PRISM UHH GK-12

Genetic Variation

Concepts
Within a population of organisms, individuals will exhibit variation or differences among their features.
Genes are the basic units of heredity and they are what make each individual's characteristics, traits and behaviors different.

Standards addressed
7.1.3, 7.5.2, 7.5.3

Duration
60 (+) minutes

Vocabulary
Genetics
Variation
Genes
DNA
Nucleic Acids
Chromosome
Alleles
Traits
Dominant
Recessive
Homozygous
Heterozygous

Source Material
Adapted from FOSS

Exploring Human Traits

Summary
Genetics can be a confusing concept for many students to understand. In order for the class to begin to understand genetics, they will first study variation in human traits. Students will start learning about the study of heredity by surveying their own features. They will learn that they possess single gene traits with simple dominance inheritance patterns such as earlobe attachment, tongue rolling, and bent little finger. Students will work in groups, and after surveying their partners, the data of the class will be collected and patterns of inheritance will be discussed.

Objectives
- Students will describe human traits.
- Students will distinguish which trait they possess for chosen features.
- Students will organize data, calculate percentages, and create graphs.
- Students will identify patterns and discuss conclusions for those observed patterns.

Materials
Rulers (1 for each group of 2)
Grid for Vocabulary Bingo, or have each student take out a piece of paper and make their own grid (5 squares down x 5 squares across).
Vocabulary Review Sheet-Can be used as transparency or a handout.
Internet access if added background material is needed-

Teacher Prep Activity
- Xerox "Genetic Variation" readings, grids for Vocabulary Bingo Vocabulary Review Worksheet and Exploring Human Traits Record Sheets for students.
- Xerox a single copy of the Human Traits that can be used for teacher.

Background
With the invention of better microscopes in the late nineteenth century, biologists were able to discover the basic facts of cell division and sexual reproduction. With these new discoveries, scientists began to focus genetics research to understanding how hereditary traits are passed on from parents to their children. **Genetics** is the branch of science that deals with inheritance of biological characteristics. Within a population of organisms there will be **variation** among the individuals in the population and this is the reason for population change and differences. Within a population of sexually reproducing organisms, every individual within that population will be unique and vary in their traits, behaviors and environmental needs. **Genes** are the basic units of heredity and they are what make each individual's characteristics, traits and behaviors different. Genes are found along the DNA strand. **DNA (**deoxyribonucleic acid) is made up of **nucleic acids,** which are large molecules that hold the story of life. DNA is the specific nucleic acid that deals with determining the genetic code of each individual. Typically, DNA molecules are quite long, approximately 5 cm long and in order to fit within the nucleus of the cell, they are coiled and tightly wound into a structure called a **chromosome**. branch of science that deals with inheritance of biological characteristics.

Organisms have different number of chromosomes, some organisms has as few as two, while some have up to a thousand. Humans have 23 different chromosomes and each of those has an identical partner chromosome. The paired chromosomes that are similar are considered to be homologues and each chromosome has the same genes. These two genes interact with each other to produce the characteristic they are assigned to and the two copies of the genes are called **alleles**. When the two alleles are considered together, they make up a single gene. When a gene is composed of two identical alleles it is considered **homozygous**. When the gene is composed of two different alleles, the gene is **heterozygous**.

Gregor Mendel, an European monk, became known as the "father of modern genetics" for his study of inheritance of traits in pea plants. Through selective cross-breeding of different **traits** (tall, short, purple flower, white flower, smooth seed) of pea plants Mendel discovered the basic principles of heredity. Over many generations of breeding pea plants, Mendel discovered that certain traits show up in offspring without any blending of parent characteristics. For example, when pollen from tall plants was used to pollinate the flowers of short plants, all the offspring were tall. There was no mixing of tall and short plants. In the previous example, the trait of "tall" which exclusively appeared in the first generation (F_1) and reappeared in the second generation (F_2) was identified as the **dominant** trait. The second generation also revealed the "short" trait that was absent in the F_1 generation. This trait that was absent in the F_1 generation but present in the F_2 generation was identified as the **recessive** trait. Unfortunately, Mendel did not know about DNA, chromosomes, or genes and was unable to understand the biological and physical processes that allowed inheritance to occur and the importance of his work was not recognized until many years later.

Procedure

1). First have students read background information about Genetic Variation. This can either be assigned as homework, or this can be done as a lesson during class prior to this activity. If the reading is to be assigned as homework, be sure to take a period to go over the information since some of the vocabulary can be complex.
2). Play a round (or two) of Vocabulary Bingo and then review genetics vocabulary sheet as a class.
3). Divide students into groups of two and give each group a ruler (ruler will only be used if the traits that you assign to survey need to be measured). First ask the students if they think there are differences among humans and have them give examples of possible differences. Ask them if there were going to describe a person, for example, if they needed their parents to go pick up a friend that their parents had never met, how would they describe their friend to their parents. Hopefully they say things like "my friend has brown hair, they are tall, they have brown eyes, etc.". Explain to them that they just described traits about a person. They will now survey their own traits.
4). On the list of traits provided, choose up to five traits and be sure to introduce the traits and go over them with the students. Each feature only has two traits, so each student should have one or the other trait. Let students know that their assignment is to discover which trait they have for each of the assigned features. For example, if the tongue trait is chosen, the student will either be able to curl their tongue or not.
5). Give the students about 10 minutes to observe each other and determine which traits they possess. Have the students record their traits on a piece of paper. They should write which feature they have and the trait, either the dominant or recessive trait. Dominant traits will be symbolized by 2 capital letters (TT) and recessive traits will be symbolized by 2 lower-cased letters (tt). This actually defines the genotype of the trait.
6). Poll the class by having the students come to the board and tally their results. On the board, have each trait written out and next to each trait, each student can make a tick or a check next to the trait.
For example:

Tongue rolling:	TT	𝍸	"5 students"
	tt	||	"2 students"

Then determine the percentage of students in the class that have the certain trait.
The class can also be polled using a transparency, having the students raise their hands and report to the teacher which traits they have.

7). Talk about the results. Is there variation among the students? Which traits occurred the most? Are the traits linked? If you can roll your tongue, is your little finger always bent? Summarize the results, determining that there is variation among the students in the classroom.
8). Have the students create a bar graph of their results on the back of their Exploring Human Traits Record Sheet.

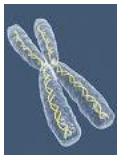
Teacher Resource Extensions:
FOSS Genetic Vocabulary Review Worksheet (included)
When introducing the material, students can visit the web site http://www.dnaftb.org/dnaftb/1/concept/index.html (DNA from the beginning) and choose chapters to explain some of these complex concepts. The animation tab for each chapter is a beneficial way to have students engaged in the material. Chapters 1-5 can be used for the topics of inheritance.

Resources
file:///Users/universityofhawaiihilonsfprismgk-12/Desktop/GK-12%20/Human%20Traits.webarchive
http://www.dnaftb.org/dnaftb/1/concept/index.html
Foss-Populations and Ecosystems

Human Traits

1. Shape of face (probably polygenic)	Oval dominant, square recessive
2. Cleft in chin	No cleft dominant, cleft recessive
3. Hairline	Widow peak dominant, straight hairline recessive
4. Eyebrow size	Broad dominant, slender recessive
5. Eyebrow shape	Separated dominant, joined recessive
6. Eyelash length	Long dominant, short recessive
7. Dimples	Dimples dominant, no dimples recessive
8. Earlobes	Free lobe dominant, attached recessive
9. Eye shape	Almond dominant, round recessive
10. Freckles	Freckles dominant, no freckles recessive
11. Tongue rolling	Roller dominant, nonroller recessive
12. Tongue folding	Inability dominant, ability recessive
13. Finger mid-digital hair	Hair dominant, no hair recessive
14. Hitch-hiker's thumb	Straight thumb dominant, hitch-hiker thumb recessive
15. Bent little finger	Bent dominant, straight recessive
16. Interlaced fingers	Left thumb over right dominant, right over left recessive
17. Hair on back of hand	Hair dominant, no hair recessive

Exploring Human Traits Record Sheet



Name:

Use this tally sheet to keep track of the different traits that your classmates have. Under "Trait" write the different traits that your class has decided to survey, such as Dimples or Tongue Rolling. Under "Dominant" or "Recessive", record the tally marks or check marks of your classmates. Then determine the percentage of students that are either dominant or recessive for the trait.

TRAIT	**DOMINANT**	**RECESSIVE**	**% (# ÷ Class total)**
Example: Dimples	**√√√√√√√√**	**√√√√**	**8 ÷ 4 = 2% Dominant**
_____:	_____	_____	_____(D) _____(r) = _____%
_____:	_____	_____	_____(D) _____(r) = _____%
_____:	_____	_____	_____(D) _____(r) =_____%
_____:	_____	_____	_____(D) _____(r) =_____%
_____:	_____	_____	_____(D) _____(r) =_____%

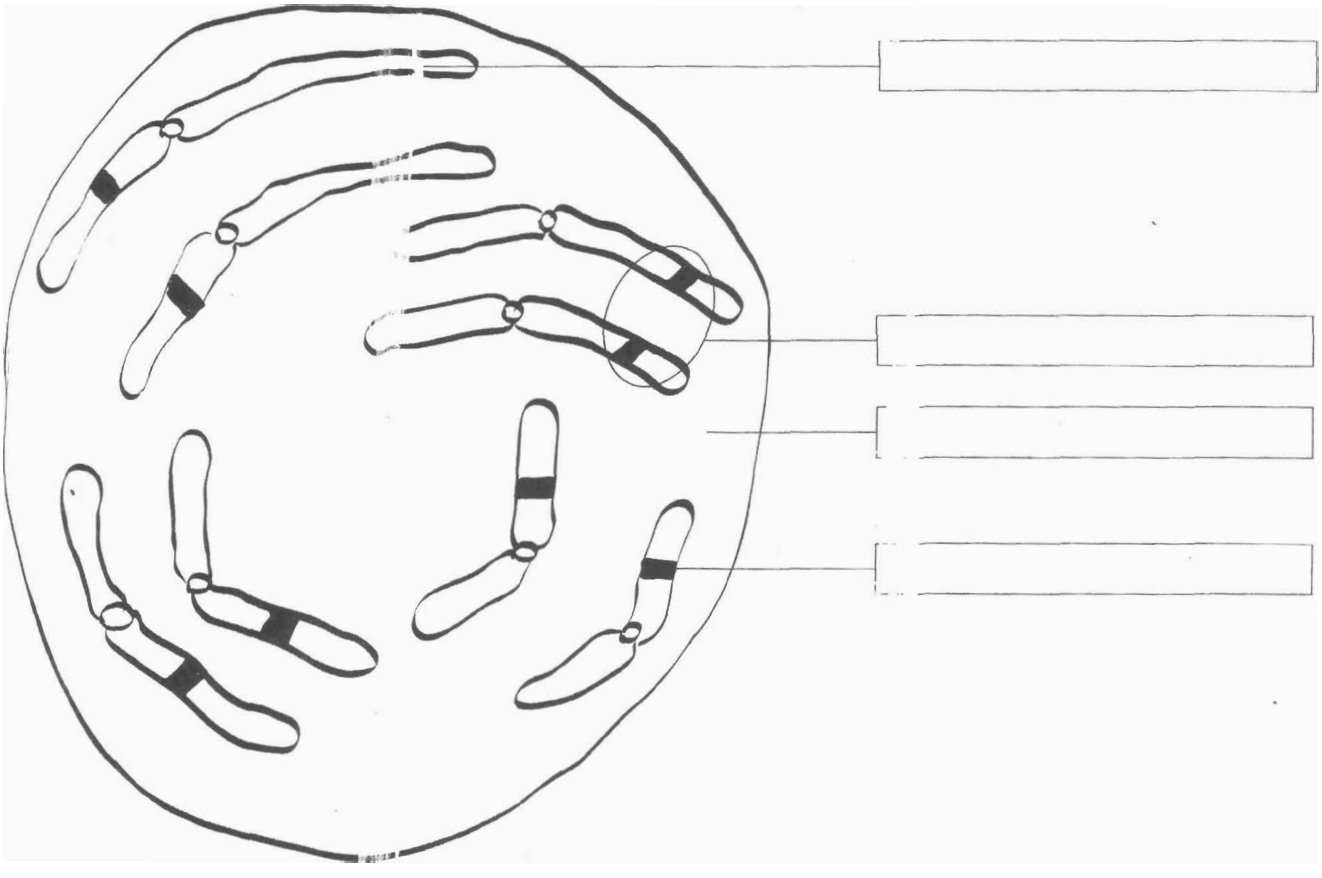
Name _____

Period _____ Date _____

GENETICS VOCABULARY

The offspring of organisms often grow up to look like one or both of their parents. This is because offspring inherit information from their parents that directs their development.

The inherited information is located in the _____ **of every cell in the organism. The** information is coded in the huge _____ molecule. The huge molecules are coiled into compact hot dog–shaped structures called _____. _____ are always present in almost identical pairs. **Locations on chromosomes that affect features of** organisms are called _____. A gene is composed of _____ An organism's unique combination of genes is its _____. The traits produced by an organism's genes is its _____. Alleles that have more influence in determining traits are _____ alleles. Alleles that have less influence in determining traits are _____ alleles.



Answer Key for Genetics Vocabulary Worksheet

1). Nucleus

2). DNA (nucleic acid)

3). Chromosomes

4). Chromosomes

5). Genes

6). Bases (sequence of bases or nucleotides)

7). Genotype

8). Phenotype

9). Dominant

10). Recessive

Answers for picture of cell

First Block: Chromosome

Second Block: Gene

Third Block: Nucleus

Fourth Block: Allele

BINGO

Endemic	Variation	Dominant	Phenotype	Founder Species
Genetics	chromosome	Pu'u Wa'a wa'a	Adaptation	Alleles
Trait	Nucleus	Hawaiian Honeycreeper	Gene	DNA
Recessive	Palila	Niche	Population	Homozygous
Indigenous	Heterozygous	Punnet Square	Genotype	Adaptive Radiation

PRISM UHH GK-12

Genetic Variation

Concepts
Genes are passed on from one generation to the next and this is the concept of heredity. Genes code for what an organism will look like and are carried by chromosomes. Chromosomes, which occur in nearly identical pairs in the nucleus of every cell, are responsible for passing on hereditary information. Depending on which alleles an organism has will determine how the organism will look and behave.

Standards addressed
7.5.2, 7.5.3, 7.5.6

Duration
1-2 60 minute class periods

Vocabulary
Happy-face Spider
Homologous
Phenotype
Genotype
Punnet square
Probability
Homozygous
Heterozygous
Morphs

Source Material
PRISM

Happy-Face Spider Propagation

Summary
Students will act as captive breeders in order to simulate how genes are passed on from one generation to the next. They will also observe how small differences accumulate over time to produce descendants that look very different from their ancestors. Students will use the Happy-face spiders (*Theridion grallator),* a spider that is endemic to the Hawaiian Islands and exhibits genetic variation. Spiders on the island of Maui follow basic Mendelian genetic patterns, so they will be useful organisms for this lesson. This simulation will help students determine how genetic information is transferred during breeding, and what the resulting **phenotype** (how they look) will be. They will decide which traits are most important to breed in order for better survival for the spiders. Students will also be introduced to Punnet squares, which will be used to predict the proportion of offspring with each trait.

Objectives
- Students will learn about a species that is endemic to Hawaii
- Students will simulate how genes are passed from one generation to the next.
- Students will act as captive breeders and choose which traits will help the survival of the spiders.
- Students will use Punnet squares to predict the proportion or frequency of which genes will be passed on.

Materials
Pictures of Happy-face spiders that show variation in color.
Pink and Blue Card Stock-each group of 2 students should have a total of 12 pink cards and 12 blue cards. (Size of playing cards). Need one set for use in explaining concept to students.
Clear transparency to go over Punnet squares
Paper for student Punnet squares.
Hand-out of Happy-face Spider for students to color using their color choice.

Background
Happy-face spiders are found in the rainforests of the Big Island, Oahu, Maui and Molokai. They are usually found on the underside of leaves. Happy-face spiders have a pattern on their body that resembles a smiley face. Every spider has a unique pattern and the body color differs from island to island. Some of the spiders lack the pattern of the smiley face alltogether. These different **morphs** (forms) are caused by the different gene versions carried by the spiders. The combination of alleles on the **homologous** chromosomes (similar, paired chromosomes) which determine a specific trait or characteristic is the organism's **genotype**. The way the information is expressed and how the spider looks is considered its **phenotype**. Genotypes and phenotypes of an organism can be determined with the use of a **Punnet square** which estimate the **probability** (likelihood) of genetic combinations being passed on to potential offspring. A Punnet square is created by crossing either **homozygous** (two identical alleles) alleles, **heterozygous** alleles (two different alleles) or a combination of both on a grid.
Researchers believe that the variation of color and pattern in Happy-face Spiders is a possible type of camouflage against birds, their only significant natural predator.

In order for these spiders to escape predators they must be able to blend into their natural environment. If the student is to be the captive breeder they must decide what would be the best color for the spider to survive in the wild.

Teacher Prep for Activity

- Review background reading for Genetic Variation
- Xerox Happy-face Spider Drawing page.
- Cut out cards for the students: a group of two students will have one set of 12 blue cards and one set of 12 pink cards. Be sure to make a set to use as an example when explaining the activity to the students. Except for the set to be used by the teacher, the other sets of cards should remain blank since the students will be writing in the color traits that they will be using. These cards could be laminated and used year after year, if dry erase markers that could be cleaned off were used.
- Have a clear transparency handy to go over the Punnet squares after they have finished the "card game".

Procedure

1). Split students into groups of two and pass out drawing sheet. One student will act as the MOTHER passing on traits to its offspring and they will receive 12 blank PINK cards. The other student will act as the FATHER passing on traits to its offspring and they will receive 12 blank BLUE cards.
2). Before the students start working on the cards, have them draw a Punnet square (more information about Punnet squares can be found on pg. 257 in the FOSS readings at the back of the lessons) to determine what the probability of allele combinations will be (this can be done on the back of the drawing page). The students will have to choose if the dominant parent will be either heterozygous (Ww) or homozygous (WW or ww). They should work together on creating the Punnet square.
3). Ask the students to determine which color they would like to represent. Remember: this color should be beneficial for their survival in the wild. If a student chooses fluorescent pink, they will have to explain how this color would allow the spider to be camouflaged in the rainforest. The mother and the father should be 2 different colors. For example: Mom=White, Dad=Yellow.
4). Next, ask the students to choose which color is going to be dominant and which is going to be recessive and assign the correct genotype to the respective trait. Remember: the letter designated must be the same for each color but must be represented by either a capital letter or lower cased letter. For example, if mom is considered to be dominant for White, then her genotype would be WW or Ww (students can choose, WW x ww will only have Ww offspring which will all be the dominant color, white in this case. If more variation is wanted in offspring, have the dominant parent be Ww, since Ww x ww will have 50% white and 50% yellow) and eventhough dad is yellow, his recessive genotype would be ww.
5). Ask the students to take a card and write one allele type per card. For example, for mom, each pink card should have a W written on half (6) the cards and the other half (6) will have a lower-cased w written on them, if you make mom heterozygous. If mom is homozygous then all her cards will have W on each one. For the blue cards, for dad, each card should have a lower-cased w written on it, since the gene is recessive he will only be passing the recessive gene on.
6). Now have the student with the pink cards shuffle their cards and the student with the blue cards shuffle their cards as well. Then have the students lay all the pink cards out next to each other and below that row of cards, lay out all the blue cards. Be sure the cards are lined up above and below each other to show how the different genes line up.
7). Once the cards are laid out, have the students look at the frequency of the combinations of traits. Ask the students to compare the probabilities of the allele combinations from their Punnet squares (on the back of their drawing page) to the frequencies created from the cards they made.

Assessments

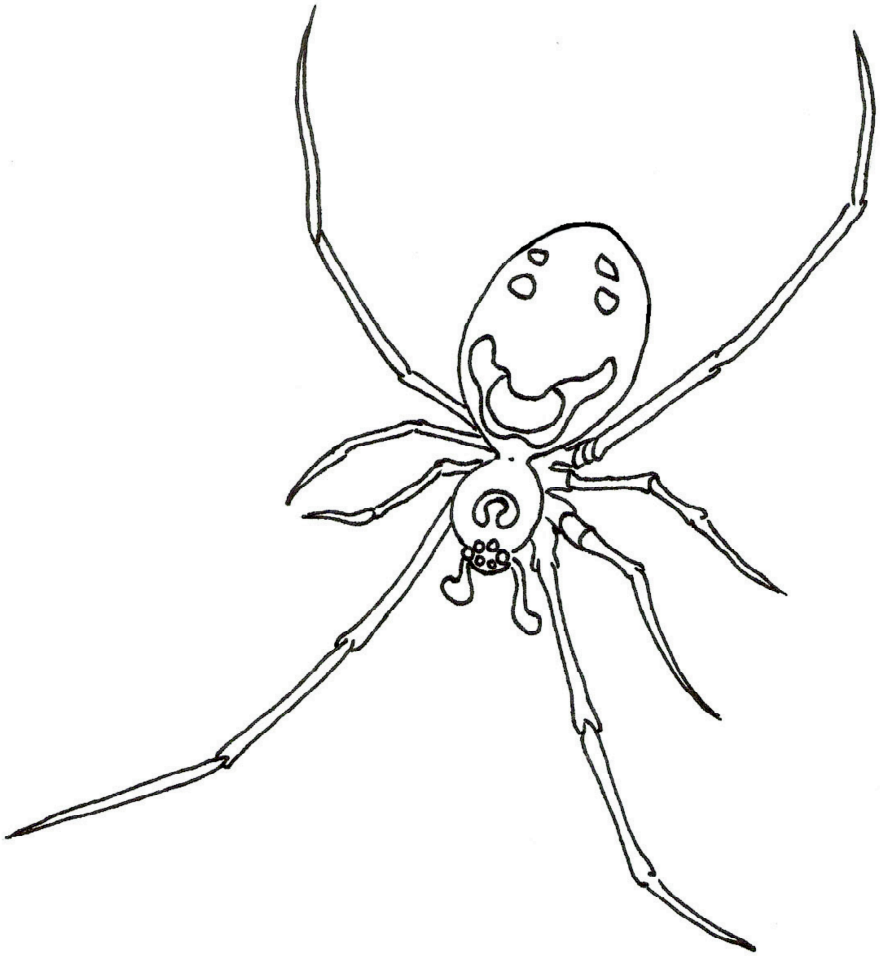
Journal writing and coloring picture of spider to accompany writing or defense of color choice.
Class presentation on spider color choice

Resources

http://evolution.berkeley.edu/evolibrary/article/_0/happyface_02
Google images-http://images.google.com/
Foss-Populations and Ecosystems

Name: _____

Color the body of the Happy-Face Spider the color that was chosen to breed the spider for survival in the wild.
Use the extra space behind the spider to draw the habitat where this spider can be found.



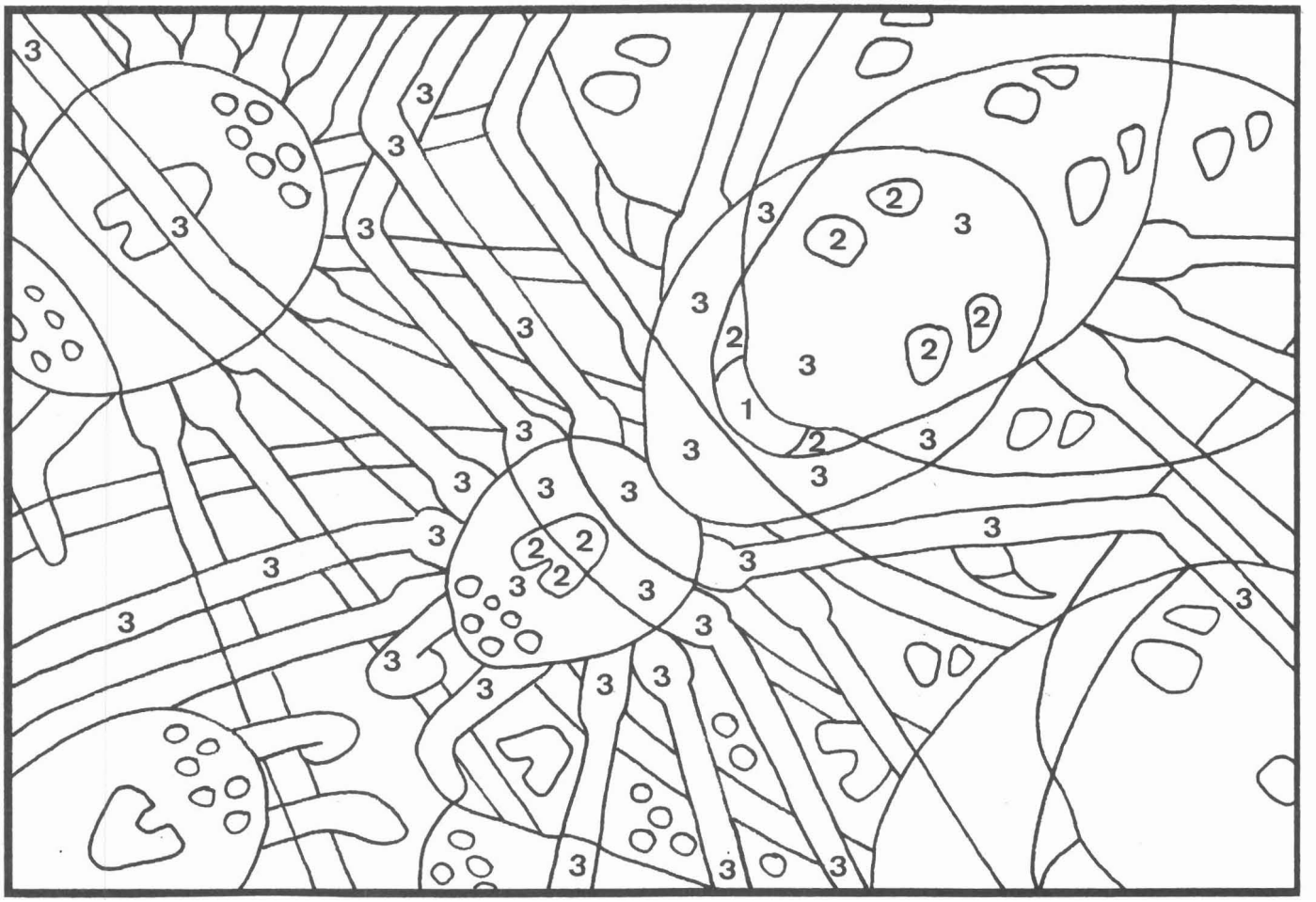
UHH PRISM
Drawing by: Bobby Hsu

Look under a leaf and find a smiling surprise. But look out, because I like to catch my prey in a silken trap.

WHO AM I?

Color the numbered spaces to find me.

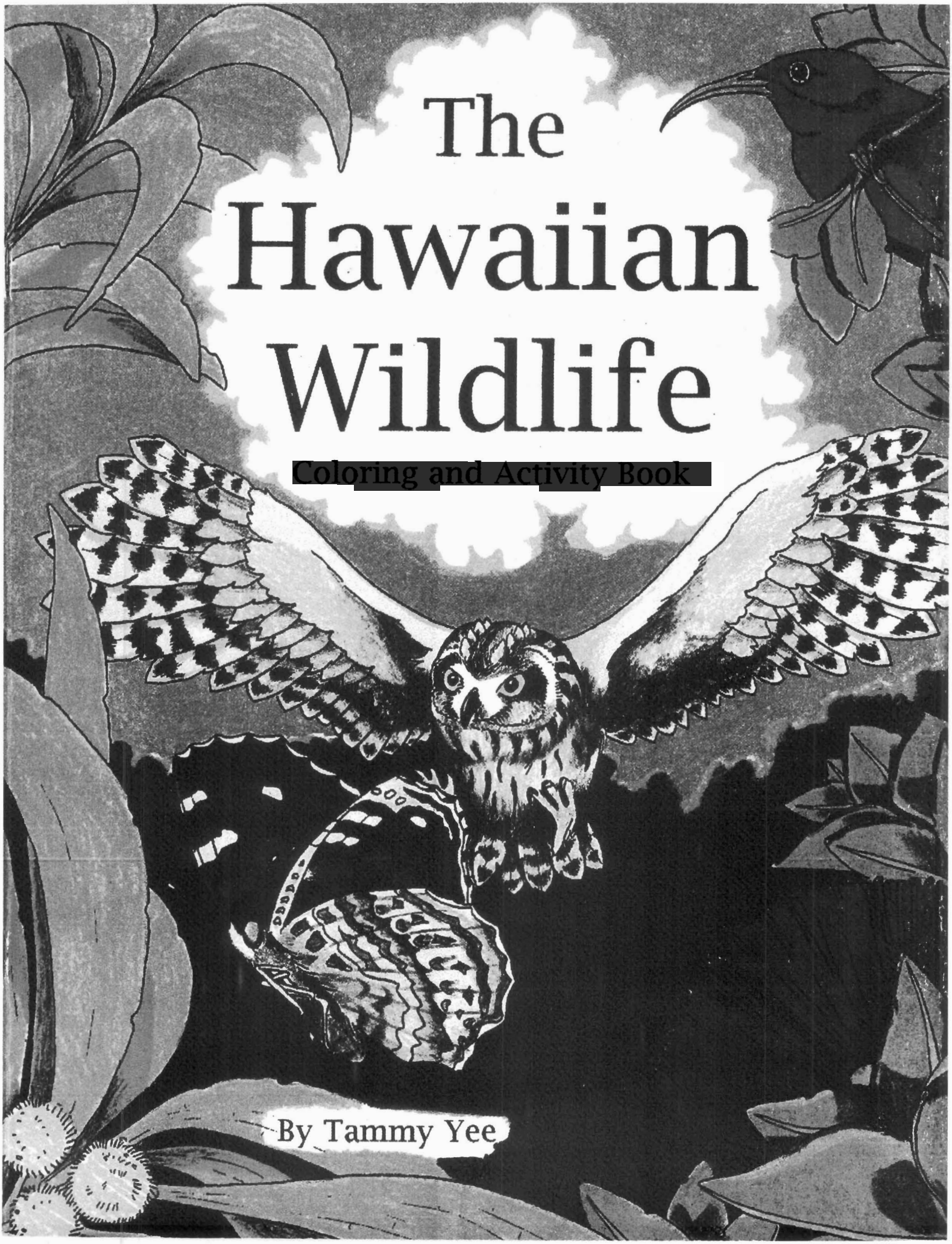
1 = red
2 = black
3 = [redacted] Color Student Chooses



Unscramble the letters to find out.

P Y P A H E F A C D E P I R S

_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _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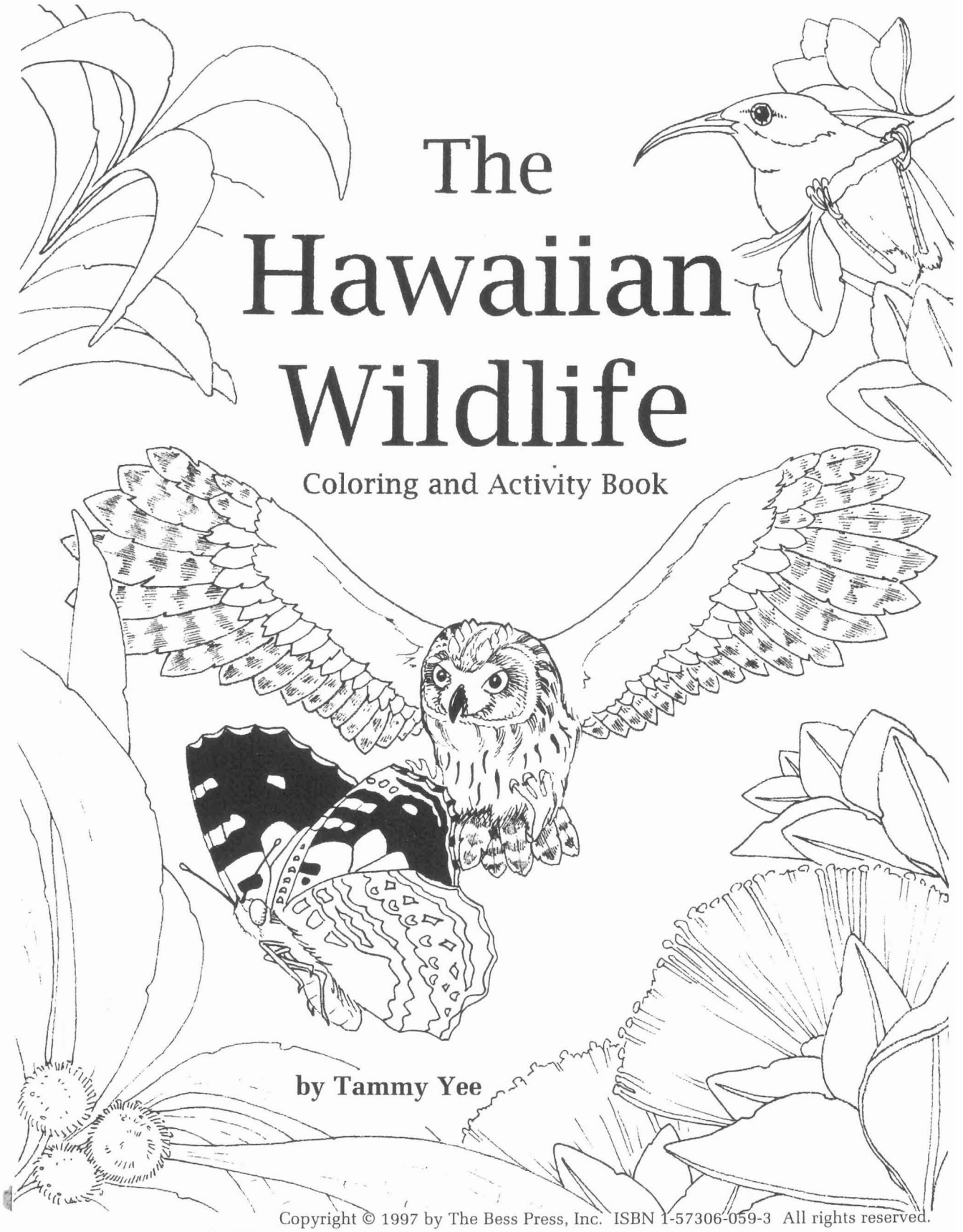
The Hawaiian Wildlife

Coloring and Activity Book



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http://nature.berkeley.edu/~gillespi/research.htm


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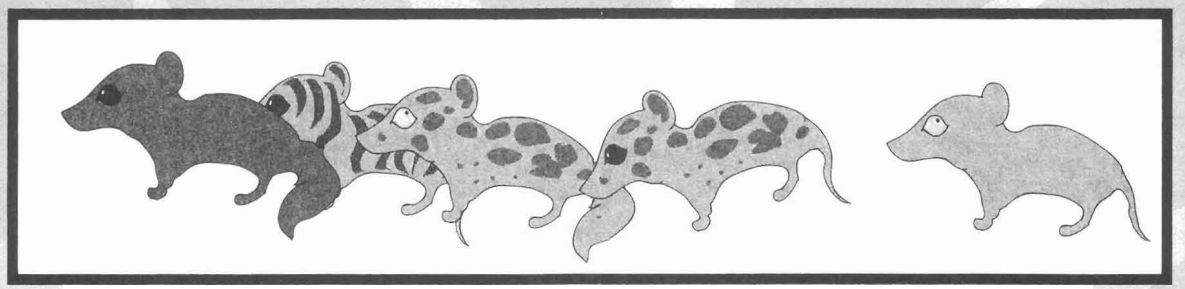
INVESTIGATION 9:
GENETIC VARIATION



GOAL

In *Genetic Variation* students learn the basic genetic mechanisms that determine the traits expressed by individuals in a population.

OBJECTIVES

SCIENCE CONTENT

- The individuals in every population vary from one another in their traits.
- Heredity is the passing of information from one generation to the next.
- Chromosomes are structures that contain hereditary information and transfer it to the next generation; they occur in nearly identical pairs in the nucleus of every cell.
- Genes are the basic units of heredity carried by chromosomes. Genes code for features of organisms.
- Alleles are variations of genes that determine traits in organisms; the two alleles on paired chromosomes constitute a gene.
- Alleles can be dominant or recessive. Dominant alleles exhibit their effect if they are present on one chromosome; recessive alleles exhibit their effect only when they are on both chromosomes.
- An organism's particular combination of paired alleles is its genotype; the traits produced by those alleles result in the organism's phenotype.
- A gene composed of two identical alleles (e.g. both dominant or both recessive) is homozygous; a gene composed of two different alleles (i.e. one dominant and one recessive) is heterozygous.

CONDUCTING INVESTIGATIONS

- Observe variation in human traits and larkey traits.
- Use a simulation to determine the transfer of genetic information during breeding and the traits that result.
- Use Punnett squares to predict the proportion of offspring that will have certain traits.

BUILDING EXPLANATIONS

- Explain how organisms inherit features and traits from their parents.
- Describe how dominant and recessive alleles interact to produce traits in a population.

SCIENTIFIC AND HISTORICAL BACKGROUND

In their ecoscenario studies, students were introduced to two dozen or so key organisms that interact in a particular ecosystem. That's quite a few organisms to keep track of for middle schoolers, but in fact, the handful of species presented for study represents only a tiny fraction of the actual number of species living and interacting in the most diverse and robust ecosystems.

Diversity raises questions. How can so many different populations live in the same ecosystem? And where did all the different species come from in the first place?

In Investigation 8 students were introduced to important concepts that get at the first question. The simple answer is that all organisms living in an ecosystem have adaptations that let them get the resources they need to live and reproduce. Close analysis reveals that every species has a unique suite of adaptations. This ensures that when resources are limited, every organism will use at least slightly different resources, in a slightly different way, at a slightly different time, in a slightly different place. In this way organisms keep out of each other's way and avoid excessive competition for valuable resources. In a sense an organism is defined by its adaptations; similarly its role in the ecosystem is defined by its adaptations. Organisms that are not adapted to live in a particular ecosystem are not found there.

Why there are so many different kinds of organisms in an ecosystem is one of the monster questions in biology. Presumably life started on Earth as one kind (or possibly several) and over the last 3.5 billion years diverged into hundreds of millions of different kinds, a small fraction of which are living on the planet at this time. What process could have produced so many kinds of organisms?

Most biologists concur that the theory of natural selection provides the answer. The theory stands on several tenets.

First, there is **variation** in a population of organisms. The variation can be the result of mutations and recombinations in the genetic code, but these concepts will not be pursued in this course. Variation in a population may be the result of immigration and emigration (gene flow) or the random change in the frequencies of alleles (genetic drift). We will accept as a fact of life that there is variation in the many **features** of individual organisms, and they stem from natural processes. These variations are **traits.**

Second, environments are dynamic, continually presenting new and different challenges for the organisms living in them. The environmental change could be the introduction of a new organism better adapted to compete for resources, a change in the climate, a disaster of some kind, or any number of subtler changes. An organism that was adapted before the change in the environment may not be adapted to cope after the change. Ecologists call this changed condition a

selective pressure. The change in a very real way selects the organisms that will succeed and those that will fail. There is, of course, no conscious decision to select this organism and eliminate that one.

If the selective pressure is radical, a whole population may succumb. If the pressure is slight or incremental, however, the pressure may be felt by only *some* members of a population. That is to say, some traits, such as thin fur, pale skin, or short legs, might preclude an organism from acquiring resources or reproducing, so those traits will be selected against in the population. Other members of the population might continue to survive and reproduce, perpetuating their traits. In this way the appearance and/or behavior of a population as a whole can change, sometimes in a relatively short time.

The third factor contributing to natural selection and the evolution of new species is isolation. As long as the members of a population interact and breed, they will not normally generate a new species. The population may change over time, but will not become a new species. If one portion of a population is separated from the other, either physically (isolated by geography) or behaviorally (exploiting different food sources), creating two populations, new species may evolve.

When a portion of a population emigrates or is transported to an island or new continent, the selective pressures in the two environments—the originating environment and the new environment—may favor different traits. After a period of time, from decades to scores of millennia, the two populations may have diverged to such an extent that, even if they were reunited, they would continue to conduct their separate lives, unable to mate and reproduce.

That's an oversimplified picture of the origin of species, but in practice the science of identifying the precise point in this process when a new species has arrived is daunting, and even a precise definition of what constitutes a species is illusive. We will not enter these deep waters in this course.

MECHANISMS FOR POPULATION CHANGE

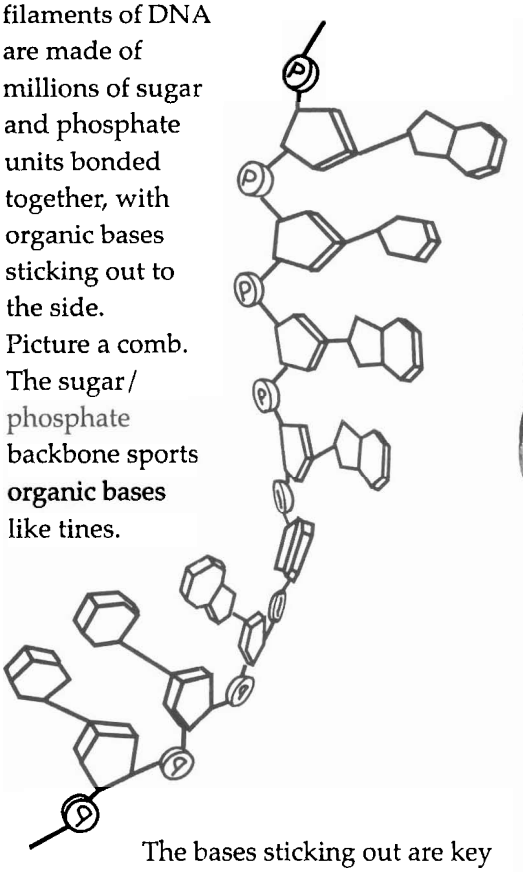
The key to population change is variation among the individuals in the population. In a population of sexually reproducing organisms, each individual is unique and therefore has ever-so-slightly different needs, behaviors, tolerances, and responses to stimuli from the environment. When the environment changes, the makeup of the population changes in response.

What makes each individual unique? Genes. The genes that direct the assembly of molecules into organisms are different for every individual.

NOTE

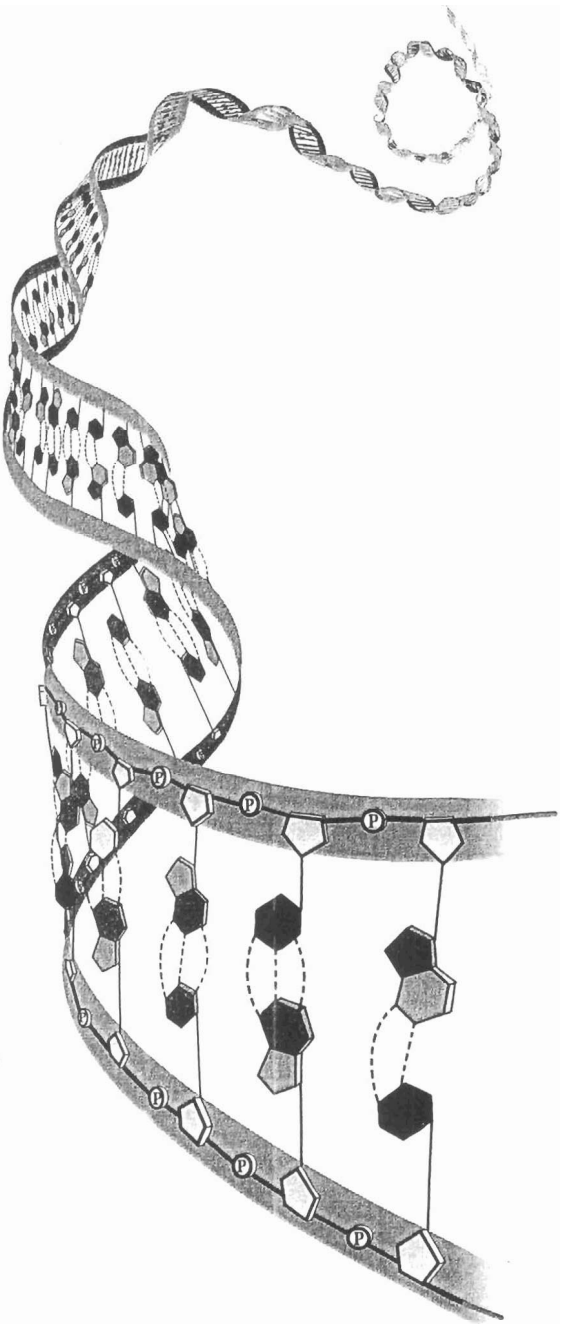
This discussion applies to organisms that reproduce sexually. Organisms that reproduce by simple division, producing two genetic clone daughters, follow a slightly different path to achieve population change.

The simple version of genetic transfer of information goes like this. The story of life is recorded in huge molecules called **nucleic acids.** The specific nucleic acid that handles the genetic code is DNA (deoxyribonucleic acid). The long filaments of DNA are made of millions of sugar and phosphate units bonded together, with organic bases sticking out to the side. Picture a comb. The sugar/phosphate backbone sports **organic bases** like tines.



The bases sticking out are key to the structure of DNA. The four bases are adenine, thymine, guanine, and cytosine, usually represented by the symbols A, T, G, and C. The bases can bond with one another, but *only* in specific bonding pairs. A and T can bond with one another, and C and G can bond, but A cannot bond with C or G, and so on. Base pairing is specific, and there are no exceptions.

The bases on two sugar/phosphate strands bond and form a double DNA strand called a double helix. The result is a long ladder with the bonded bases forming the rungs.



A typical DNA molecule might be 5 cm long. To fit in the nucleus of a cell, the huge molecule is coiled (wound into a helix) and recoiled into a compact structure called a **chromosome.**

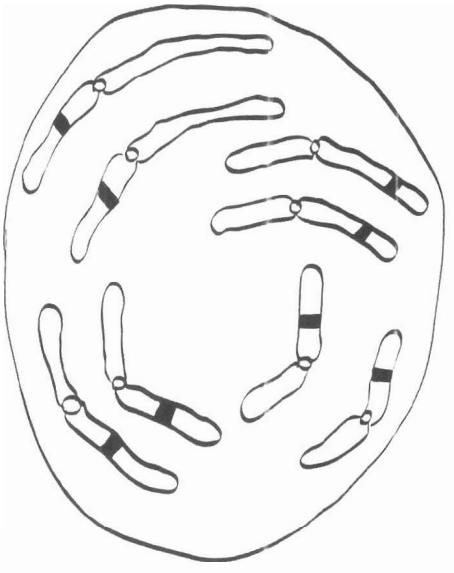
Organisms have different numbers of chromosomes—as few as two to well over a thousand. Most vertebrates fall into the 20- to 80-chromosome range, and humans have 46. Toads have 22 chromosomes, and chickens have 78. Plants and animals that reproduce sexually generally have an even number of chromosomes because a set of chromosomes is made of nearly identical pairs. In humans, for instance, there are 23 distinctly different chromosomes, and each of those has an almost identical partner. The two similar chromosomes are called **homologues.**

Every cell in every plant and animal on Earth has a complete set of chromosomes that define the organism. The chromosomes reside in the cell's nucleus. Every time a cell divides to produce two daughter cells, the complete set of chromosomes is duplicated. Each new cell is provided with a full complement of DNA—the complete set of blueprints and operating instructions for assembling and managing one particular kind of organism.

NOTE

Organisms that have pairs of chromosomes are called diploid. Some organisms have multiple copies of similar chromosomes and are called polyploid. We will deal only with diploid organisms in this discussion and in this course.

The order in which the paired bases are aligned along the length of the DNA molecule is all important in decoding the message to make a new organism. Just like the 26-letter alphabet can be used to make untold numbers of words, depending on their sequence, the four-letter genetic code can make untold millions of "words," depending on the number and sequence of the bases. The plan for making a mosquito, tree frog, banana plant, gila monster, begonia, blue whale, or any other organism is encoded in the sequence of the same four bases distributed along the incredibly long double helix molecule.



DETERMINING TRAITS

Features, characteristics, traits, and behaviors are determined by genes. Large ears on jackrabbits are determined by genes. The gray color of elephants is determined by genes. The spots on rainbow trout, the little friction area that lets crickets crick, and every other feature of every organism is the product of a genetic message.

Genes are the units of heredity. Genes are specific sequences of sugars, phosphates, and bases along the DNA strand in the chromosome. A gene is a sequence of bases that code for how to assemble a certain protein. The proteins manufactured in response to these messages flow into the organisms' cells and make things. The things they make are fats, bone, muscle, nerves, and everything else that is required to make organisms, complete with the characteristic structures and behaviors that are both typical of their kind and unique.

There is another important piece to understanding genes. The homologous chromosomes (the two that are almost identical) each have the same genes. So it would seem that every organism has two genes for every characteristic. This is not entirely true because the two genes *interact* to produce the characteristic. The two copies of the gene are called **alleles.** The two alleles considered together constitute a gene.

The homologous chromosomes are usually identical with regard to gene location, but are not identical in sequence of bases. Those differences in DNA structure can result in two forms of a gene or alleles.

When alleles are identical, both forms of the gene produce the protein that makes, for instance, attached earlobes or a widow's peak.

If the alleles are not the same, however, and the messages coming from the two slightly different alleles do not agree, what happens? In the simplest case (the case we introduce to students in this investigation), one of the alleles dominates the other, and the effect of the dominant gene is exhibited in the organism. Such an allele is called a **dominant allele,** and the "overruled" allele is the **recessive allele.**

THE DISCOVERY OF HEREDITY

The pioneer work on heredity was undertaken by the brilliant Gregor Mendel, son of a Moravian farmer. Young Mendel demonstrated an aptitude for academics, but was in no position to pursue a university career. In order to continue his studies Mendel joined an Augustinian monastery. There he undertook his detailed inquiry into the role of heredity in conveying characteristics from one generation to the next.

Mendel worked extensively with pea plants. He started his long series of experiments by developing a number of strains of pure breeding stock. He did this by raising several generations of self-fertilized plants. The result was separate populations of peas that produced clearly defined and predictable characteristics, such as tall, short, purple flower, white flower, smooth seeds, and wrinkled seeds. Whenever he planted seeds from his purple-flower stock, for example, all the plants produced purple flowers.

He then began cross-pollination experiments. He used pollen from tall plants to pollinate the flowers on short plants, and pollen from short plants to pollinate the flowers on tall plants. What Mendel discovered was that all of the offspring were tall. This was confusing to him.

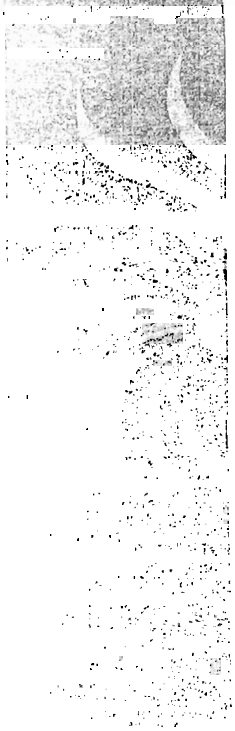
Undaunted, Mendel collected the seed from the tall pea plants, which he named the first filial generation (F_1) and planted them (filial = son or daughter). Some of the offspring that grew from the F_1 seeds (F_2 generation) were tall, and some were short. Both characteristics were present in the offspring. The characteristic of height had not blended to produce all medium-height plants; the characteristics were passed along intact, some exhibiting the tall trait and some the short trait. He concluded that even though all the F_1 seeds came from plants that were tall, when they grew into mature plants, some were tall and some were short. Both traits were present in the offspring, the F_2 generation.

Mendel paid close attention to the numbers of each growth form and discovered that there were more tall forms than short forms in the ratio of 3:1, that is, 75% tall and 25% short.

At this point Mendel made his revolutionary surmise. He reasoned that each offspring must get half its information about height from each parent. Further, the influence of the information from the two sources was not necessarily equal. Mendel knew nothing about DNA, chromosomes, or genes. He constructed a functional model for genetic heredity without knowing the biochemical and physical processes that carry the process forward.

Tall and short are traits. The parental trait that appeared exclusively in the F_1 generation and prevailed in the F_2 generation, Mendel identified as the **dominant trait.** The trait that disappeared in the F_1 generation but reappeared in the F_2 generation, he dubbed the **recessive trait.** Whenever a seed acquired the dominant trait from both parents *or from just one parent,* the dominant trait was expressed in the plant that grew from that seed. If the seed acquired the recessive trait *from both parents,* the recessive trait was expressed by the plant that grew from that seed.

Some 150 years after Mendel puzzled out the probable mechanism for heredity, we understand that dominant and recessive traits are transmitted by genes on chromosomes. When a gene is represented by two dominant alleles, the trait is that of the dominant allele (e.g. purple flowers). Such a condition is called **homozygous** (same allele) dominant. When a gene is represented by two recessive alleles (homozygous recessive), the trait is that of the recessive allele (e.g. white flowers). When a gene is represented by one dominant allele and one recessive allele, the organism is **heterozygous** (different alleles), and the trait is that of the dominant allele (e.g. purple flowers).



Here is an important point. Where purple flowers are exhibited as a result of a heterozygous condition—the combination of a dominant and a recessive allele—the recessive allele for white flowers *is still there.*

NEW COMBINATIONS OF ALLELES

During the production of sperm and eggs, a process called **meiosis** occurs, the homologous pairs of chromosomes separate so that each egg or sperm cell has only half of the usual number of chromosomes. The two alleles that make a gene are, therefore, separated. (Meiosis, the mechanism for passing just one allele from the male and one allele from the female to the offspring, is not explored in this course, but it is one of the most important factors in hereditary biology.) During fertilization, one set of chromosomes comes from the father (sperm) and a homologous set comes from the mother (egg). As the sperm and egg cells fuse, the two sets of chromosomes create new homologous pairs of chromosomes with corresponding alleles. The new sets of alleles form genes that are unique to the offspring.

If two purple-flowered parents are both heterozygous for flower color, it is possible that the recessive allele for white flowers will be passed to the offspring by both parents. Two purple-flowered parents can have white-flowered offspring if both parents had a recessive gene for white flowers, and each passed it to the offspring. This will happen, on average, in one out of every four offspring.

NOTE

See page 53 in the Resources book for diagrams of mitosis (cell division to form two daughter cells) and meiosis (cell division to form sperm and egg cells.)

GENOTYPE AND PHENOTYPE

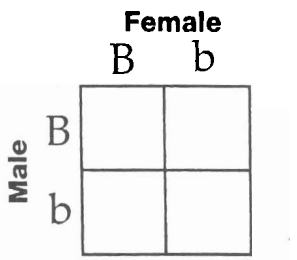
Geneticists refer to the genetic makeup of an organism as its **genotype.** For instance, in the example of the two parent pea plants, the gene for flower color can be represented by the letter *b* (bloom). An uppercase *B* represents a dominant allele for purple color, and a lowercase *b* represents a recessive allele for white color. Our two heterozygous parents would have the following genotype for flower color:

The way the genes are expressed in fur, feather, flesh, and function is an organism's **phenotype.** The simplest way to think of phenotype is how an organism looks—its traits. Purple flowers, tall growth form, and wrinkled seeds are phenotypical traits. An organism's genotype determines its phenotype.

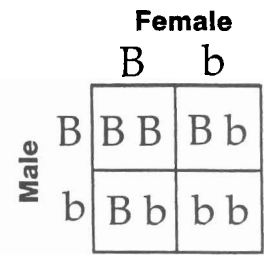
During sexual reproduction, each parent contributes one allele to the genotype of the offspring. The heterozygous flowering peas contribute either a B or a b. If either parent (or both) contributes the dominant B allele to the offspring, it will have purple flowers. But there is a chance that both parents will contribute the recessive b allele, in which case the offspring will have white flowers.

PUNNETT SQUARES

About 100 years ago Reginald Punnett, a Cambridge professor of genetics, developed a simple and useful technique for predicting the characteristics of offspring when the dominant and recessive traits of the parents are known. It is known as the **Punnett square.** The square is a grid, with the alleles of one parent on the top and the alleles of the other parent on the left. The flower-color Punnett square looks like this.



Each grid square represents the combination of two alleles. Transcribe those two alleles into the squares, like this.



The completed Punnett square shows the four possible combinations of alleles contributed by these two parents. These are only possibilities linked with probability, not absolutes.

- One homozygous dominant
- Two heterozygous
- One homozygous recessive

The heterozygous condition is always recorded with the dominant allele first, followed by the recessive allele.

B b not bB

This Punnett square suggests that there is a possibility that three out of four offspring will have purple flowers, and one out of four will have white flowers.

BLENDED EFFECTS

It's not always that simple, however. Not all alleles are wholly dominant or recessive. Some are partially dominant. In this case homozygous dominant alleles will produce one trait, homozygous recessive alleles will produce a second trait, and heterozygous alleles will produce a third trait, often a blend of the two other traits.

Students are introduced to this when they work with the feature of fur pattern on