well as humans, females have two X chromosomes, but males have an X and a Y chromosome. As a result, males have only one copy of any gene on the X. This means that an X-linked trait behaves differently in males; there is no typical dominant/recessive interaction between two alleles because there is only one allele.

Focus Questions

Did you notice any particular combination of alleles that gave surprising results? How would you describe what you learned with someone else?

How does fire-breathing work like other traits we have seen in drakes? How does it work differently?

If you are breeding two parents that can breathe fire, do you predict that any offspring will also breathe fire? How about if you breed two parents that do not breath fire?

•Use the following Focus Questions to guide student thinking.

The Case of the Calico Cat Worksheet

•Ask students if they can think of any traits that might be inherited this way in cats or dogs? Would sex-linked traits be difficult to breed for? Why or why not?

•The calico coat pattern found in cats is caused by a sex-linked and codominant allele. This means that the gene for this specific coat pattern is only found on the X chromosome. Because of this, generally only female cats will display the calico patterns. Have students work in pairs to answer questions and explain the calico phenomenon in their worksheets.

Teacher Talking Points

Codominance is very similar to incomplete dominance. With incomplete dominance, a heterozygous genotype results in combined phenotype. With codominance,the heterozygous genotype results in a phenotype where both alleles are equally shown.

Pedigree Chart

- Now that students have a better understanding of alleles and genotypes, introduce them to a pedigree chart. Model and work through some examples.

Teacher Talking Points

A **pedigree chart** is a diagram that shows the occurrence and appearance the phenotypes of a particular organism and its ancestors from one generation to the next.

•Assign *Pedigree Charts Worksheet* for homework.

Town 3: Tarrin's Crag (Incomplete Dominance Traits)

Green vs. Purple Coloring

- In **Tarrin's Crag**, green and purple coloring are simple dominant/recessive traits, although later in the game they become part of a more complicated multigenic trait.

Genetics Hints

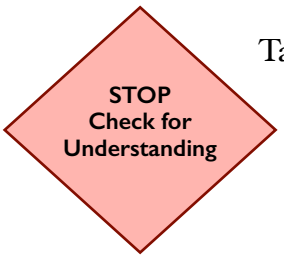
Color alleles:

- G1 (green) is dominant to G2 (purple)

Color genotypes and phenotypes

- G1G1 or G1G2 = green coloring
- G2G2 = purple coloring

Drake	Features	Outcomes
3.1 Purple	Two new alleles are revealed: G1 (green) and G2 (purple). Need to backcross in order to breed target.	Students will learn that the purple trait is recessive to the green trait
3.2 Green & Forward Horns	Breeding for one dominant and one recessive trait. There will be no need to backcross if students use the chromosome selection feature.	Students will work on breeding for multiple traits. There will be different breeding options to arrive at the target drake.
3.3 Green & Forward Horns	The **cross-over feature** is unveiled.	Students will be able to better understand how crossover results in the shuffling and recombination of alleles.



Take a moment to discuss the importance of crossing over. Using the Two-Minute Paper format (FACT, Appendix I), give students the following prompt: What is the importance of crossing over? If crossing over never occurred, what effects would that have on a population? Relate this back to humans.

Drake	Features	Outcomes
3.4 Nonmetallic & Purple	Breeding for two recessive phenotypes.	Students will need to strategically breed and backcross several times in order to get the target drake.

Wide vs. Medium vs. Narrow Spikes

Teacher Talking Points

Incomplete Dominance: some alleles are neither completely dominant nor completely recessive. For certain traits, these incompletely dominant alleles combine to form an intermediate trait.

Drakes 3.5-3.8 introduce students to a new inheritance pattern--incomplete dominance. A heterozygous individual will display an intermediate phenotype. In this case, medium spikes.

Genetics Hints

Spikes alleles:

- S_1 allele = wide spikes
- S_2 allele = narrow spikes

Spikes genotypes and phenotypes:

- S_1S_1 = wide spikes
- S_1S_2 = medium spikes
- S_2S_2 = narrow spikes

Drake	Features	Outcomes
3.5 Wide Spikes	Two new alleles are revealed: S1 (wide spikes) and S2 (narrow spikes).	Students will discover that spikes follow an incomplete dominance inheritance pattern
3.6 Narrow Spikes	Students will need to breed a drake with two S_2 alleles	A review of probability when working with a trait that follows an incomplete dominance inheritance pattern.
3.7 Male, Medium Spikes & Fire-Breathing	Breeding for one incompletely dominant trait and one recessive trait.	Students will work on breeding for multiple traits.
3.8 Metallic, Purple & Narrow Spikes	Breeding for three recessive traits.	Students will work on breeding for multiple traits and backcrossing.

Incomplete Dominance Discussion

STOP Check for Understanding

Working with their neighbor, have students draft a rule for how this trait behaves, giving evidence and reasoning for how spikes are inherited. Some students may suggest that having a combination of spike alleles results in an intermediate phenotype. If you would like, pick a FACT from the list and follow the format to assess for student understanding (See Appendix I).

- During this time, also discuss the green/purple trait. Have students define which pattern of inheritance it falls under.
- Have students complete the *Incomplete Dominance Worksheet* for homework.

Focus Questions

When you cross a drake with wide spikes with a drake with narrow spikes, were you surprised at the resulting offspring? Were you surprised by the results from the other crosses? Do these results make sense?

What is the ratio of spike phenotypes for your offspring? Are there any differences in the class?

How would you describe this pattern of inheritance?

Town 4: Narran (Polyallelic Traits)

Long Tail vs. Kinked Tail vs. Short Tail

- The following drakes will allow students to explore their first **polyallelic** trait: the trait for different tail shapes. This is a very different type of inheritance pattern, so group work may be necessary.

Teacher Talking Points

Polyallelic: these types of genes have more than two alleles, which form an allelic series, affecting a gene. In an example of a gene with three different alleles (A, B and C), A is dominant to B and B is dominant to C (and therefore A is dominant to C as well).

Genetics Hints

Tail alleles:

- T_1 = long tail
- T_2 = kinked tail
- T_3 = short tail

Tail genotypes and phenotypes

- T_1T_1, T_1T_2 and T_1T_3 = a drake with a long tail
- T_2 T_2 and T_2 T_3 = a drake with a kinked tail
- T_3 T_3 = a drake with a short tail

Drake	Features	Outcomes
4.1 Kinked Tail	Two new alleles are revealed: T1 (long tail), T2 (kinked tail). Will need to backcross a heterozygous male to reach the target.	Students will discover that T1 is dominant to T2
4.2 Short Tail	A third allele for tail is revealed: T3 (short tail). A backcross is needed.	Students will discover that T2 is dominant to T3

STOP
Check for Understanding

Stop students after this second drake and have them hypothesize, either alone or in groups, how they think the three alleles interact. At this point students will not have seen T1 and T3 alleles together so they may be unsure of their relationship. Record student responses on the board and return to them after Drake 4.4

Drake	Features	Outcomes
4.3 Fire-Breathing & Short Tail	Breeding for two recessive traits. Students will need to use the chromosome selection and backcross features.	Students will learn the last tail relationship: T1 is dominant to T3
4.4 Green, Kinked Tail & Wide Spikes	Breeding for two dominant traits and one intermediate trait.	Students will work on their understanding of the crossing over feature.

- As this is the last challenge in the polyallelic level, return to students' previous hypotheses about how the three T alleles interact. Were they correct? Why or why not? Have students amend their rule and officially define the tail trait as polyallelic.
- Using the Agreement Circles FACT (Appendix I), pose the following question to students: *Which of the following patterns of inheritance that you have learned about is most common in humans? Why? What support do you have?*
    - Students should move to the area of the room that corresponds to the inheritance patterns (dominant/recessive, incomplete dominance, polyallelic and sex-linked) that they believe is the correct answer to the prompt. Have them defend their position.

Polyallelic Traits and Yours Pets Worksheet

- Extend students' understanding of polyallelic traits by having them work through an example of the tabby gene in cats with the *Polyallelic Traits and Your Pets* worksheet. This can also be done as homework.

Armor vs. No Armor

- Armor is a unique trait in that it the presence of the characteristic is actually a recessive quality.
- Have students predict which trait is dominant and which is recessive. Record their responses and ask students to defend their position.

Genetics Hints

Armor alleles:
- A1 (no armor) is dominant to A2 (armor)

Armor genotypes and phenotypes
- A1 A1 or A1 A2 = no armor
- A2 A2 = armor

Drake	Features	Outcomes
4.5 Armor	Two new alleles are revealed: A1 (no armor) and A2 (armor).	Students will discover the presence of armor is the recessive phenotype.
4.6 Female & Armor	Students will need to breed a homozygous recessive female (XX) drake.	Students will review dominant/recessive traits and probabilities associated with two heterozygous parents.
4.7 Female, Purple & Medium Spikes	Breeding for an intermediate trait and a recessive trait. Will need to get the correct alleles on one chromosome by using the cross over function of meiosis control.	Students will work on their understanding of dominant/recessive and incomplete dominance traits, crossover and backcrossing.
4.8 Purple, Short Tail & Armor	Breeding for three recessive traits.	Students will continue to work on cross over, chromosome selection and backcrossing.

- As an optional extension, have students complete the trihybrid cross with a Punnett square. They should use the parents that ultimately produced the target drake. From that cross, have them determine the the ratios of potential phenotypes. Determine probability of obtaining the target *without* using meiosis control.

Town 5: Luxceros (Multigenic Traits)

Blue vs. Red Coloring

- This section introduces students to multigenic traits. In the following tasks, an additional gene for color is revealed, producing four colors: green, purple, blue and red. Students must uncover how color is determined as well as inherited. Additionally, students will need to couple their understanding of multigenic traits with all of the previous inheritance patterns.

Genetics Hints

Color alleles

- D_1 (full color) is dominant to D_2 (dilute) and is X-linked
- G_1 (green) is dominant to G_2 (purple)

Color genotype and phenotype

- G_1G_1/D_1D_1 or G_1G_2/D_1D_2 = green
- G_2G_2/D_1D_1 or G_2G_2/D_1D_2 = purple
- G_1G_1/D_2D_2 or G_1G_2/D_2D_2 = blue
- G_2G_2/D_2D_2 = red

Teacher Talking Points

Multigenic traits: when two or more genes interact with each other to affect a specific trait. A common example is skin color; many genes factor into determining a person's natural skin color.

Drake	Features	Outcomes
5.1 Blue	Two new alleles are revealed: D1 and D2.	Students will find D2 to be recessive to D1 and that these alleles follow an multigenic inheritance pattern.
5.2 Nonmetallic & Blue	Breeding for one recessive trait and one recessive set of D alleles coupled with a homozygous dominant or heterozygous set of G alleles.	Students will review sex chromosomes and previous inheritance patterns.

STOP
Check for Understanding

Stop students after this second challenge and discuss what they think is going on with these new D alleles. How are they related to color? If you would like, pick a FACT from the list (See Appendix I).

Drake	Features	Outcomes
5.3 Blue, Long Tailed & Metallic	Breeding for a combination of recessive and dominant traits.	Students will review sex chromosomes and previous inheritance patterns.
5.4 Male, Blue, Nonmetallic & Fire-Breathing	Breeding for a combination of four different traits.	Students will review sex chromosomes and previous inheritance patterns.
5.5 Female, Metallic & Red	Breeding for gender, one dominant trait and one recessive trait.	Students will understand the complete relationship between G1/G2 and D1/D2.
5.6 Female, Metallic, Red, Forward Horns, Kinked Tail & Armor	Breeding for gender, one dominant trait, three recessive traits, and one intermediate trait.	Students must understand the various traits previously uncovered and the probability of inheritance to succeed in this final challenge.

Multigenic Trait Discussion

- After having finished the last challenge, students should hypothesize about the mode of inheritance of color. As a class decide on the top three best possible solutions and then test them out. Which explanation of how color is inherited is correct and why? Why are the others incorrect?

- Students should list the possible genotypes for each phenotype. Note, that although purple drakes were not used in the last few challenges, they too follow this particular pattern of inheritance.

Focus Questions

How many different drake colors are there? What are the colors?

How many genes are involved in the production of drake color?

How do these genes interact to create all of the various drake colors?

Are there any differences in common colors of male and female drakes? Describe these.

Final Thoughts

Lesson Goal/Aim

Students will further explore the processes and decisions made when breeding animals, especially outside of a controlled game. They will conclude this unit by assimilating all of the concepts addressed in the previous lessons, demonstrating their understanding of meiosis, alleles and inheritance patterns.

There is a choice of culminating activities; choose one or both.

The Impacts of Breeding

Materials

- Computers for research
- Breeding articles

Procedure

Taking into account what they learned in the game, students should begin to consider the effects that repeated breeding could have on a species. Students should either research articles on their own or be provided articles from the list in Appendix IV . A recommended article is "*Bowwow Ouch*" by Benoit Denizet-Lewis. Tie this into genetic engineering if you wish. Students should construct and then present their arguments either in the form of a paper, debate or group presentation.

Question: Using your new knowledge of heritability, as well as the following articles, construct an argument either supporting or opposing one of the following statements:

- "Inbreeding and other breeding practices are a safe and effective means to obtain the ideal cat or dog"
- "Breed the best and hope for the best"
- "Phenotypes of pets are completely random; there is no way to predict what a litter or puppies or kittens will look like"

Concept Map

Materials

- Pens/pencils/colored markers and white paper

Procedure

In order to assess connections to key concepts and ideas, students will construct a concept map. Encourage students to organize the map in whatever way makes sense to them. Stress that there are many ways to make and show these connections, but that they will need to be able to validate their concept map.

Terms: dominant, recessive, model, allele, homozygous, heterozygous, back cross, test cross, gene, data, trait, phenotype, genotype, segregation, incomplete dominance, polyallelic, multigenic, X-linked, meiosis, haploid, diploid, crossing over, gamete, chromosome, parent, offspring and DNA.

APPENDIX I: FACTs (Keeley, P. (2008). Science: Formative assessment. Corwin Press)

Agreement Circles
Students stand in a circle as a teacher reads a statement. If students agree with the statement, they move to the center of the circle. While facing each other, have students defend their positions--either supporting or refuting the original statement.

Commit and Toss
Give students a question or a prompt. Have them write their answers on a small sheet of paper, being sure not to write their names down. When finished, students should crumple up their papers. Toss the paper balls around the room several times. Students should read and then share the paper they end up with--describing/agreeing/disagreeing with someone else's anonymous ideas.

Explanation Analysis
Present students with a scientific explanation (can be real or student/teacher created). Have students assess and critique the statement, providing claim and appropriate scientific evidence to to support their views.

Fishbowl
Group 4-5 students together in the center of the room. Present a prompt to the group. Have the group 'think out loud' and discuss the prompt, while the other students listen from outside. Students should then reconcile their own thinking with their peers.

Fist to Five
Have students indicate their level of understanding of a concept by holding up a range of fingers with a closed fist being no understanding and 5 fingers being full understanding.

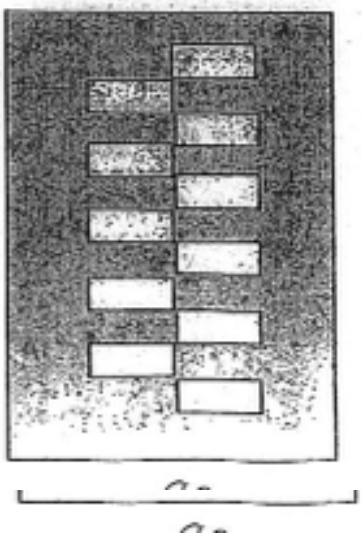
I Think-We Think
Folding a sheet into columns, label on side "I Think" and the other "We Think". Write individual ides about a concept in the "I Think" column. After a group/class discussion add to the "We Think" column.

Muddiest Point
Have students take a moment or two to write down the most difficult or confusing point of the class. Discuss as a group.

Two-Minute Paper
Give students two minutes to respond to a predetermined prompt.

What Are You Doing and Why?
Imagine that a visitor walks into the classroom and asks "What are you doing and why?" Have students describe and explain their actions.

- You will need 2 sheets of construction paper, of different colors. (You'll only use ½ a sheet of the second color though.)
- Fold the frame color into fourths horizontally (hamburger folds).
- Back-fold the same piece in the opposite directions so that it is well creased and flexible.
- Fold the frame at the center only, and make cuts from the fold up to the next fold line. 7 cuts for 8 sections is easy to do, but cut as many as you like.
- Fold the second color of paper into fourths as well. Cut these apart. You will only use 2 of the strips.
- Basket-weave the two strips into the cut strips of the frame. The two sides need to be woven in opposite directions.
- To use the flipper, write questions on the woven colors. To find the answers, fold the flipper so that the center is pointed at you, then pull the center apart to reveal answer spaces.
- Flipper works in this way on both sides!



APPENDIX III: Stages of Meiosis

- Interphase I: Chromosomes replicate resulting in two genetically identical sister chromatids.
- Prophase I: The chromosomes condense. Synapsis occurs, where homologous chromosomes (each made up of two sister chromatids) come together as pairs. Each chromosome pair is now part of a tetrad, or four chromatids. At many places along their length, sections of chromatids crossing over, exchanging segments of DNA. Crossing over of chromosomes leads to increased genetic variability of resulting gametes.
- Metaphase I: Chromosomes are now lined up at the metaphase plate at the center of the cell. Microtubules at the poles of the nucleus are attached to a chromosome from each homologous pair.
- Anaphase I: The spindle apparatus moves the homologous chromosomes toward opposite poles. Sister chromatids remain attached to each other and therefore move as a single unit.
- Telophase I and Cytokinesis: The spindle apparatus continues to separate the homologous chromosome pairs until the chromosomes reach the poles of the cell. Each pole now has a haploid chromosome set, but each chromosome still has two sister chromatids. Cytokinesis, or the division of the cytoplasm, occurs resulting in two daughter cells. There is no further replication of genetic material prior to the second division of meiosis.
- Prophase II: A spindle apparatus forms and chromosomes move towards the second metaphase plate at the center of the cell.
- Metaphase II: The chromosomes are lined up at the metaphase plate, similar to the arrangement in mitosis.
- Anaphase II: Sister chromatids separate. Individual chromosomes move towards opposite poles of the cell.
- Telophase II and Cytokinesis: Cell division occurs, resulting in four daughter cells, each with the haploid number of chromosomes.

Take Home Points

- Egg & sperm cells resulting from meiosis have only ½ set of chromosomes.
- Assortment of chromosomes into the different egg or sperm cells during meiosis is random and therefore different each time.
- Fertilization is random, resulting in similarities & differences between offspring from the same set of parents.
- In most sexually reproducing organisms, special chromosomes determine sex.

APPENDIX IV: List of Articles

Denizet-Lewis, B. (2011). Bowwow ouch. *New York Times*. http://query.nytimes.com/gst/fullpage.html?res=9906E2DC1131F934A15752C1A9679D8B63

Drape, J. (2008). Breeding for speed, ignoring durability. *New York Times*. http://www.nytimes.com/2008/05/11/sports/othersports/11breeding.html?pagewanted=all

Drape, J. (2009). Celebrity pedigrees don't guarantee successful breeding. *New York Times*. http://www.nytimes.com/2009/05/31/sports/31breed.html?scp=1&sq=celebrity+pedigrees+don%27t+guarantee+successful+breeding&st=nyt

Fountain, H. (2008). A tortoise may be bred back into being. *New York Times*. http://www.nytimes.com/2008/09/23/science/23obtort.html

Wade, N. (2006). DNA offers new insight concerning cat evolution. *New York Times*. http://www.nytimes.com/2006/01/06/science/06cats.html?_r=0

Vocabulary Guide

- **Allele**: one or more versions of a gene that exists at the same location on a pair of homologous chromosomes. and codes for a particular trait. They are variations within a particular gene.
- **Backcross**: when an offspring from the F1 generation is crossed with a parent from the P1 generation
- **Behavioral trait**: a characteristic of the way an individual acts i.e. a sheepdog's herding instinct.
- **Cell:** the smallest unity that can perform all life processes; cells contain DNA.
- **Character**: refers to a heritable feature that can vary among individuals i.e. eye color.
- **Chromosome**: is made up of DNA and protein and found in the nucleus of organisms.
- **Crossing over:** the exchange of genetic material (DNA) between homologous chromosomes. Crossing over results in genetic recombination.
- **DNA:** Deoxyribonucleic acid; a molecule that contains the information that determines the traits of a living thing inherits.
- **Dominant**: the expressed allele when the alleles for a specific trait are different (heterozygous) and one allele is fully expressed while the other has no noticeable effect on phenotype.
- **Gametes:** a haploid egg or sperm cell that is formed during meiosis.
- **Gene**: are segments of DNA that code for specific proteins.
- **Generation:** the act of producing offspring; a parent-child relationship.
- **Genetics:** is the science of genes, heredity and variation in living organisms.
- **Genotype**: is the genetic makeup as it is the combination of alleles for one or more specific traits.
- **Heterozygous**: having two different alleles for a particular trait.
- **Homozygous**: having two of the same alleles on their chromosomes.
- **Incomplete dominance:** when alleles are neither completely dominant nor completely recessive and combine to form an intermediate trait.
- **Meiosis**: a process in cell division during which the number of chromosomes decreases to half the original number.
- **Multigenic**: when two or more genes interact with one another to affect specific trait i.e. the way many genes factor in to determining a person's natural skin color.
- **Nucleus:** an organelle found in a cell that contains the cell's DNA.
- **Pedigree chart**: a diagram that shows the occurrence and appearance the phenotypes of a particular organism and its ancestors from one generation to the next.
- **Physical trait/Phenotype**: an organism's appearance that results from that organism's genotype and environment i.e. height, hair color, eye color, etc.
- **Polyallelic**: a type of gene that has more than two alleles (which form an allelic series) affecting a gene i.e. in the case of a gene with three different alleles (A, B, and C), A is dominant to B and B is dominant to C.
- **Probability:** the likelihood that a possible future event will occur in any given instance of the event.
- **Punnett square:** a diagram that is used to predict an outcome of a breeding experiment.
- **Recessive**: the allele that is not expressed when the alleles for a specific trait are different (heterozygous) and one allele is fully expressed while the other has no noticeable effect on the phenotype of that organism.
- **X-linked/Sex-linked**: when a gene is only located on the X chromosome. Because males have only one X chromosome, they have only one copy of any gene on the X meaning that there would be no typical dominant/recessive interaction. X-linked genes only follow the dominant/recessive pattern in females as they have two X chromosomes.
- **Test cross**: a cross between an organism with an unknown dominant genotype and an organism that is homozygous recessive for the trait in question
- **Trait**: is a variant of character, such as blue or green eyes. Traits are usually observable, physical characters. They can be the result of genetics, environmentally influenced, or a combination of both.