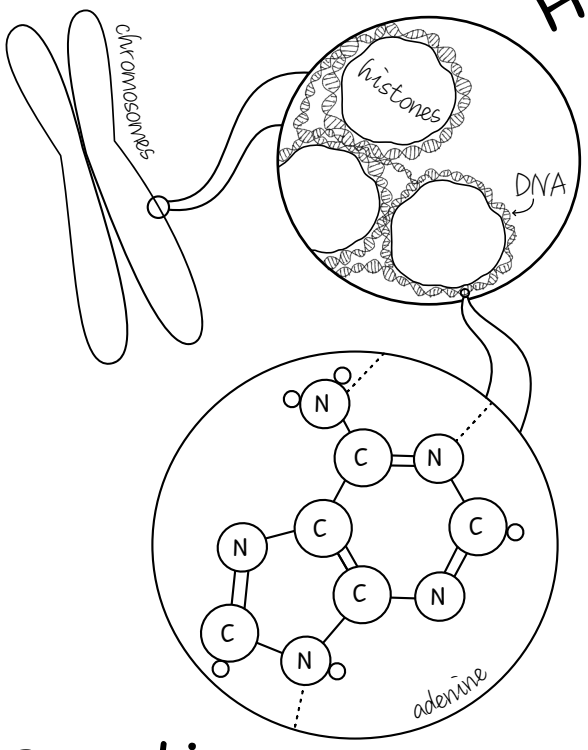
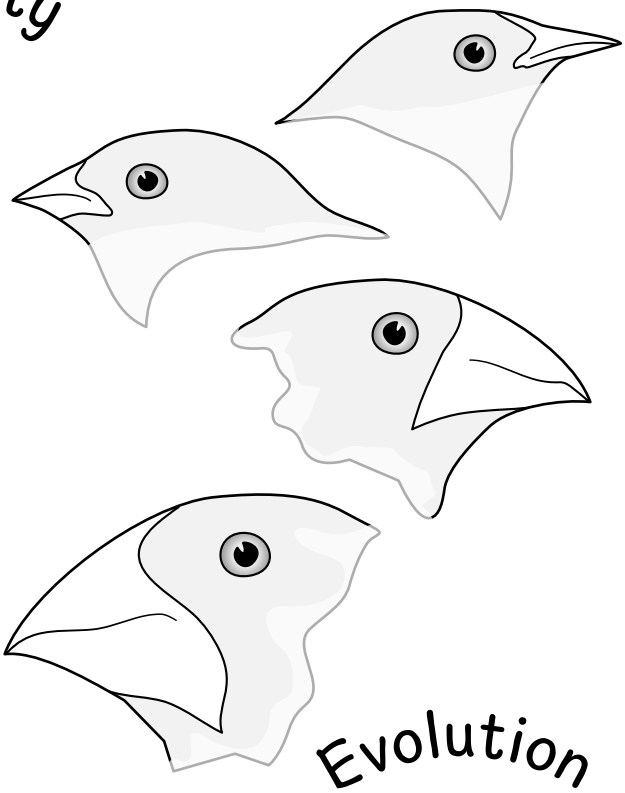
BIOLOGY TWO

	AB	Ab	aB	ab
AB	AABB	AABb	AaBB	AaBb
Ab	AABb	AAbb	AaBb	Aabb
aB	AaBB	AaBb	aaBB	aaBb
ab	AaBb	Aabb	aaBb	aabb

Heredity



Genetics



Evolution

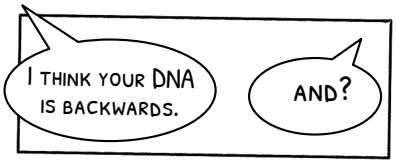
BIOLOGY

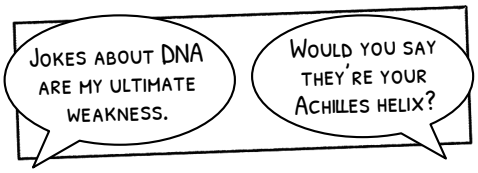
~ SPRING 2022 ~

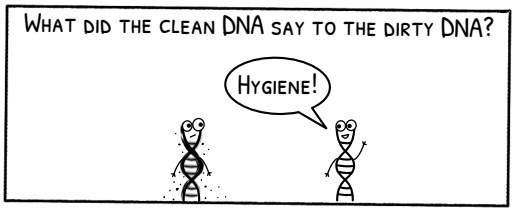
	Date	Topic	Page(s)
Week 1	Monday, Jan 24	What is a species?	6-7
	Wednesday, Jan 26	Life finds a way	8-9
	Friday, Jan 28	*Activity: Vegetative propagation with potato*	10-15
Week 2	Monday, Jan 31	Mendel's famous experiment	16-17
	Wednesday, Feb 2	Inheritance explained	18-21
	Friday, Feb 4	*Deep dive: Why aren't Zebras domesticated?*	
Week 3	Monday, Feb 7	The laws of heredity 1	22-25
	Wednesday, Feb 9	The laws of heredity 2	26-29
	Friday, Feb 11	*Deep dive: Punnett Square Practice*	
Week 4	Monday, Feb 14	Pet pedigree puzzle	30-33
	Wednesday, Feb 16	Bigger Punnett squares	34-37
	Friday, Feb 18	**Heredity Quiz Show**	38-41
Week 5	Monday, Feb 21	What is a gene?	42-44
	Wednesday, Feb 23	Chromosomes	45-47
	Friday, Feb 25	*Deep dive: Fingerprints*	
Week 6	Monday, Feb 28	Meiosis and mistakes	48-49
	Wednesday, Mar 2	The Genetic Code 1	50-51
	Friday, Mar 4	*Activity: Gummy worm karyotypes*	52-55
Week 7	Monday, Mar 7	The Genetic Code 2	56-57
	Wednesday, Mar 9	Blood types explained	58-60
	Friday, Mar 11	*Activity: What's your blood type?*	61-63
Week 8	Monday, Mar 14	Mutations	64-65
	Wednesday, Mar 16	Nature and nurture	66-67
	Friday, Mar 18	*Deep dive: Why Red Delicious are the least delicious apples*	68-69
Week 9	Monday, Mar 21	Calico Cats & X-linked traits	70-71
	Wednesday, Mar 23	Modifying genes and gene therapy	72-73
	Friday, Mar 25	**Genetics Quiz Show**	74-77
Week 10-11	March 28- April 8	TWO WEEK SPRING BREAK	

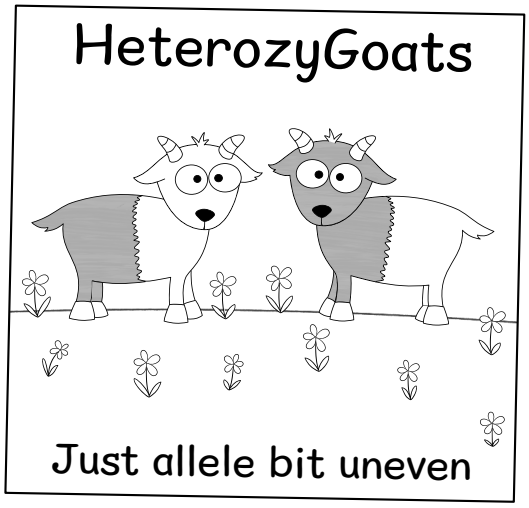
Live classes are held each Monday and Wednesday. Activities and reading assignments listed on Fridays are completed independently. There are two sessions of each of the Monday/Wednesday classes. The first session starts at 11 am EST. The second session starts at 1:00 pm EST. Each live class lasts between 30 and 45 minutes.

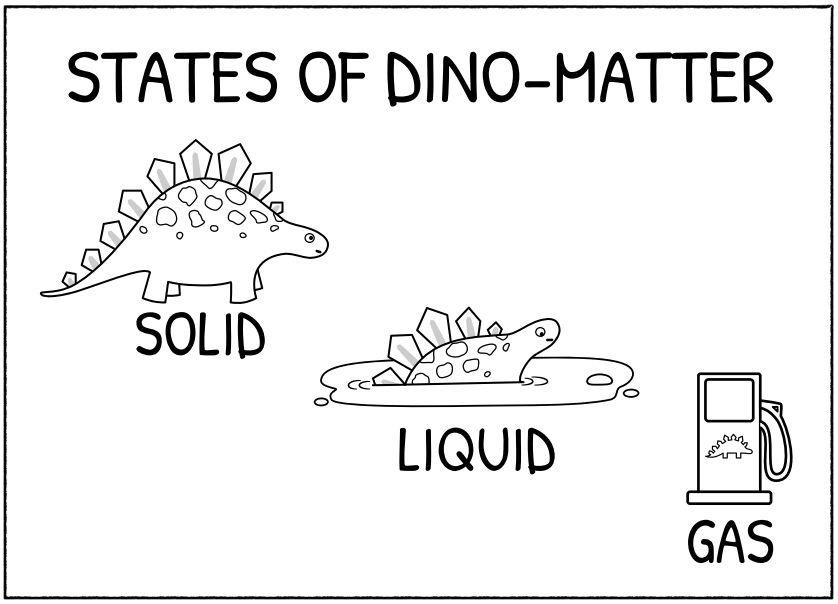
The classes are recorded and can be watched anytime after the recording date. Each week also has optional activities or reading assessments (deep dives). Students who complete and submit all activities and assignments will receive a bonus certificate of completion.











How to use this course:

For younger students (2nd-5th grade) we recommend a "get the basics" approach that focuses on the Mon/Wed classes. For older or more advanced students (6th-8th grade) we recommend completing each of the Friday activities and assignments to reinforce the concepts covered.

Option One: Get the Basics

Ideal for younger students

Participate in Mon-Wed classes only. Friday activities, articles, and other assignments are optional. They can be skipped, saved for later, or completed depending on your preference.

Option Two: The Full Course

Ideal for older students & advanced learners

Participate in Mon-Wed classes and do the Friday activities and reading assignments.

Complete all quizzes and assignments to receive a certificate of completion at the end of the course.

Tips for best learning:

- ☑ Read the pages that go with each lesson before watching the video. Take 10-15 minutes before class to see if you can fill in the blanks. If you can't fill in everything, that's okay! Listen during class to see if you can complete the page.
- ☑ If a lesson moved too fast, rewatch it later to help learn the concepts.
- ☑ Download the answer key for the notes, but don't look at the answers until after you give things a try yourself!

Project Supply List:

Jan 28 - Vegetative Propagation with Potato
- Potato or sweet potato (for quicker results, use one where the eyes have already begun to sprout)
- Knife
- 4 large pots or burlap sacks
- Potting soil

Mar 4 - Gummy Worm Karyotypes
- Enough gummy worms or other oblong-shaped colorful candy to create 16 pairs of chromosomes
- Chocolate (to melt and cover some of the gummy worms,)
- Knife or scissors

Mar 11 - What's the Blood Type?
- Home blood typing kit (optional)

Mar 18 - Apple Variety Taste Test
- Several varieties of apple including Red Delicious, Granny Smith, and three other types.
- Knife

April 13 - Journey of HMS Beagle
- Printable world map
- Paper and scissors
- Crayons, colored pencils, or markers

April 29 - Model a Gene in a Population
- 20 black marbles and 20 white marbles or ANY other items that can be drawn randomly in a sample! For example, beans, candy, coins, or dice marked with tape.

May 13 - Build your own phylogeny
- Paper and art supplies

May 18 - History of Earth Timeline
- Paper, tape, and crayons, markers, or colored pencils

Which science standards are covered in this course?

The standards listed below are the national science standards for K-12 education in the United States. They are commonly referred to as Next Generation Science Standards or NGSS.

MS-LS1-4. *Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants respectively.* ***Apr 11, Apr 13, Apr 18, Apr 20***

MS-LS1-5. *Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.* ***Mar 16***

MS-LS3-1. *Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism.* ***Feb 21, Feb 23, Mar 2, Mar 7, Apr 14, Apr 11***

MS-LS3-2. *Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation.* ***Jan 26, Jan 31, Feb 2, Feb 7, Feb 14***

MS-LS4-1. *Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.* ***May 4, May 16***

MS-LS4-2. *Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.* ***Apr 27, May 4***

MS-LS4-3. *Analyze displays of pictorial data to compare patterns of similarities in the embryological development across multiple species to identify relationships not evident in the fully formed anatomy.* ***May 2***

MS-LS4-4. *Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment.* ***Apr 18, Apr 20, Apr 27***

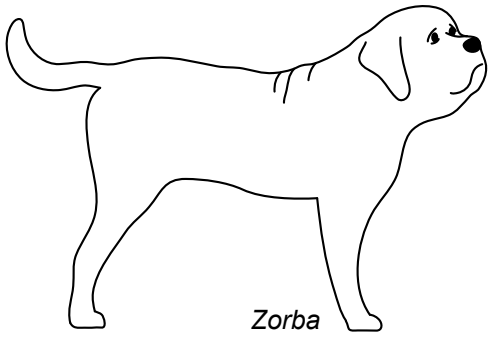
MS-LS4-5. *Gather and synthesize information about the technologies that have changed the way humans influence the inheritance of desired traits in organisms.* ***Mar 23***

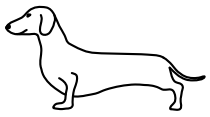
MS-LS4-6. *Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time.* ***Apr 29***

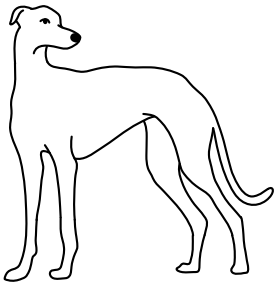
Date	Topic	NGSS	Page(s)
Wednesday, Jan 26	Life finds a way	MS-LS3-2	8-9
Monday, Jan 31	Mendel's Famous Experiment	MS-LS3-2	16-17
Wednesday, Feb 2	The laws of heredity 1	MS-LS3-2	22-25
Monday, Feb 7	The laws of heredity 2	MS-LS3-2	26-29
Monday, Feb 14	Pet Pedigree Puzzle	MS-LS3-2	30-33
Monday, Feb 21	What is a gene?	MS-LS3-1	42-44
Wednesday, Feb 23	Chromosomes	MS-LS3-1	45-47
Wednesday, Mar 2	The genetic code 1	MS-LS3-1	50-51
Monday, Mar 7	The genetic code 2	MS-LS3-1	56-57
Monday, Mar 14	Mutations	MS-LS3-1	64-65
Wednesday, Mar 16	Nature and nurture	MS-LS1-5,	66-67
Wednesday, Mar 23	Modifying genes and gene therapy	MS-LS4-5	72-73
Monday, Apr 11	Endangered vs invasive species	MS-LS1-4, MS-LS3-1	78-79
Wednesday, Apr 13	Darwin and the Galapagos	MS-LS1-4	80
Monday, Apr 18	Survival of the fittest	MS-LS1-4, MS-LS4-4	84-86
Wednesday, Apr 20	Selection and adaptations	MS-LS1-4, MS-LS4-4	87-88
Wednesday, Apr 27	Species and gene pools	MS-LS4-2, MS-LS4-3 MS-LS4-6	91-92
Friday, Apr 29	Drifting marbles and population models	MS-LS4-6	93-94
Monday, May 2	Taxonomy and similar traits	MS-LS4-4	95-97
Wednesday, May 4	The fossil record	MS-LS4-1, MS-LS4-2, MS-LS4-3	98-99
Monday, May 9	Phylogenies and family trees	MS-LS4-1	100-101
Monday, May 16	Timeline of life on Earth	MS-LS4-1	104-105

What makes a species?

The domestic dog includes hundreds of different breeds with diverse personalities, shapes, and sizes. The biggest dog, an English Mastiff named Zorba, weighed more than 143 kg (315 pounds) and measured 94 cm (37 inches) tall from ground to shoulder. The smallest dog, a Chihuahua named Milly, is just under 10 cm (4 inches) tall and weighs just 0.5 kg (about 1 pound). Mastiffs, Chihuahuas, Dachshunds, and Greyhounds are all called dogs, but they are incredibly different animals!







English Mastiff	Chihuahua	Dachshund	Greyhound
70-91 cm / 28-36 in 54-104 kg / 120-230 lbs	15-25 cm / 6-10 in 1.4-3 kg / 3.3-6.6 lbs	20-23 cm / 8-9 in 7-14 kg / 16-32 lbs	68-76 cm / 27-30 in 26-40 kg / 57-88 lbs

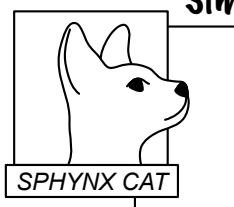
1. What makes a dog a dog? Share your opinion:

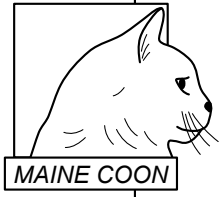
Answers will vary. Some possible characteristics to include could be that dogs are four legged, have fur, are carnivorous, and are social animals.

2. If the characteristics you described above were used as the official definition of a dog, would cats also be called dogs?

Answers will vary.

3. List three similarities and differences between cats (*Felis*) and dogs (*Canis*):



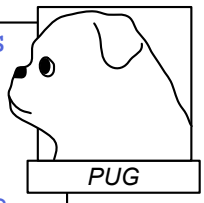


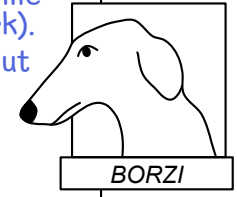
Similarities between cats and dogs:

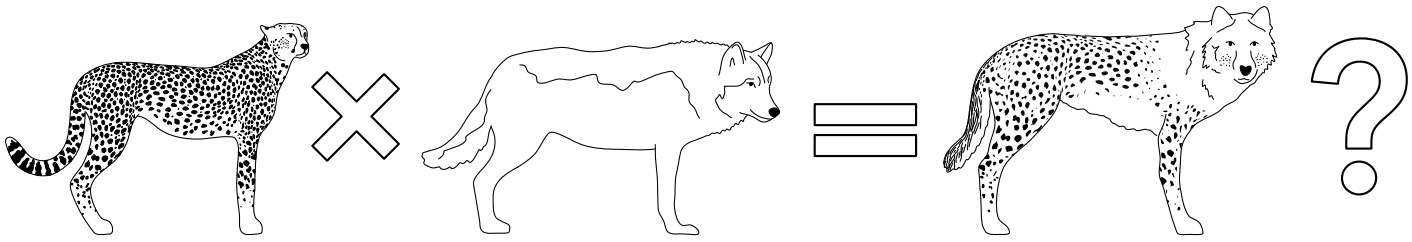
- Quadripeds (4 legs)
- Have fur
- Both kept as pets by humans
- Both have whiskers
- Both can be trained.
- Both have tails.
- Both have breeds with distinct traits.
- Both have wild relatives (wolf, coyote, lynx, bobcat)

Differences between cats and dogs:

- Dogs are pack animals, while cats are solitary hunters.
- Dogs are diurnal (active during the day) while cats are primarily nocturnal
- Dogs bark/howl (can't purr) while cats purr and meow (can't bark).
- Cats have retractable claws, but dogs don't.
- Cats climb trees. Dogs can't.
- Dogs are omnivores and scavengers. Cats are obligate predators.
- Cats have 30 teeth, dogs have 42
- Cats can't taste sugar, dogs can.



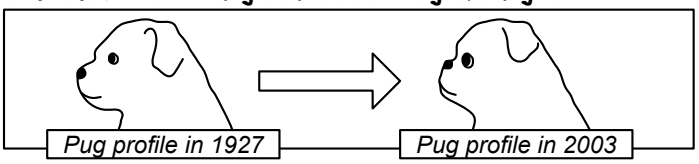




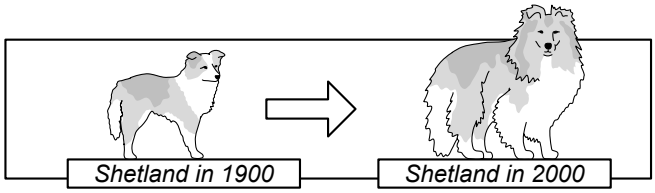
4. Coyotes, wolves, and dogs can all interbreed, creating hybrids like the wolfdog, coywolf, coydog or dogote. Lions and tigers can also be bred to create hybrids, which are called ligers or tigons. In your opinion, would it be possible to cross a cheetah with a wolf? If so, what would you call this hybrid? A woltah? A cheef?

Answers will vary.

Selective breeding can cause big changes



Breeders prized the "squished face" appearance of the Pug and chose dogs with shorter and shorter snouts. Because of their face shape, modern Pugs are susceptible to eye trouble and breathing problems.



In 1900, Shetland Sheepdogs were reported to weigh between 7 and 10 pounds and have medium length fur. The modern Shetland Sheepdog has doubled in size and has much longer fur.

5. Suppose that a settlement on Mars uses Great Danes for pulling sleds while a different settlement uses Chihuahuas for hunting cockroaches that hide in small spaces. If the people in the first settlement selectively breed their Great Danes to be larger and stronger while the people in the second settlement breed their Chihuahuas to be smaller and faster, what would you expect Mars dogs to look like after approximately 1,000 years have passed? Would Great Danes and Chihuahuas be different species from each other then?

Answers will vary.

It may still be possible to cross the breeds if they had the same number of chromosomes, but if the anatomical differences became too great the dogs would not be able to breed naturally and would become a "ring species." However, if chromosomal changes were great enough that they could not breed at all, they would be definitely be considered different species.

Martian Great Dane in 3022

Have fun drawing! Does your Martian Dane look similar to a bear?

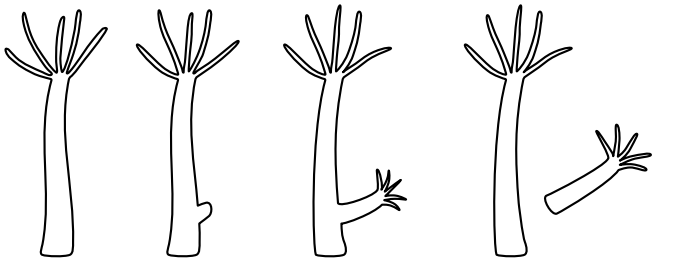
Martian Chihuahua in 3022

Have fun drawing! Does your Martian Chihuahua look similar to a weasel?

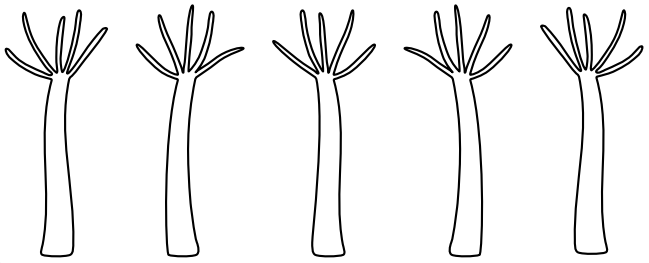
Life finds a way

The **ability to reproduce** is one of the key characteristics in most definitions of life. There are two main strategies: asexual reproduction, which creates identical clones, and sexual reproduction which creates offspring that are different from each parent.

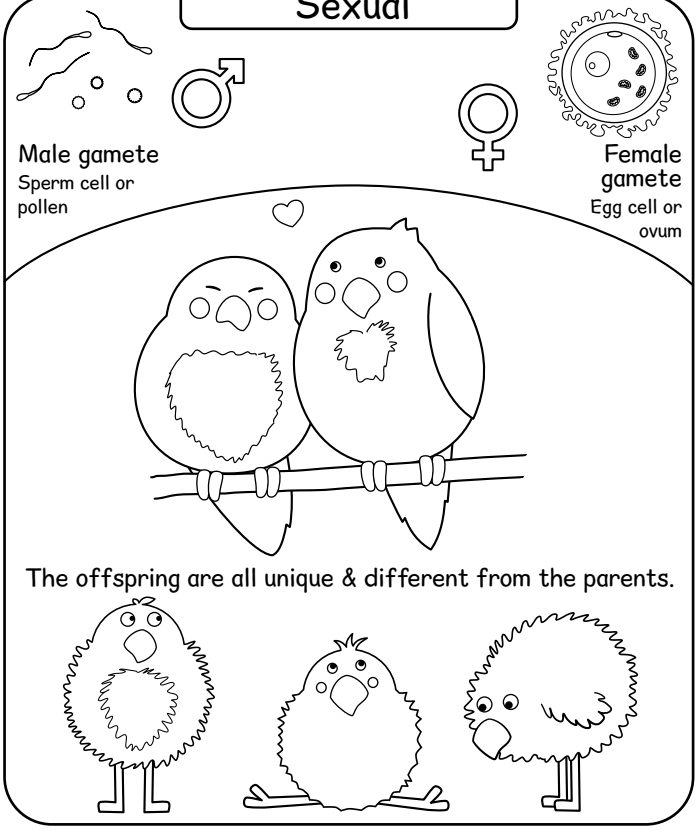
Asexual



The offspring are clones. They are genetically identical to the parent.



Sexual



Record the primary advantages and disadvantages in each category below. Consider the following:

- Speed of reproduction: Is the next generation formed and independently growing within minutes or days? Does it take years to form an independent next generation?
- Genetic diversity: is the diversity high (which provides greater resistance to disease) or low (which makes a population more at risk from disease)?
- Does reproduction require a mate? Could one individual reproduce?

ASEXUAL REPRODUCTION

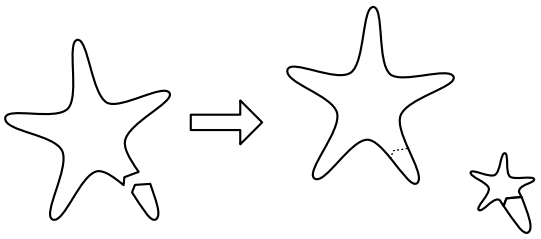
advantages:	disadvantages:
• No need for partner • Faster • One individual can form a colony or community of organisms.	• Low genetic diversity • More risk from disease

SEXUAL REPRODUCTION

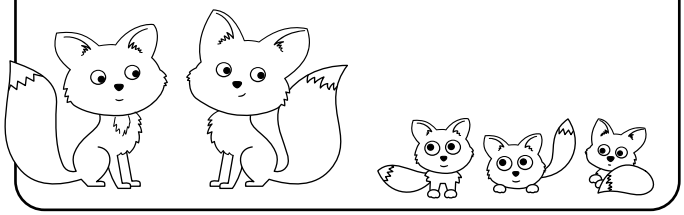
advantages:	disadvantages:
• High genetic diversity • Less risk from disease	• Need a partner to reproduce. • Generally takes more time to grow next generation

Match each reproductive strategy with the correct definition:

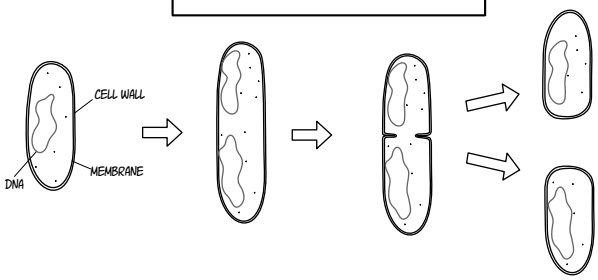
FRAGMENTATION



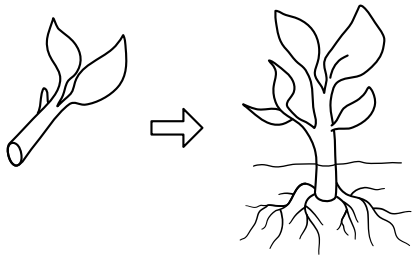
SEXUAL REPRODUCTION



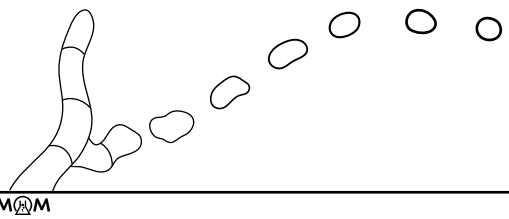
BINARY FISSION



VEGETATIVE PROPAGATION



SPORE FORMATION



Genetic information from two individuals is combined to create offspring that are genetically different from both parents. This reproductive strategy is common among animals, fungi, and plants.

An organism is split into pieces. Each of those fragments then develops into adult individuals that are clones of the original organism. Molds, lichen, sponges, certain worms, and sea stars all use this reproductive strategy.

The division of one cell into two identical cells. This reproductive strategy is used by many types of single-celled life forms including bacteria and archaea.

A specialized cell is formed that can withstand harsh environmental conditions such as drought or extreme heat. Once conditions improve, this cell germinates and begins growing. This reproductive strategy can be either sexual or asexual. Commonly used by fungi.

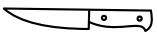
A form of reproduction occurring in plants where a fragment or cutting is separated from the parent plant and grows as a separate individual. Commonly used with food crops such as bananas, sweet potato, sugarcane, and pineapple.

Hands-on Science Project

PROPAGATE A POTATO

MATERIALS:

Potato or sweet potato



Knife

Rubbing Alcohol

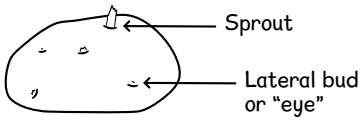
4 identically-sized pots or bags
Use a large pot or bucket with drainage holes, or a large burlap sack.

Potting soil
Enough to fill all 4 containers

For best results, use sprouting potatoes

Most commercially-available potatoes are treated with chlorpropham, a compound that prevents sprouting. For best results, select a tuber where you can see small sprouts or swelling in the "eyes" of the tuber. If you do not see any sprouts or signs of budding, let the potato sit in a dark location at room temperature until sprouts form.

Potatoes are tubers, specialized root structures that store starch. Tubers contain buds that can grow into new plants!



1. Place the potato in a dark and warm area (such as a kitchen cupboard) and let it sit there until sprouts have formed at the eyes. This may take between 1 to 3 weeks.

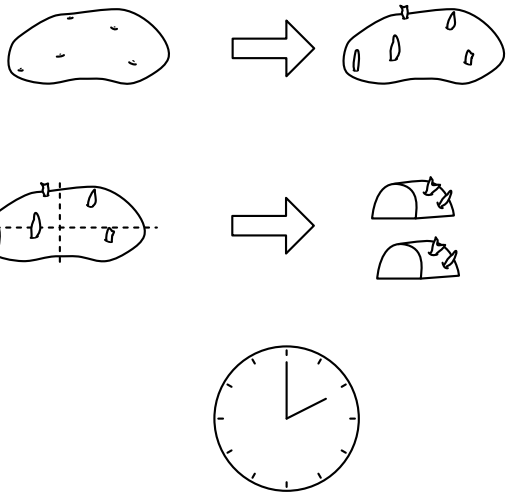
2. When the potato has sprouts, clean the knife with rubbing alcohol. Use the clean knife to cut the potato into 4 pieces that are roughly equal in size. Make sure that each piece of potato has at least one or two "eyes" with sprouts. If there are many sprouts on the piece of potato, break off some of the sprouts so there will be no more than two sprouts per quadrant.

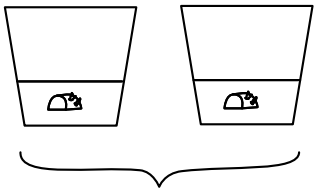
3. Let the cut pieces sit at room temperature for 24 hours. This drying process helps prevent mold from growing on the potatoes after they are planted.

4. Fill the pots or burlap bags 1/3 full with potting soil. Place one potato piece in each container so that the potato is approximately 5 cm or 2 inches below the surface of the soil.

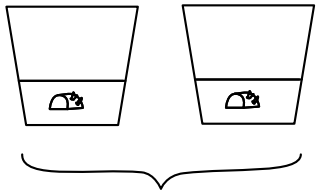
5. Water the soil in each pot so that it is moist. Place two of the pots in a very sunny location and the other two pots in a shady location.

6. Care for the plants by keeping the soil moist with regular watering. Do not let the soil become too wet or waterlogged, and be careful that it doesn't dry out completely.





Place two pots in a bright location, either under lamps or next to a window that receives several hours of full sunlight.



Place two pots in a location with less light (but not dark).

Indoors or Outdoors?

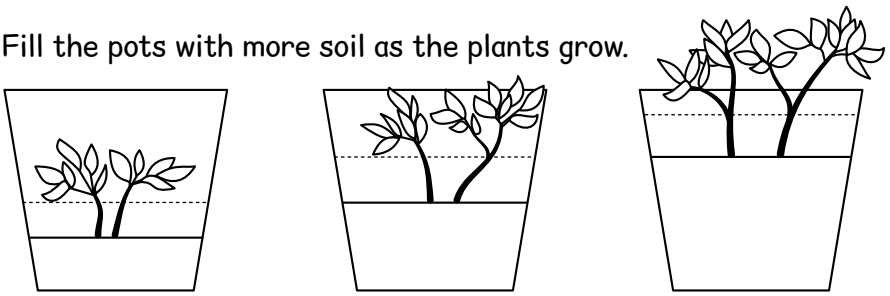
This activity can be done either indoors or outdoors. If you have space and it's winter time, we recommend indoors! If you have cats or dogs, take care that they don't eat the above-ground leaves and stems of the potato plant, which are poisonous. If you would prefer to plant your potatoes outdoors, plant them no earlier than 4 to 6 weeks before the average last frost. They are cold hardy and can handle some freezing or near-freezing temperatures. Whether the plants are indoors or outdoors, they will need at least 10 to 12 weeks of growth to produce a crop of new tubers.

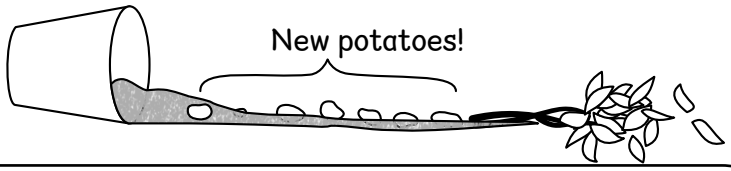
7. After sprouting, continue to add additional layers of potting soil until the pot is full. Record your observations about the size and appearance of the above-ground plants at regular intervals.

8. After 10 to 15 weeks or when the plants begin to die back, pour out the potting soil and sort through it to find the new potato tubers. (See page 13 for more detailed instructions).

How many tubers did you find? Which plants produced the most potatoes?

Fill the pots with more soil as the plants grow.

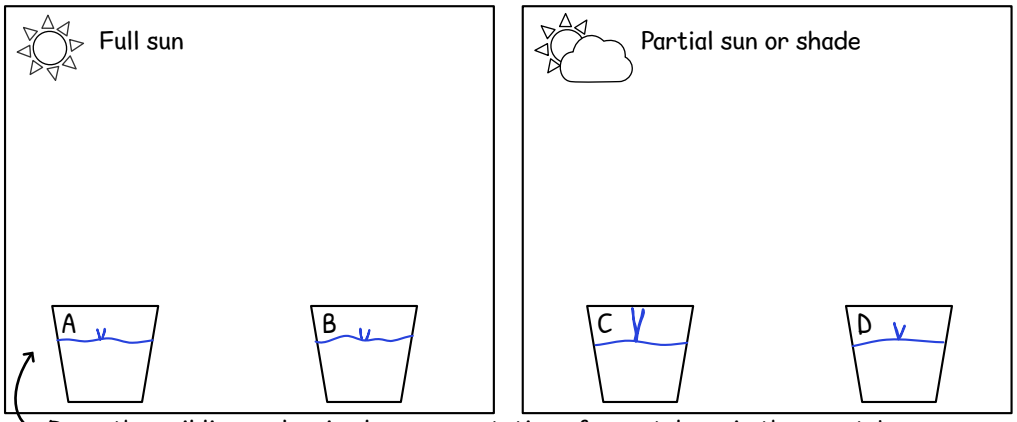




Observations just after the first sprouts emerge:

Noting the date is a vital part of recording research!

DATE:
1/02/2022



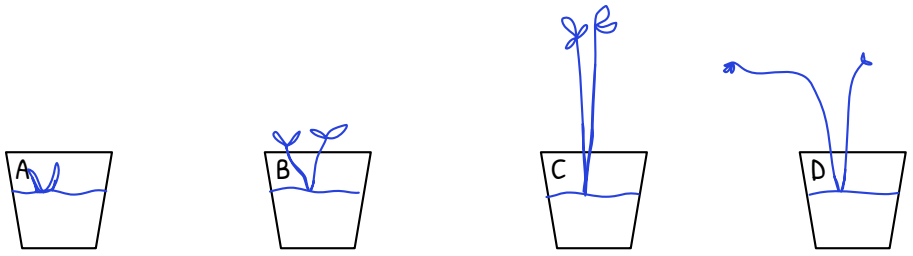
Draw the soil line and a simple representation of your tubers in these pots!

Observations will vary! These entries are examples from when we planted potatoes.

Write a line or two about what you observe.

Observations 1 week after the first sprouts emerge. Draw the approximate size and shape of the potato plants growing in each container.

DATE:
1/09/2022

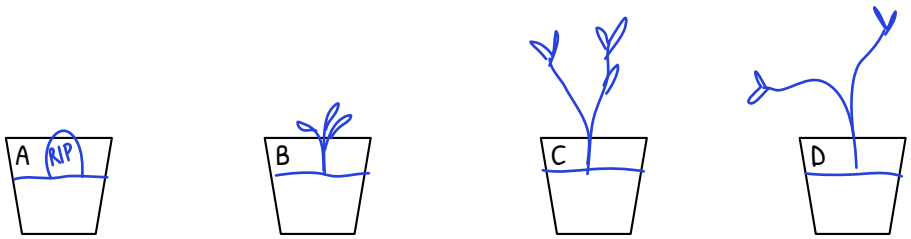


The leaves are starting to curl on the plant in pot A. I think it may be sick.

Observations 3 weeks after the first sprouts emerge:

DATE:

1/23/2022

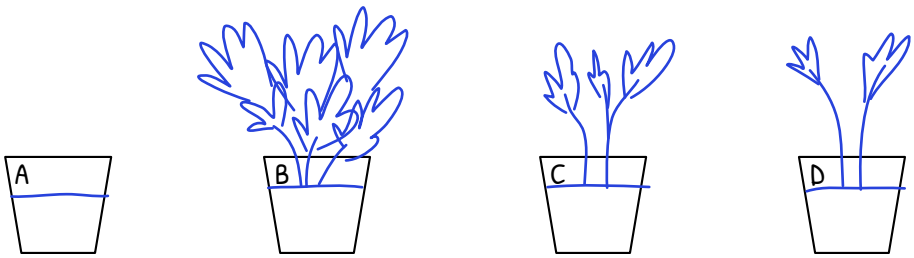


We added more soil at week 1. Plant A got sick with a fungus and died on 1/16/2022.

Observations 6 weeks after the first sprouts emerge:

DATE:

2/13/2022

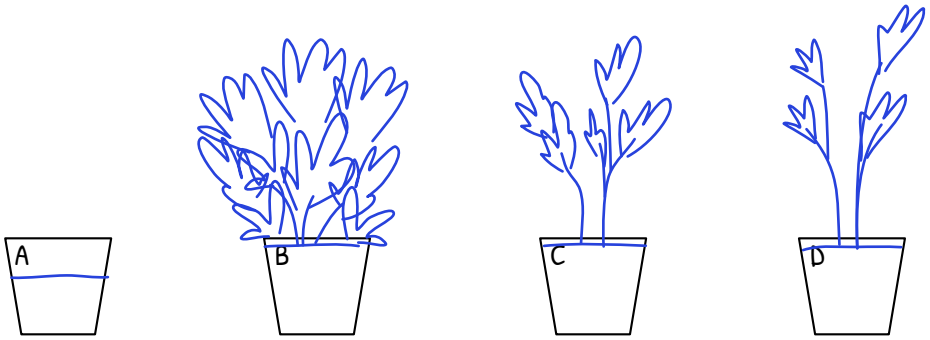


The full sun plant looks much more robust and larger than the part shade plants.

Observations 10 weeks after the first sprouts emerge:

DATE:

3/6/2022



Leaves are yellowing - The plants seem to be getting ready to die back.

DATE:
3/10/2022

POTATO HARVEST
Before harvesting your potatoes, answer the following questions:

1. Which plants have the most above-ground material? Count the approximate number of leaves on each plant and record their numbers.

The plant with the most above-ground mass: B

The number of leaves on each plant:

A	B	C	D
NA. Died on week 3	125	20	35

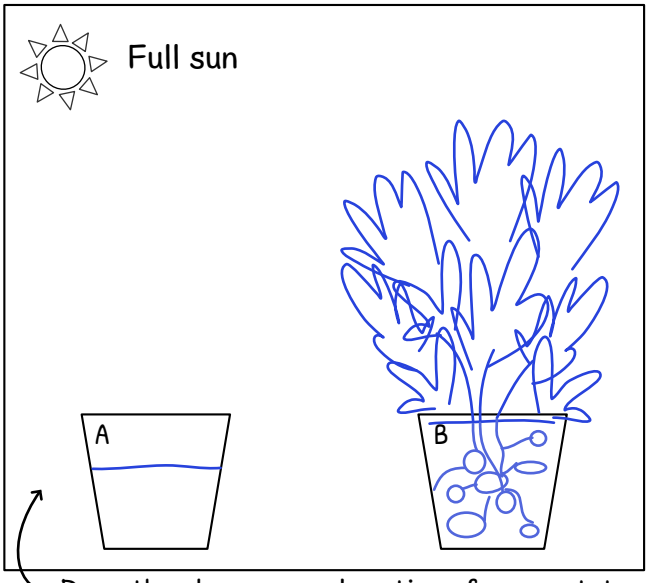
2. How different were the light conditions between your "full sun" and "partial sun" plants? If possible, study the locations for one day and count the number of hours of direct light each plant experienced.

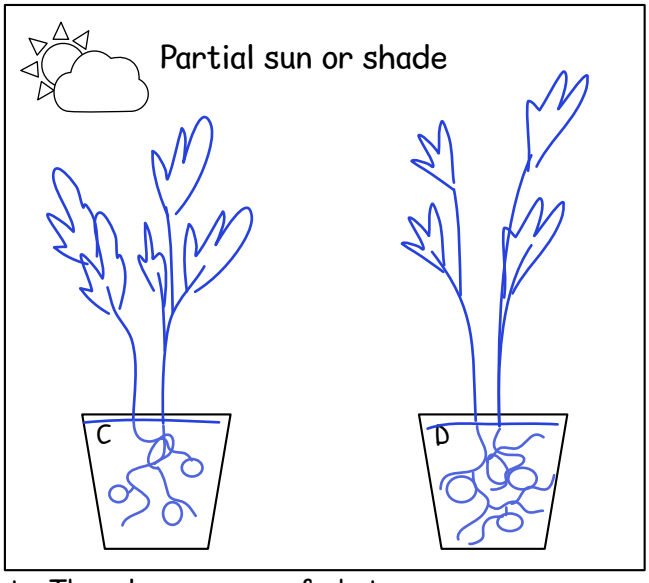
Full sun = window with 9 hours of direct light each day

Part shade = window with 2 hours of direct light.

4. Plants get their energy from photosynthesis, which requires light. Which plants were able to do the most photosynthesis during the experiment? What did the plant do with the energy it gathered from photosynthesis?

The full sun plants gathered most energy by photosynthesis. They used some of that energy to make tubers!





Draw the above ground portion of your potato plants. Then draw a guess of what you think the root structure will look like. How many tubers do you expect to find?

When to harvest potatoes

Farmers usually wait until the tops of the potato plants have turned yellow and died back before harvesting. This allows the plant to store the most starch in the tubers.

With potatoes grown indoors, you can wait for the plants to go dormant or you can harvest them anytime after 10-12 weeks of growth. The choice is yours. Harvesting before 10 weeks will result in very small (pea and marble size) potatoes.

How to harvest potatoes

If the plants are in containers, take them outside and empty the dirt from the container. Sift through all the dirt and separate the tubers from the roots and potting soil.

If the plants are in the ground, loosen the soil around them with a shovel. Pull up the plants and then thoroughly explore the area with shovel and hands to be sure you found all of the tubers.

Wash and dry the potatoes and store them in the fridge until ready to eat. If the skin of a new potato is scratched or damaged during harvesting, then they won't store for as long and should be eaten sooner rather than later.

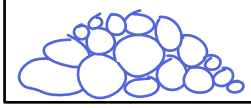
POTATO HARVEST

After harvesting your potatoes, answer the following questions:

1. Which plants produced the greatest number of tubers? Count the record the number of tubers from each plant.

A	B	C	D
	17 potatoes (Most potatoes)	9 potatoes	11 potatoes

2. Which plant produced the greatest biomass of tubers? In other words, which plant grew the most food? If you don't have a scale to weigh the potatoes, that's okay! Compare the size of the potatoes from each plant and draw pictures to represent the potato production of each.

A	B	C	D
			

3. The main variable studied in this experiment was light. Ideally, everything else would have been the same for each potato plant. But in real life, experiments don't always have ideal conditions! Were there any other variables that impacted your plants, such as disease, an injury, waterlogged roots, or drought stress?

Yes. Plant A got sick with a disease and died on week 3. It showed signs of illness just 5 days after sprouting.

CONCLUSIONS

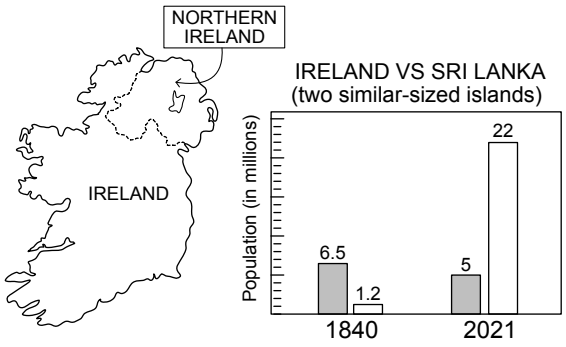
DATE: 3/10/2022

Your potatoes were genetically identical clones. Did they grow into identical plants or did they look different from each other? What impact did light have on the production of your potatoes? Do you have any advice for someone who wants to grow their own potato clones?

They looked very different! The plants with full light produced more potatoes and larger potatoes than the plants with part shade. Only advice is to really carefully wash and clean potatoes before cutting them.

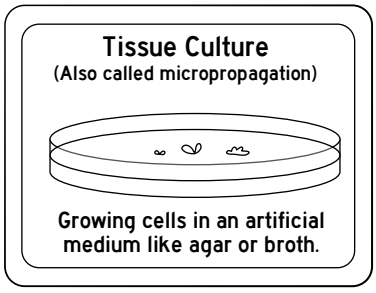
Potato Blight and the Irish Potato Famine

From 1845-1852, Ireland experienced a devastating famine when a fungus-like microorganism called Phytophthora infestans caused a serious disease known as potato blight. The blight caused the Irish to lose about ¾ of their most important food crop and resulted in over a million people dying of starvation and millions emigrating away from the island in the following years when the potato harvest was poor. Ireland is possibly the only country in the world that has a lower population today (5 million) than in 1840 (about 6.5 million).



How Potatoes are Grown Today

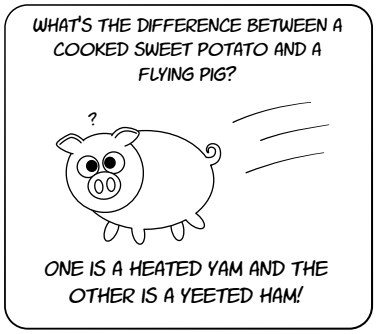
Potatoes can be infected by many different pathogens including viral, fungal, bacterial, and protozoan! Because they are susceptible to so many diseases, many of which are hard to detect, the crops of modern potato farmers actually start out in test tubes!



It's called tissue culture and it all begins with a small piece of plant about the size of a flake of pepper. This flake of green leaf tissue is taken from a parent plant which was grown in a controlled environment free from viruses.

The disease-free bit of the plant (meristem) is placed in a test tube that is has all the nutrients that the plant needs in order to grow. The test tube remains in the sterile lab until the cells have grown into a "plantlet," a small plant with distinct roots, stem, and leaves.

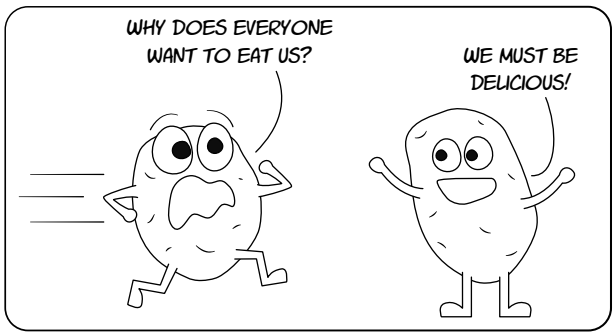
When the plantlets are large enough, they are moved to a greenhouse and planted in the ground. Then, just like regular potatoes, they grow for a few months, forming miniature tubers. After harvesting, these small tubers (called seed potatoes) are sorted and stored until it's time to plant the large crop of potatoes in regular fields.

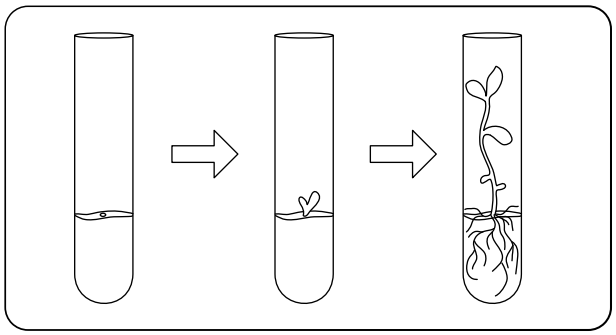


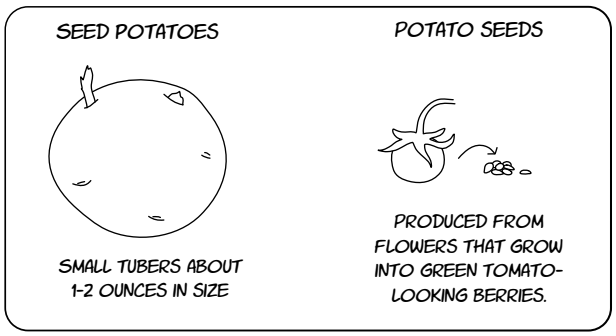
Certified seed potatoes have been tested multiple times to be sure they are free from bacterial, fungal, and viral infections.

When the seed potatoes are ready to be planted, a large machine uses sharp spikes or suction cups to grab each seed potato and drop it into the designated furrow of soil.

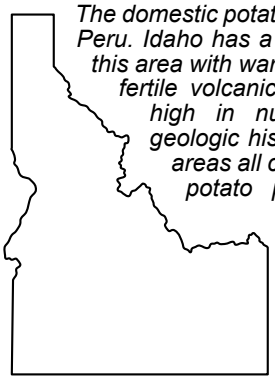
The buds on the seed potatoes sprout into plants and as the plants grow, so does their network of tubers underground. it is now up to the farmer to care for the potatoes by irrigating and fertilizing them. They'll be ready to harvest between 80 to 115 days after planting. At harvest, they're carefully dug up and stored between 10 and 14 days in cool temperatures (≈15°C) to allow the skins time to harden and minor injuries to seal. Then they're sent to a grocery store near you!







Why is Idaho famous for its potatoes?



The domestic potato originated in the mountains of Peru. Idaho has a similar climate and geology to this area with warm sunny days, cool nights, and fertile volcanic soil that is well-draining and high in nutrients. The high elevation, geologic history, location, and surrounding areas all combine to make Idaho ideal for potato production. The state grows about 13 billion pounds of potatoes every year.

Idaho even has a museum dedicated to the potato with an exhibit of the world's largest potato chip!

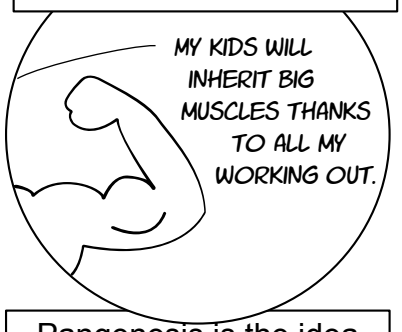
The question of inheritance

Throughout history people have had different ideas about how traits are inherited. The three ideas described below were common when Mendel was alive. Which of these ideas best explains what you have observed about traits and how they are inherited? Rate them from one star (not accurate, e.g. there are lots of counter examples for this idea) to four stars (this idea explains inheritance very well).

Lamarckism

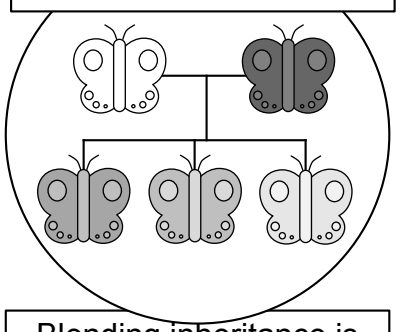
Lamarckism is the belief that acquired traits can be inherited. Giraffes are able to lengthen their necks by constantly stretching, so their offspring will inherit a longer neck.

Pangenesis



Pangenesis is the idea that every part of the body produces small particles called gemmules which are then passed on to offspring.

Blending



Blending inheritance is the idea that each trait will be inherited by the offspring at about the average level of each parent. For example, your hair color falls between your parents' hair colors.

Gregor Mendel

Mathematician, biologist, abbot, and founder of genetics

FILL IN THE BLANKS USING THESE WORDS:

garden inheritance traits pea genetics

Gregor Mendel was a monk at St. Thomas Abbey. During Mendel's lifetime, the question of how traits were passed from one generation to the next was one of the great mysteries of science. Popular ideas to explain inheritance included Lamarckism, the idea that acquired traits could be passed on to offspring.

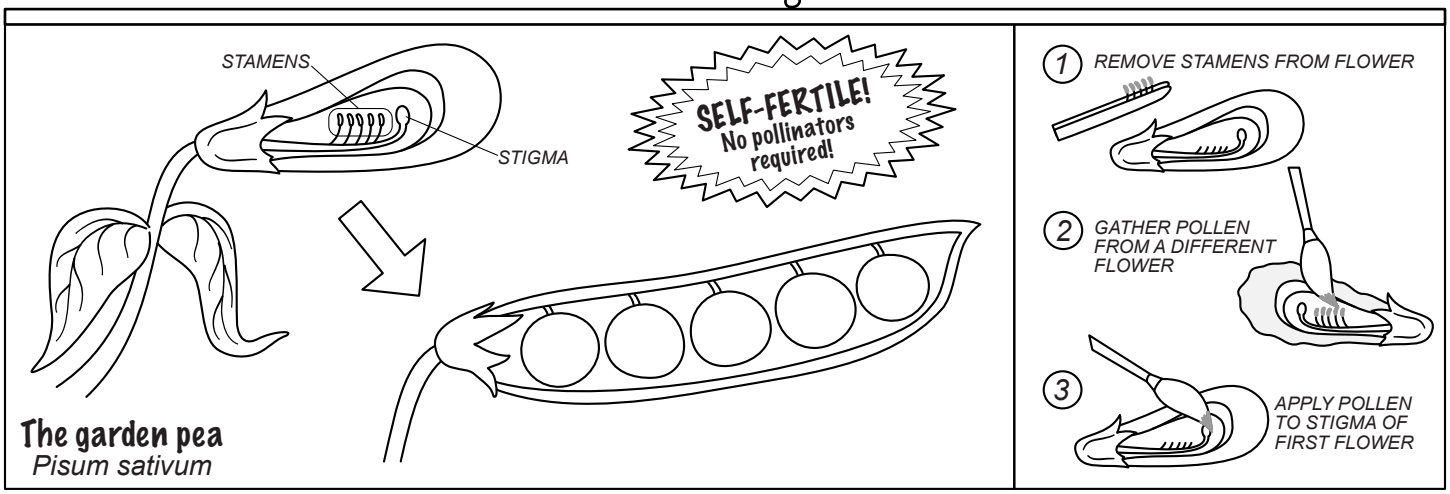
In the 1850s, Mendel conducted experiments to discover how inheritance worked. He studied the characteristics of pea plants, such as green and yellow seeds. His experiments were conducted in a small garden next to the abbey.

His conclusions were incredibly advanced for his time and he is widely considered to be the founder of modern genetics.

THE LOCATION OF ST. THOMAS ABBEY

GREGOR MENDEL 1822-1884

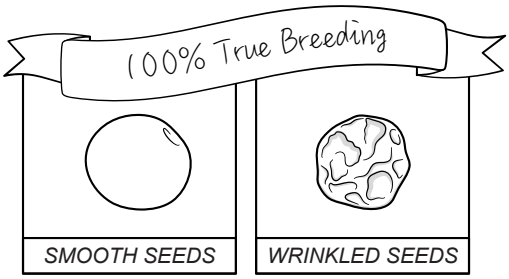
A famous experiment

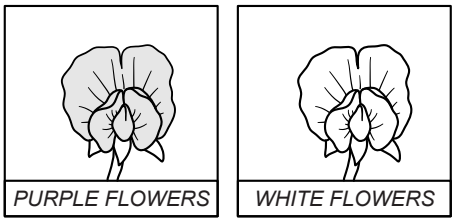


The garden pea
Pisum sativum

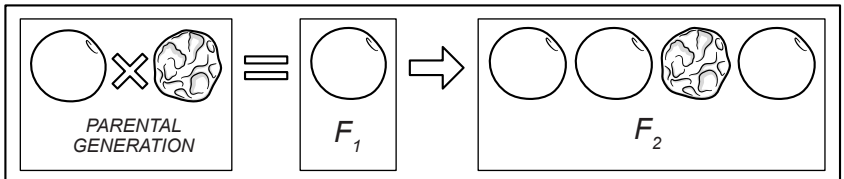
Peas are self-fertile. They do not need pollinators and unless a person intervenes, the pollen on the stamens will fertilize the stigma and produce a pea pod filled with seeds. To cross-pollinate two different pea plants, Mendel used tweezers to remove the stamens from one flower (1) and used a paintbrush to gather pollen from the flower of a different plant (2). The pollen was then applied to the stigma of the first plant to produce hybrid seeds (3).

MEET THE PARENT PEAS!





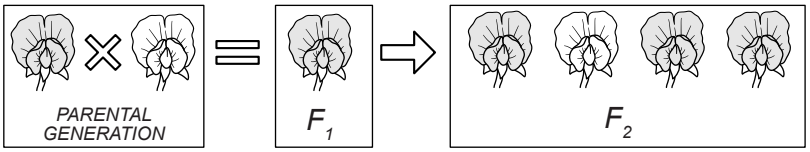
THE EXPERIMENT



A pea plant with smooth seeds is cross-fertilized with a plant that has wrinkled seeds.

ALL of the seeds in that first generation (called the F_1 generation) are smooth.

When those first generation seeds (F1) are self-fertilized, the next generation shows a 3 to 1 ratio of smooth to wrinkled seeds.



We see the same result with flower color.

If you were Mendel, how would you explain these results? Why is one trait disappearing in the F_1 generation and then coming back again in the next?

Answers will vary.

Disappearing and reappearing traits?

Mendel's results explained

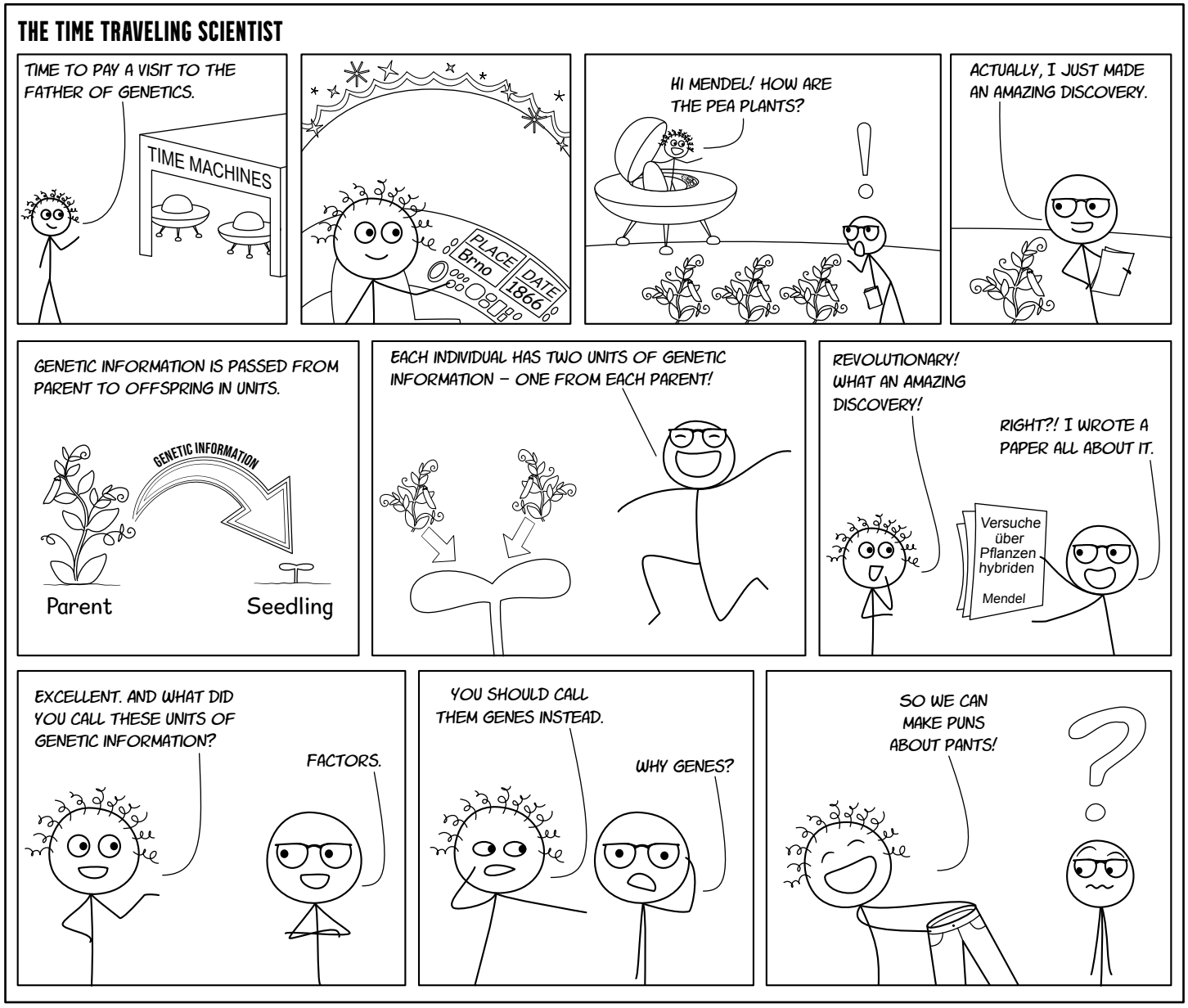
FILL IN THE BLANKS USING THESE WORDS:

alleles | inherited | generation | ignored | traits | dominant

When crossing two true-breeding pea plants with different traits, Mendel found that the F_1 or first generation of plants looked identical to one of the parent plants. The trait from the other parent had "disappeared." But when these plants were self-pollinated, they were no longer true-breeding. Both of the traits appeared with a consistent ratio: ¼ of the plants had the trait that had disappeared while ¾ of the plants had the other trait.

To explain this phenomenon, Mendel said that each plant inherited two factors, one from each parent. Some factors were dominant and others were recessive. Today, we call these factors genes or alleles.

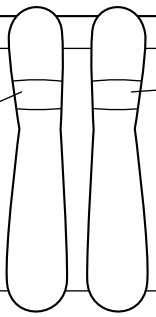
He published his research, but it was ignored for more than thirty years. Mendel wasn't recognized for his work until other scientists discovered the same facts in the 1900s.



Genotype

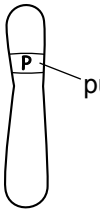
the genetic information

In this example, we use "**P**" to represent the allele for purple flower color and "p" to represent the allele for white flower color.



The gene for flower color.*

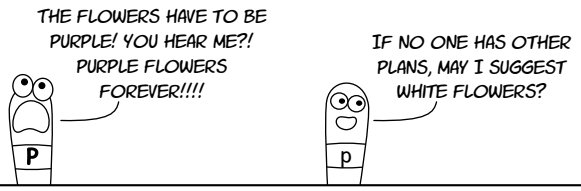
There isn't just one gene for flower color! There are different versions of this gene. One has instructions for purple flowers. Another version has instructions for white flowers. Different versions of the same gene are called **alleles**.



purple allele

white allele

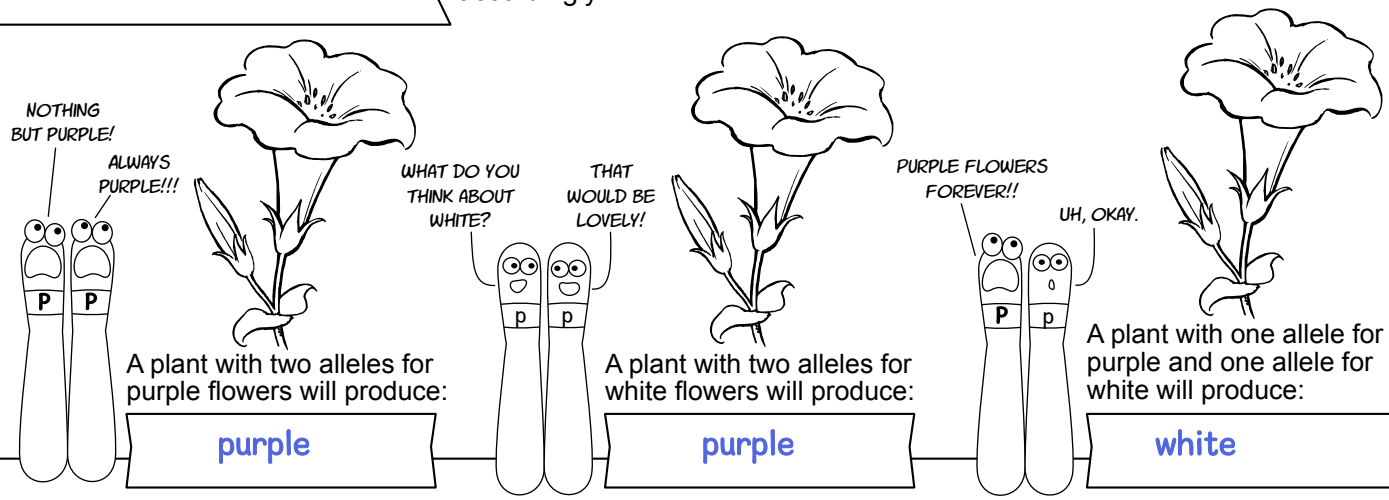
*We'll learn more about what genes are (segments of DNA) and where they are located (on chromosomes) in the next unit. For now, we can think of them as little bosses telling the organism what to do.



Phenotype

the observed trait

In this example, there are two phenotypes: purple flowers and white flowers. Write the expected phenotype in each box below. Then color the flowers accordingly.

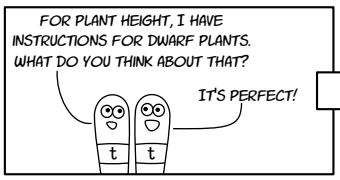


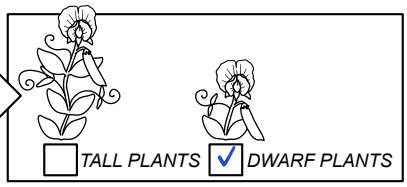
A plant with two alleles for purple flowers will produce: **purple**

A plant with two alleles for white flowers will produce: **purple**

A plant with one allele for purple and one allele for white will produce: **white**

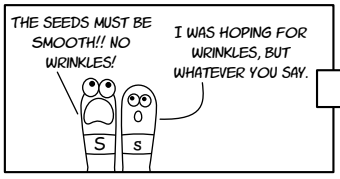
*In the example above, the purple allele is **dominant** and the white allele is **recessive.** The traits below also have a dominant allele (represented by a capital letter) and a recessive allele (lower case letter). Use this information to indicate the phenotype that will be produced from each pair of alleles.*

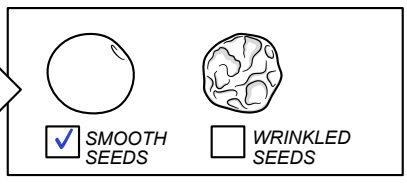




For plant height, if the **genotype** is: **Tt**

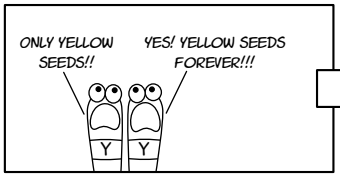
The **phenotype** will be: **tall**

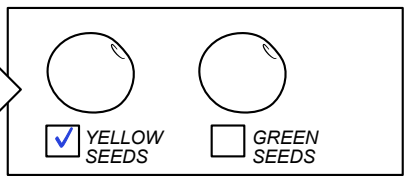




For seed texture, if the **genotype** is: **Ss**

The **phenotype** will be: **smooth**

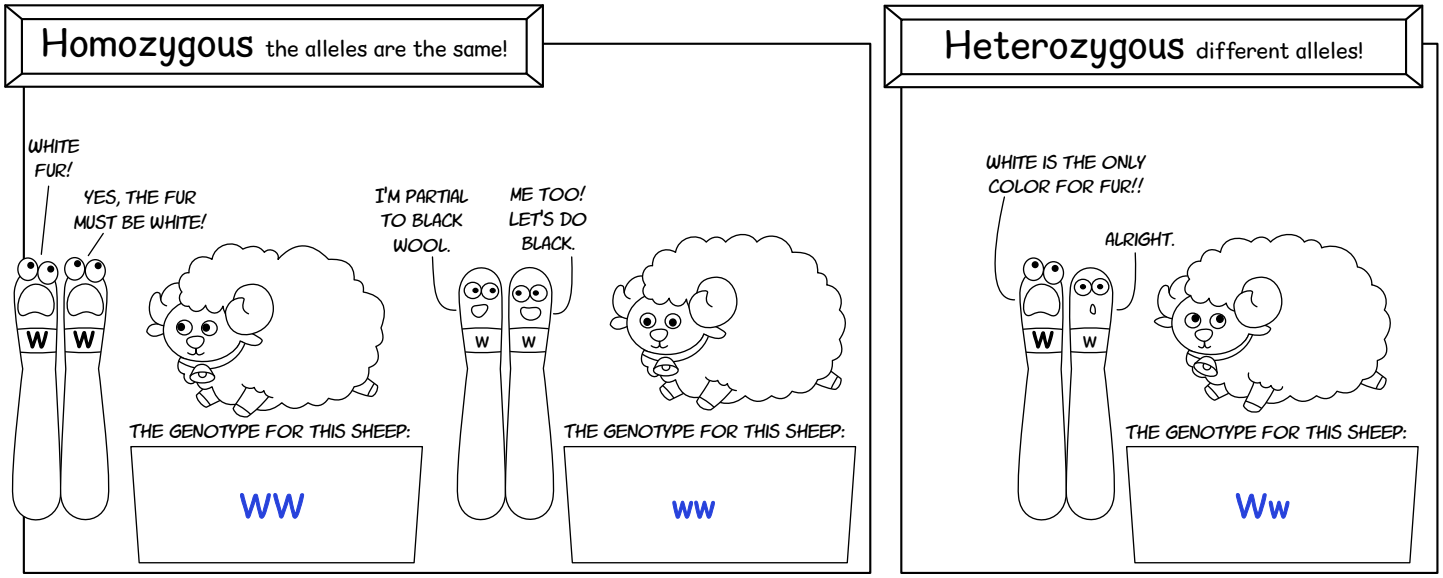




For seed color, if the **genotype** is: **yy**

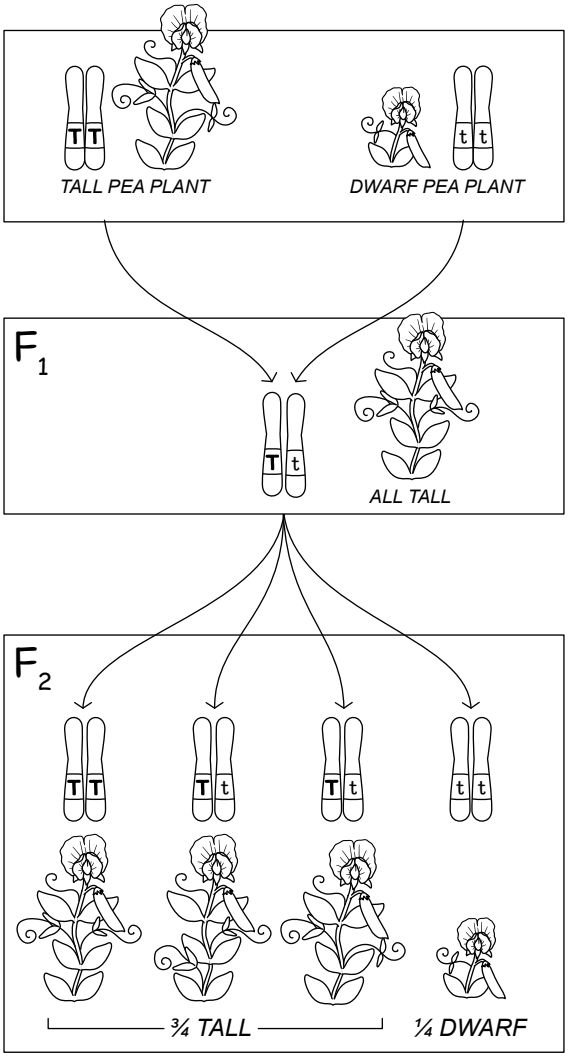
The **phenotype** will be: **green**

The traits Mendel studied follow a **dominance / recessive** pattern. The trait of wool color in sheep does as well, which explains why black sheep are less common than white. Color in the sheep below with the correct phenotype and then label each block below as either "Homozygous dominant," "Homozygous recessive," or "Heterozygous."



Mendel's results explained (in more detail)

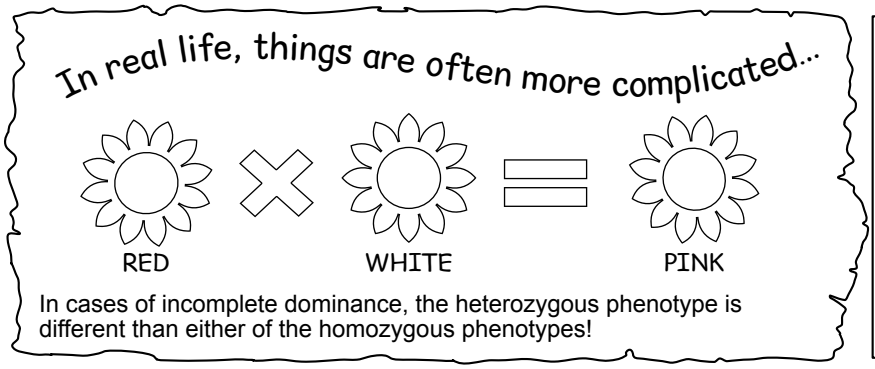
Write either "heterozygous" or "homozygous" in each of the labels below.

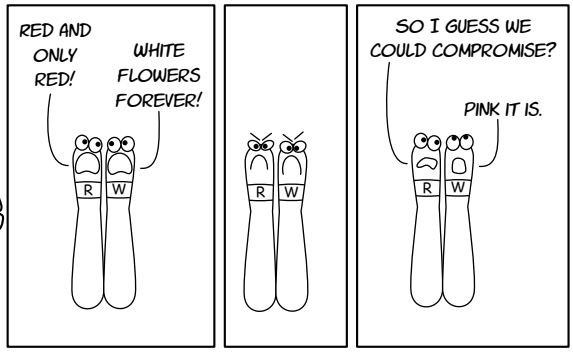


The plants in the parent generation are true-breeding or ___homozygous___ for their trait, which is plant height. The tall plants always produce seeds that grow into tall plants. The dwarf plants always produce seeds that grow into dwarf plants.

The F_1 generation received one allele from each parent plant and are ___heterozygous___ for plant height. All of the plants in this generation are tall. The plants will be self-fertilized to form the F_2 generation.

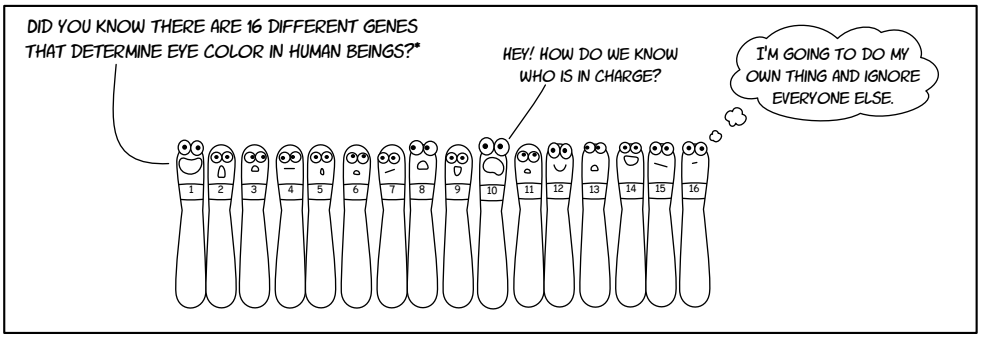
In the F_2 generation, a quarter of the plants show the phenotype of dwarfism. These plants are ___homozygous___ recessive. Two of the three tall plants are ___heterozygous___, which means they are no longer true-breeding for the trait of plant height.





Most human traits are controlled by multiple genes and have complicated inheritance patterns. We sometimes think of eye color as being a trait that follows Mendelian inheritance patterns with brown eyes being dominant and blue eyes being recessive.

But it's not that simple! With more than 16 different genes playing a role in the process, two blue-eyed parents can indeed have a brown-eyed child. The same is true with many other traits including hair color, earlobes, and more.



** For further reading, see Genotype-phenotype associations and human eye color by Desiree White in the Journal of Human Genetics. Published Oct 14, 2010.*

Draw lines to match each term with the correct description:

Recessive

Dominant

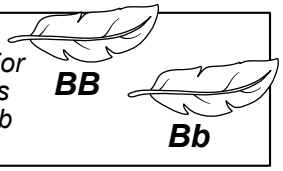
Homozygous

Heterozygous

Genotype

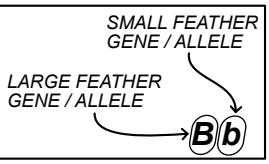
Phenotype

Only one copy (allele) of a gene is needed for the trait to be expressed. For example, if the trait for large feathers is represented by B, then both BB and Bb would result in big feathers.



The copies (alleles) of the gene are both the same. This word comes from the Greek word "homos," which means same, and "zugos," which means yoked.

The genetic information of an organism. The term can also refer to the genetic information of a specific trait.



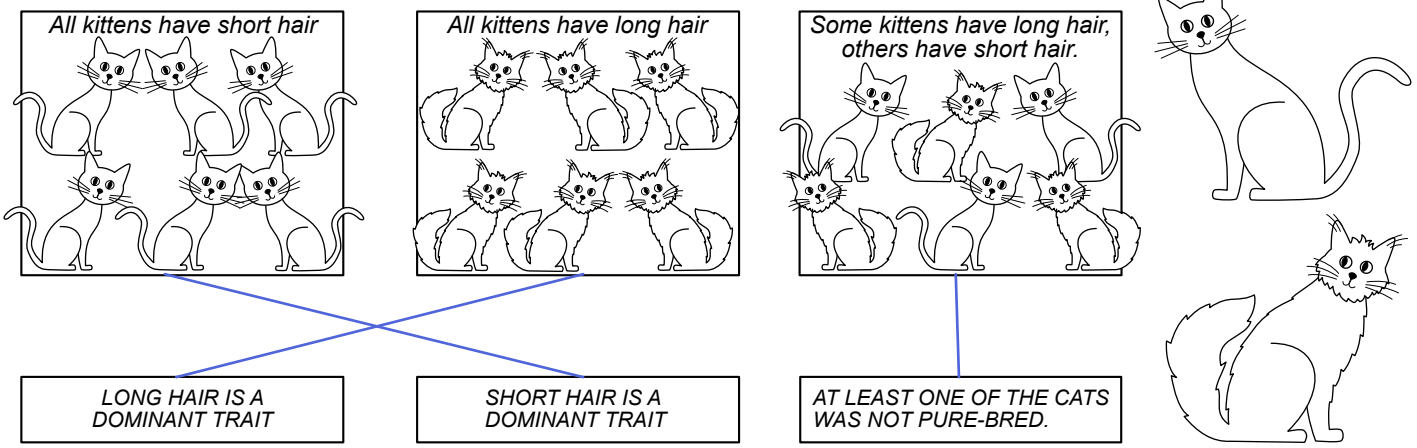
There are two different versions (alleles) of the gene. This word comes from the Greek words "heteros," which means different, and "zugos," which means yoked.

The trait will only be expressed if there are two identical copies (alleles) of the gene. For example, if small feathers are represented by b, then only the genotype of bb will produce small feathers.

The observable characteristics or traits of an individual, such as having either small or large feathers.

Laws of heredity

Yujun buys two pure-bred cats, each with a pedigree showing that all of their ancestors have the same trait for hair length. One cat is long haired. The other is short haired. Now the cats are going to have kittens. Yujun knows that hair length is a recessive/dominant trait but doesn't remember which trait is dominant. Match each of the possible outcomes with the correct conclusion.

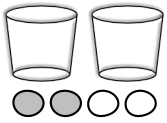


1. SEGREGATION - the alleles are distributed randomly

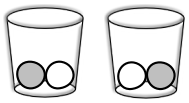
Mendel's first law states that the chance of inheriting an allele (or genetic factor) is random. For example, in the case of yellow or green seeds in pea plants, if the parent is heterozygous (Yy) there is a 50% chance the offspring will receive the dominant yellow (Y) allele and a 50% chance they will receive the recessive green (y) allele. This is called the principle of segregation.

Try it yourself!

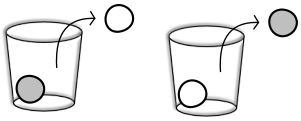
Supplies: *2 cups and 4 objects to represent dominant and recessive alleles. The objects should have the same shape and size but different colors. You could use dried peas, beans, marbles, dice, marshmallows or any items of the same size. Just make sure they are marked or colored so that you can tell tell them apart.*



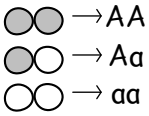
STEP 1 Place 1 object of each color in each cup. Assign one of the colors to be dominant (A) and the other to be recessive (a).



STEP 2 Without looking, draw one object from each cup.



STEP 3 Record whether you picked two dominant (**AA**), one of each (**Aa**), or two recessive (**aa**) in the tables below. Go back to **STEP 1** and repeat until the table is full.



AA	Aa	aa

STEP 4 Color each cell green if it holds **aa** and yellow if it holds **AA** or **Aa**.
When complete, do you expect the table will have more yellow or green squares? Expect more yellow

AA	Aa	Aa	aa	Aa	Aa	aa	aa	Aa	Aa	aa	aa	AA	Aa	Aa	Aa	aa	aa	Aa	aa
AA	Aa	aa	AA	AA	AA	AA	Aa	AA	aa	Aa	aa	Aa	aa	aa	AA	aa	AA	Aa	Aa

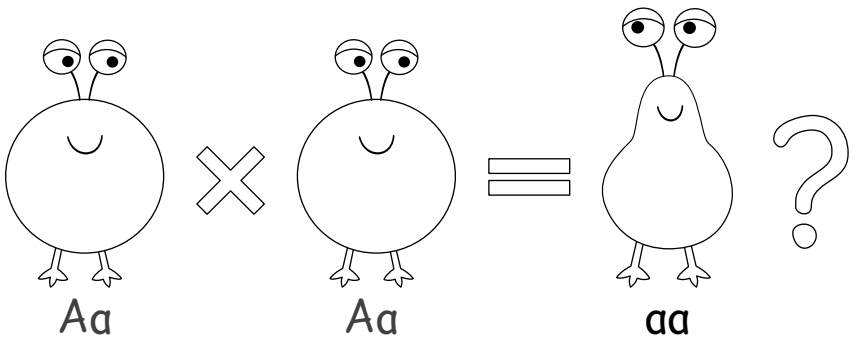
Count the number of yellow and green cells in your table. 26 Yellow 14 Green
Answers will vary! The first time we did this, we had 26 yellow and 14 green. Our second attempt had 31 yellow and 9 green.

Mendel's first law predicts 30 yellow (AA and Aa) and 10 green (aa). Were your results similar to this? If you repeated this activity 3 more times, would you expect the overall ratio to be closer to or further away from ¾ yellow and ¼ green?

Yes. If repeated more, we would expect the ratio to come closer to ¾ yellow and ¼ green.

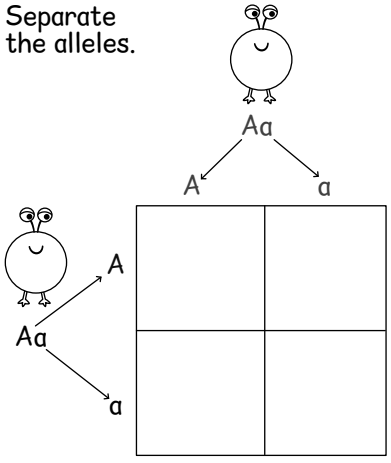
Punnett Squares

Since the probability of getting one allele or another is 50/50, we can use a tool called a Punnett square to see all of the possible combinations AND how likely they are to occur! For example, if a round shape is dominant and pear shape is recessive, a punnet square shows us how likely it is that two heterozygous aliens would produce a pear-shaped alien:

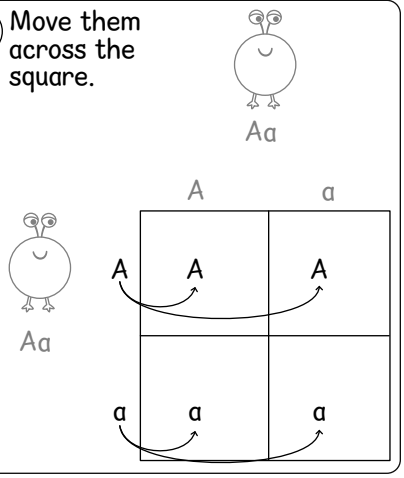


Round body shape (A) is dominant and pear body shape (a) is recessive. How many of the offspring will be pear-shaped (aa) from a heterozygous cross (Aa x Aa)? A Punnett square can tell us the answer!

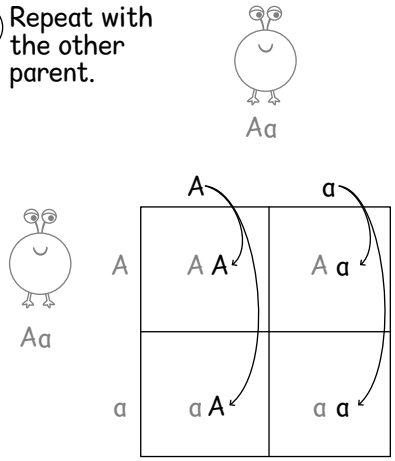
1 Separate the alleles.



2 Move them across the square.



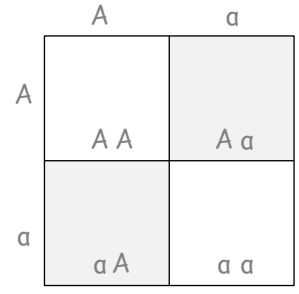
3 Repeat with the other parent.



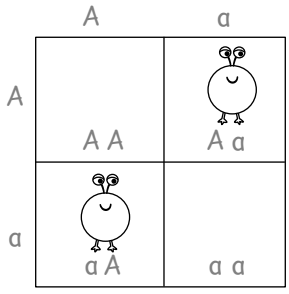
4 Evaluate your results!

We have the genotypes. Now it's time to translate them into phenotypes! First, note that Aa is the same as aA.

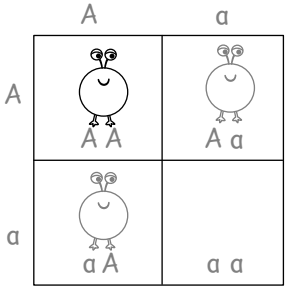
Aa = aA



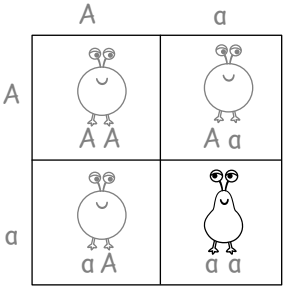
5 The phenotype for Aa is round.



6 Homozygous for the round allele (AA) also has the round phenotype.

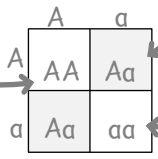


7 The phenotype for aa is pear-shaped.



8 Because each of the 4 outcomes is equally likely, the chance of any given square is 25% or ¼.

Round heterozygous aliens have a ¼ chance of producing a homozygous round alien.

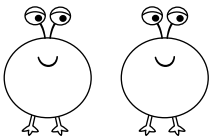


Round heterozygous aliens have a ½ chance of producing another heterozygous round alien.

Round heterozygous aliens have a ¼ chance of producing a pear-shaped alien.

Practice some crosses!

Fill in the Punnett squares for each of the following crosses. Two eyes (B) is a dominant trait. One eye (b) is recessive. Write down the chance of producing a one-eyed alien for each cross. If no squares are "bb," then a one-eyed alien can't be produced from that cross (0% chance). If one square is bb, the chance is 25%. If two squares are bb, the chance is 50%. If three squares are bb, the chance is 75%. If all four squares are bb, the chance is 100%.

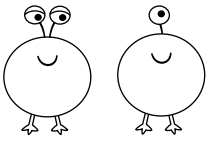


We usually just write "bB" as "Bb" so that all the heterozygous genotypes look alike.

Bb x Bb

	B	b
B	BB	Bb
b	Bb	bb

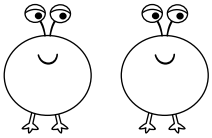
25 % chance of bb



BB x bb

	b	b
B	Bb	Bb
B	Bb	Bb

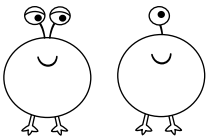
0 % chance of bb



BB x BB

	B	B
B	BB	BB
B	BB	BB

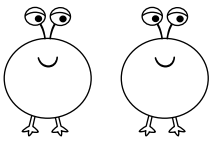
0 % chance of bb



Bb x bb

	b	b
B	Bb	Bb
b	bb	bb

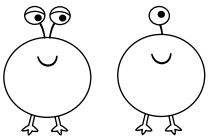
50 % chance of bb



BB x Bb

	B	b
B	BB	Bb
B	BB	Bb

0 % chance of bb

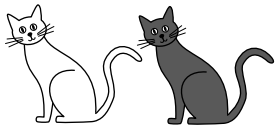


bb x bb

	b	b
b	bb	bb
b	bb	bb

100 % chance of bb

With cats, white fur is dominant (W) and black hair (w) is recessive. **Before** you fill out each Punnett squares, check a box to make a prediction about whether the cross will produce black kittens. **After** filling out the Punnett square, mark the percentage of black kittens the cross produced.



Ww x ww

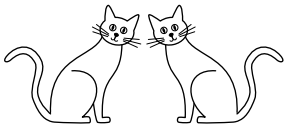
Will there be black kittens?

☑ yes ☐ no

	w	w
W	Ww	Ww
w	ww	ww

Black kittens produced:

☐ 0% ☐ 25% ☑ 50% ☐ 75% ☐ 100%



WW x Ww

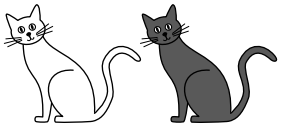
Will there be black kittens?

☐ yes ☑ no

	W	w
W	WW	Ww
W	WW	Ww

Black kittens produced:

☑ 0% ☐ 25% ☐ 50% ☐ 75% ☐ 100%



WW x ww

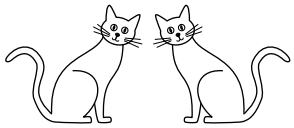
Will there be black kittens?

☐ yes ☑ no

	w	w
W	Ww	Ww
W	Ww	Ww

Black kittens produced:

☑ 0% ☐ 25% ☐ 50% ☐ 75% ☐ 100%



Ww x Ww

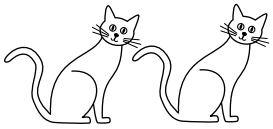
Will there be black kittens?

☑ yes ☐ no

	W	w
W	WW	Ww
w	Ww	ww

Black kittens produced:

☐ 0% ☑ 25% ☐ 50% ☐ 75% ☐ 100%



WW x WW

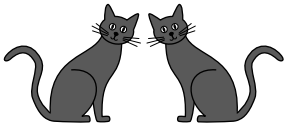
Will there be black kittens?

☐ yes ☑ no

	W	W
W	WW	WW
W	WW	WW

Black kittens produced:

☑ 0% ☐ 25% ☐ 50% ☐ 75% ☐ 100%



ww x ww

Will there be black kittens?

☑ yes ☐ no

	w	w
w	ww	ww
w	ww	ww

Black kittens produced:

☐ 0% ☐ 25% ☐ 50% ☐ 75% ☑ 100%

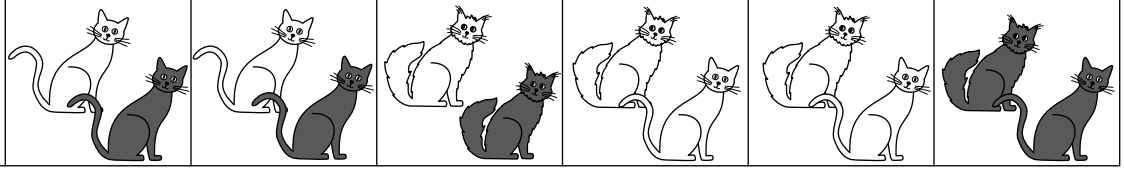
For more on Punnett Squares, check out pages 112-117 in the appendix!

2. INDEPENDENT ASSORTMENT - traits are inherited independently

Mendel's second law of inheritance says that the inheritance of one trait (such as a cat having long hair or short) has no influence on the inheritance of another trait (such as the color of the cat's fur). This is called the principle of independent assortment. It applies to a lot of traits, but not all of them! Some genes are inherited together because they are located close together on the same chromosome.

*When talking about hair color, it doesn't matter if the hair is long or short; cats with the **W** allele will be white, while cats with the **ww** genotype will be dark-haired.*

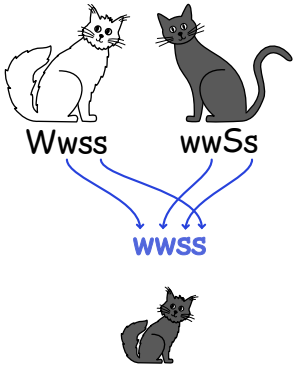
Genotype	SS	Ss	ss	WW	Ww	ww
Phenotype	*SHORT HAIR*	*SHORT HAIR*	*LONG HAIR*	*WHITE HAIR*	*WHITE HAIR*	*DARK HAIR*



*When talking about hair length, it doesn't matter what color the hair is; cats with the genotype of **SS** or **Ss** will have short hair. Long hair is only produced by the genotype **ss**.*

Could this pair of cats produce a black long-haired kitten? Check yes or no. Then show why or why not.

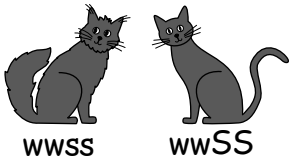
- [x] YES
- [ ] NO



The only genotype that will give a black long-haired kitten is wwss. The kitten can get the recessive alleles from both parents.

Could this pair of cats produce a white long-haired kitten? Check yes or no. Then show why or why not.

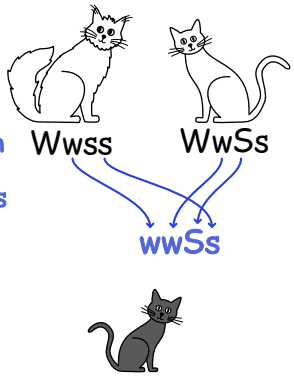
- [ ] YES
- [x] NO



There is no dominant white allele (W) to inherit. Also, the kitten needs the genotype ss for long hair, but since it receives one allele from each parent, its genotype for hair length can only be Ss.

Could this pair of cats produce a black short-haired kitten? Check yes or no. Then show why or why not.

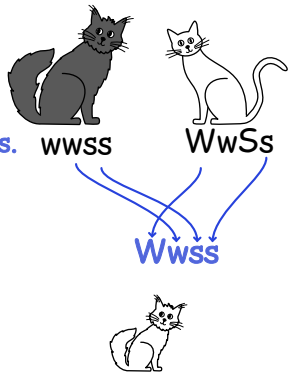
- [x] YES
- [ ] NO



Yes. It is possible to pass on the genotype wwSs. The ww gives the color black, and Ss results in short hair.

Could this pair of cats produce a white long-haired kitten? Check yes or no. Then show why or why not.

- [x] YES
- [ ] NO



The kitten can inherit Wwss. Ww yields white fur, and ss yields long hair.

The traits of pea height (tall or dwarf) and the trait of flower color (purple or white) are inherited independently.

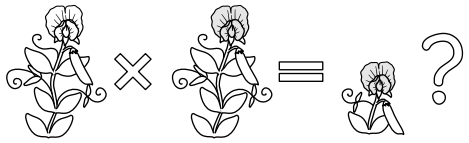
When talking about flower color, it doesn't matter if the plants are tall or dwarf; peas with the **P** *allele will be purple while peas with the* **pp** *genotype will be white.*

Genotype	TT	Tt	tt	PP	Pp	pp
Phenotype	*TALL PLANTS*	*TALL PLANTS*	*DWARF PLANTS*	*PURPLE FLOWERS*	*PURPLE FLOWERS*	*WHITE FLOWERS*

When talking about plant height, it doesn't matter what color the flower is; peas with the genotype of **TT** *or* **Tt** *will be tall. Dwarf pea plants are only produced by the genotype* **tt**.

Could this cross produce a dwarf pea plant with purple flowers? Check yes or no. Then show why or why not.

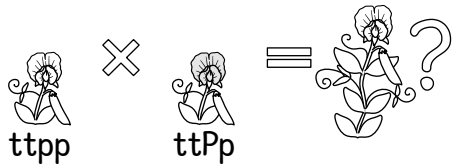
- [x] YES
- [ ] NO



The genotype tt yields a dwarf plant and Pp makes purple.

Could this cross produce a tall plant with white flowers? Check yes or no. Then show why or why not.

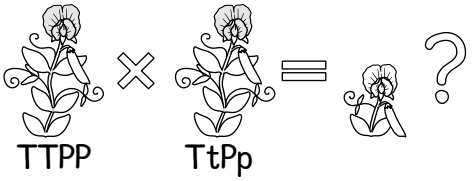
- [ ] YES
- [x] NO



The new plant will have a genotype of tt, but we need TT or Tt to get a tall plant.

Could this cross produce a dwarf plant with white flowers? Check yes or no. Then show why or why not.

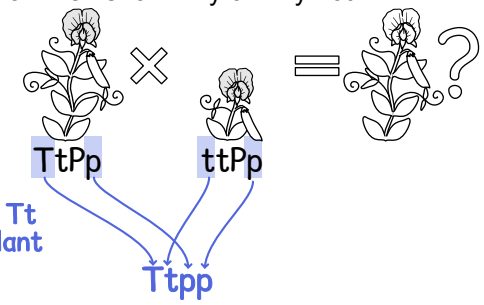
- [ ] YES
- [x] NO



This cross will always result in tall purple flower plants. For this cross, PP or Pp are the only possible genotypes for flower color and TT and Tt are the only genotypes for height.

Could this cross produce a tall plant with white flowers? Check yes or no. Then show why or why not.

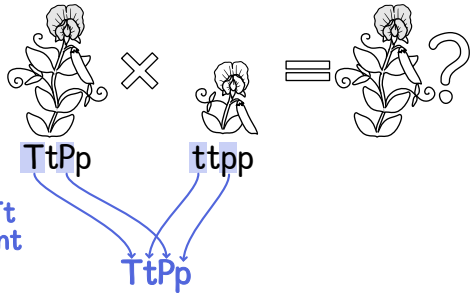
- [x] YES
- [ ] NO



The genotype Tt yields a tall plant and pp makes white.

Could this cross produce a tall plant with purple flowers? Check yes or no. Then show why or why not.

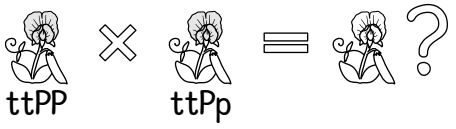
- [x] YES
- [ ] NO



The genotype Tt yields a tall plant and Pp makes purple

Could this cross produce a dwarf plant with white flowers? Check yes or no. Then show why or why not.

- [ ] YES
- [x] NO

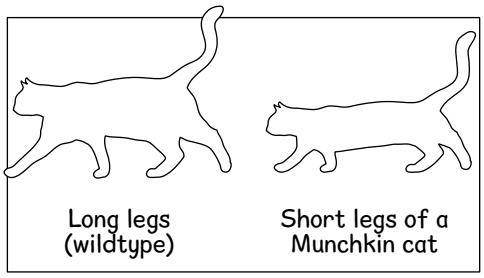


All of the offspring will be dwarf plants (tt), but the genotype for color will be either PP or Pp, resulting in a purple plant.

The Munchkin Mutation

Riley is fostering a pregnant Munchkin cat named Percy for their local animal shelter. The short legs of the Munchkin are caused by a dominant mutation (**M**). The mutation is lethal if homozygous (the **MM** genotype fails to develop in utero). Heterozygous (**Mm**) gives the Munchkin phenotype of short legs, and homozygous recessive (**mm**) results in long legs (**wildtype**).

The animal shelter has a waiting list of people ready to adopt Percy's kittens. They want to know what the probability is of the kittens being Munchkins, but no one knows if Percy's mate was a Munchkin (**Mm**) or not (**mm**). Calculate the probability of Munchkin kittens from each possible cross.

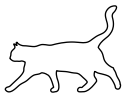


Possibility 1: Munchkin x Munchkin cross

Mm

Mm	M	m
M	~~MM~~	Mm
m	Mm	mm

Possibility 2: Munchkin x Wildtype cross



mm

Mm	m	m
M	Mm	Mm
m	mm	mm

What is the probability of Munchkin kittens if both parents are Munchkins?

- [ ] 100% - every kitten will be a Munchkin.
- [x] Approximately 67% - 2 out of every 3 kittens will be a Munchkin.
- [ ] 50% - there's a 50/50 chance of the Munchkin trait.
- [ ] 25% - there's a 1 in 4 chance of the Munchkin trait.

What is the probability of Munchkin kittens if one parent is a Munchkin and the other is wildtype (has long legs)?

- [ ] 100% - every kitten will be a Munchkin.
- [ ] Approximately 67% - 2 out of every 3 kittens will be a Munchkin.
- [x] 50% - there's a 50/50 chance of the Munchkin trait.
- [ ] 25% - there's a 1 in 4 chance of the Munchkin trait.

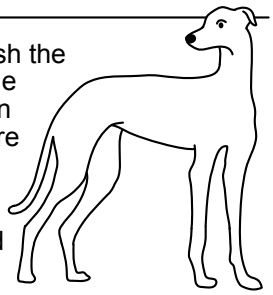
If Percy is pregnant with only two kittens, what are the possible outcomes for this litter?
Mark all genotype combinations that are possible.

- [x] Mm and Mm
- [x] Mm and mm
- [x] mm and mm

Even though we don't know the other parent's genotype, each kitten could be either Mm or mm (inheriting M or m from Percy), so all three possibilities can occur.

Ethics and Genetics

The study of genetics is about more than traits and DNA. It often impacts social and ethical questions as well. Read the following paragraphs and then write your opinion about the concerns associated with each example. There are no "right" answers here! These questions are as much about what you value as they are about heredity and genetics.



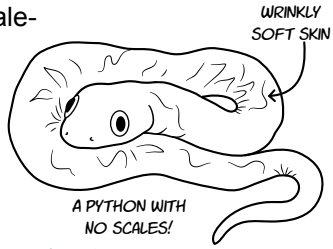
A group of dog breeders have developed a new dog breed called a Tardal.* In working to establish the Tardal as an officially recognized breed, full health histories are completed for all Tardal dogs. The studies reveal that Tardals are intelligent, loyal, and have the fastest running speed of any dog on Earth, capable of running at 70 mph. But in addition to these desirable traits, Tardals are 11x more likely than other dogs to experience hip and ankle dislocation. They also have a life expectancy that is significantly shorter than other dogs, living for just 4 to 5 years.

Should this new dog breed be accepted, a move that would cause it to become a common breed among dog owners? Or should people stop breeding Tardals be because of the health concerns associated with the breed? Write your recommendation:

Answers will vary. Similar questions to this one impact several dog breeds today. Pugs are more susceptible to eye problems and breathing issues, and large breeds such as Danes and German Shepherds are more likely to suffer from hip dysphasia.

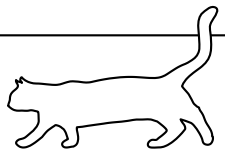
**The Tardal is an imaginary dog breed invented for this lesson.*

Remy breeds ball pythons and in one of their recent clutch of eggs they discovered a scale-less snake. Rare python morphs are valuable and Remy knows they can earn money by breeding the snake to produce more pythons without scales. But this scale-less snake has incredibly soft skin. It needs special care when shedding to avoid infection. Even with soft bedding, it is easily injured and often experiences minor cuts and scrapes from everyday movements.



Do you think Remy should breed the scale-less snake? Why or why not?

Answers will vary. Scaleless python morphs exist in real life and some snake breeders argue that they should not be bred because of their susceptibility to injury.



The Governing Council of the Cat Fancy* currently refuses to recognize Munchkins as a breed because of health issues associated with the short legged trait. Some Munchkin owners claim that the cats are healthy and happy with no more health concerns than the average cat. Others claim that the mutation hinders Munchkins ability to move and causes discomfort.

If you were a member of the GCCF, would you be in favor of recognizing Munchkins as a breed, be neutral on the issue, or be in favor of prohibiting further breeding of Munchkins?

Answers will vary.

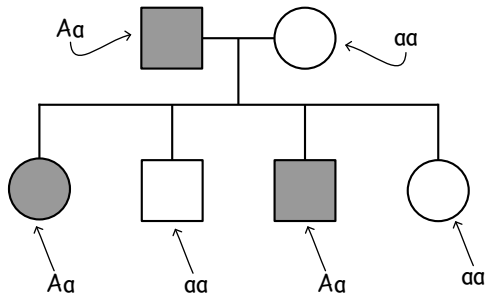
**An organization that registers pedigreed cats in the United Kingdom*

How to Read A Pedigree Chart

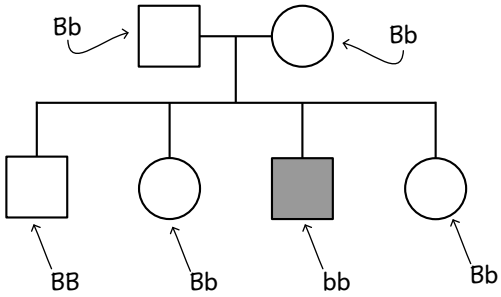
A pedigree chart is a family tree that tracks how a trait has been passed along. It typically follows the rules below:

- Males are represented by squares, and females are represented by circles.
- A filled shape means the individual exhibits the trait.
- Horizontal lines between two individuals exhibit mating pairs.
- Vertical lines descend from parents to a horizontal line that connects the offspring.

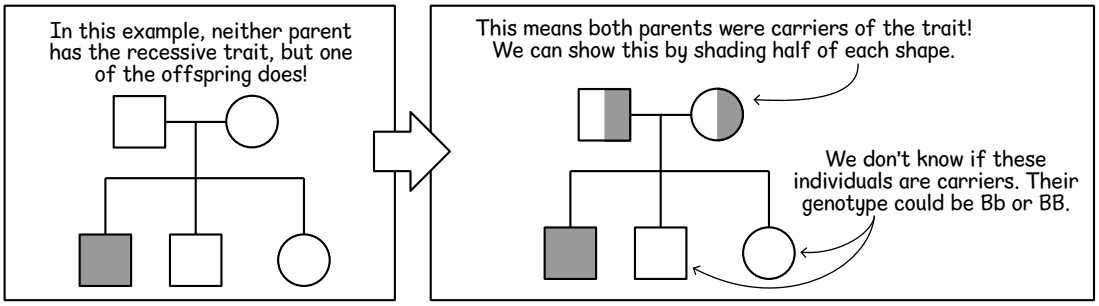
Example of a pedigree tracking the dominant trait ***A***



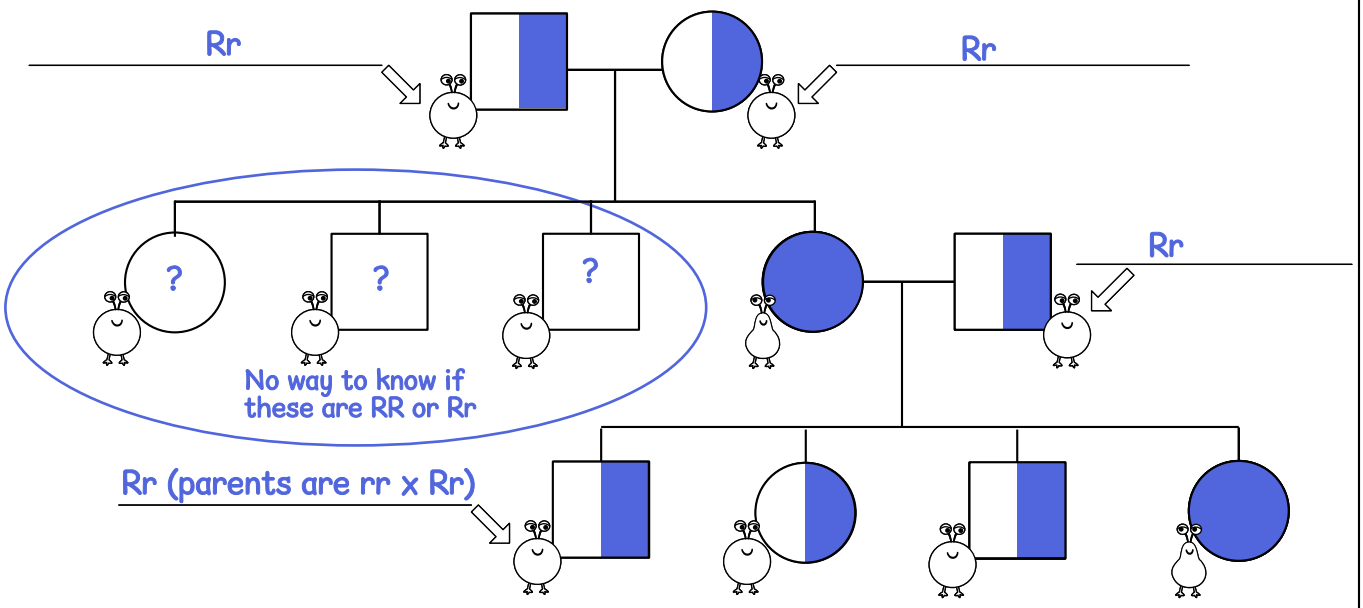
Example of a pedigree tracking the recessive trait ***b***



Each individual receives their alleles from their parents. When tracking recessive traits, sometimes it helps to identify the heterozygous individuals that carry the trait. These **carriers** are marked with half-shading.

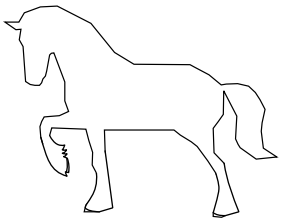


Color in this pedigree for tracking **pear shape** in the aliens. Remember, round body shape is dominant (RR) and pear shape is recessive (rr). The phenotype is known for all individuals. Can you determine the genotypes of the aliens indicated by the arrows?

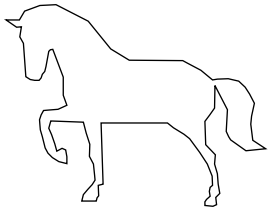


Pet Pedigree Puzzle #1

Profile of a breed with feathered feet



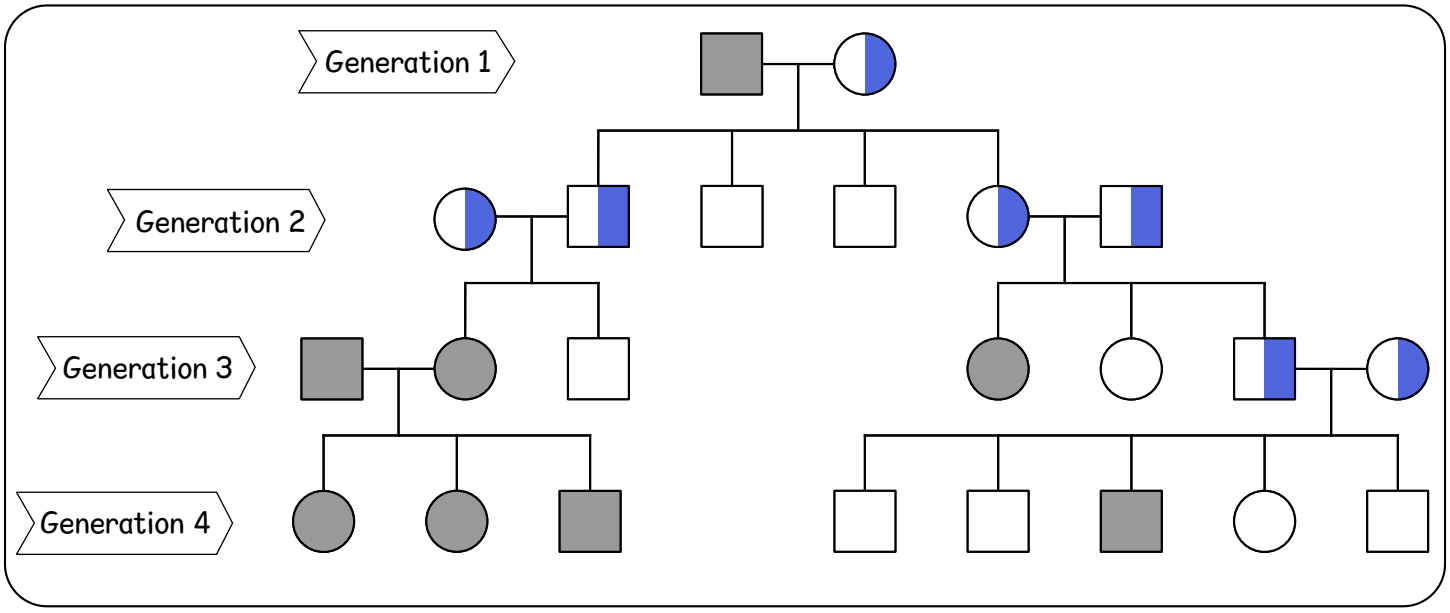
Profile of a breed without feathered feet



The "feathered" foot has long hair on the lower leg that covers the hoof.

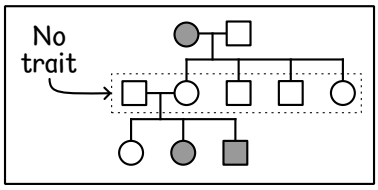
A non-feathered foot has short hair.

Below is a pedigree chart for the trait of "feathered feet," the long hair that cover the hooves of certain horse breeds like Clydesdales, Shires, Friesians, and Ardennes.* Each shaded shape represents a horse with feathered feet.



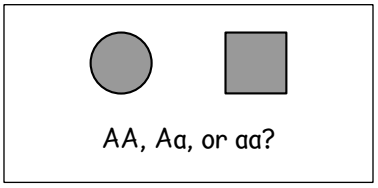
Can a dominant trait skip a generation? What about a recessive trait? Explain.

A dominant trait can't skip a generation. If the allele is present then the dominant trait will be expressed. Recessive traits can skip a generation.

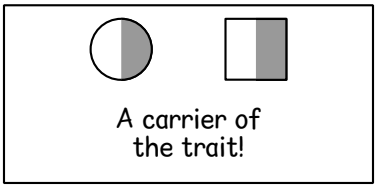


Is the trait mapped in this pedigree chart dominant or recessive? Explain how you know.

The feathered feet trait skipped a generation, so it must be a recessive trait.

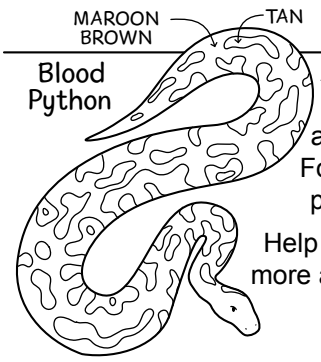


When tracking a recessive trait, a half-shaded shape is used to indicate a carrier. Can you identify a horse or horses in this pedigree that must be carriers of the trait? If yes, shade in their shapes.



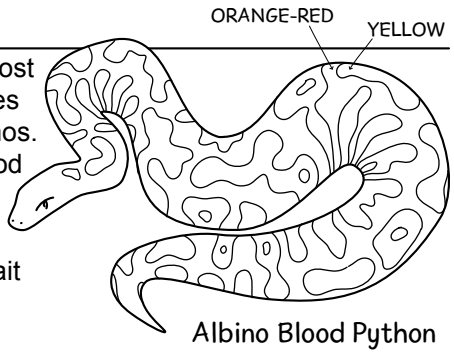
While a cross between a feathered horse (such as a Clydesdale) and a non-feathered horse (such as a Thoroughbred) will result in a horse that is non-feathered, the genetics of feathering have not been studied in detail. It's likely to include more than one gene and be more complicated than the hypothetical example used here!

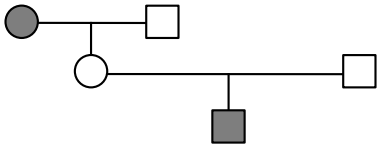
Pet Pedigree Puzzle #2



At Ella's pet store, albino blood pythons have been the most popular snake breed. Ella has space to breed two snakes and wants to choose a pairing that will produce more albinos. Fortunately, Ella has pedigree charts of the store's four blood pythons: Julius Squeezer, Basil, Medusa, and Naga.

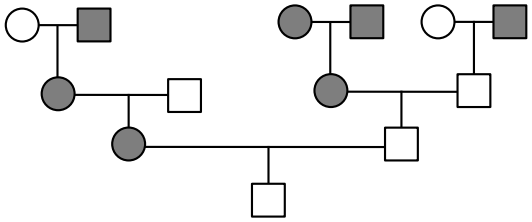
Help Ella make the choice that will give the highest chance of more albino pythons! Remember that albinism is a recessive trait and the pedigrees only show phenotype, not genotype.





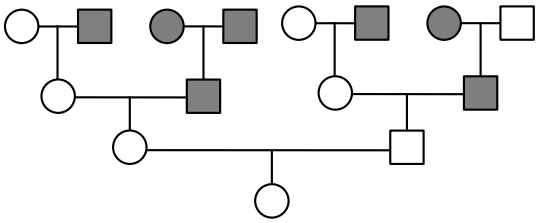
Julius Squeezer

Julius Squeezer is the an albino blood python with beautiful cream and orange coloring.



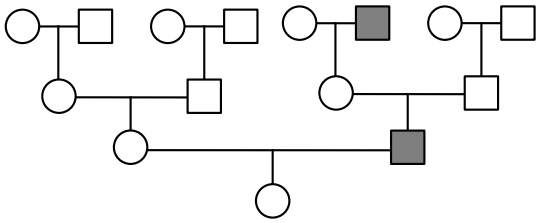
Basil

Basil has standard coloring and a very friendly temperament. He is easy to hold.



Naga

Naga has standard coloring and an aggressive temperament. Gloves are required for handling.



Medusa

Medusa has standard coloring and loves to swim. She takes a plunge anytime she's around water.

What genotype is Julius Squeezer? The standard color allele is represented by **A**. The albinism allele is represented by **a**.

☐ **AA** or **Aa** ☐ **Aa** ☑ **aa**

What genotype is Basil?

☐ **AA** or **Aa** ☑ **Aa** ☐ **aa**

What genotype is Naga?

☑ **AA** or **Aa** ☐ **Aa** ☐ **aa**

What genotype is Medusa?

☐ **AA** or **Aa** ☑ **Aa** ☐ **aa**

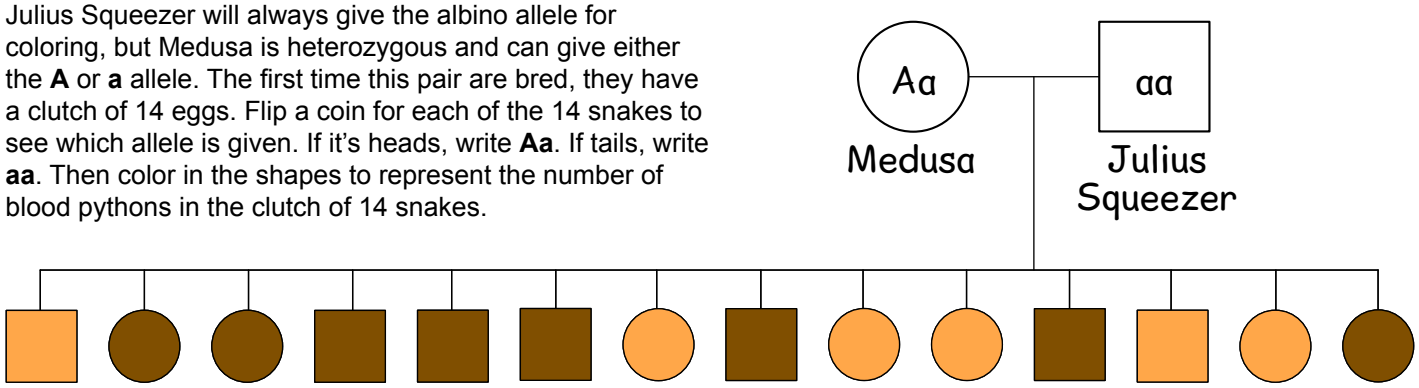
Which snakes should Ella select for breeding and why?

Julius Squeezer and Medusa are the male and female pair most likely to pass on the aa genotype, so they are most likely to have albino offspring.

Mendel's First Law is like flipping a coin...

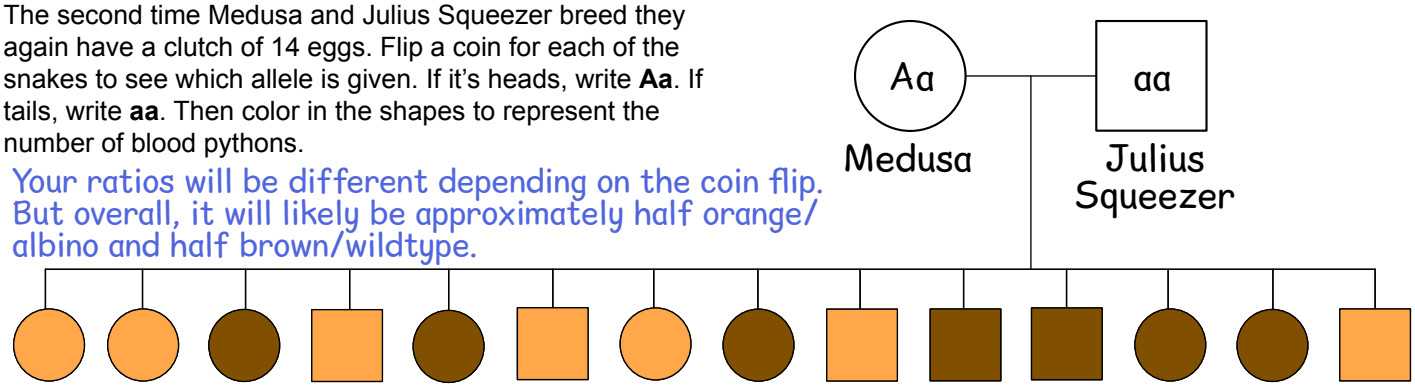
The probability of an aa x Aa cross giving albino snakes may be 50/50, but that doesn't mean you'll see that exact ratio in real life! Explore Mendel's first law by using a coin to determine whether these snakes produce albino blood pythons. Color the albinos (**aa**) orange. Use brown to mark the standard coloring (**AA** or **Aa**) which is also called **wildtype**.

Julius Squeezer will always give the albino allele for coloring, but Medusa is heterozygous and can give either the **A** or **a** allele. The first time this pair are bred, they have a clutch of 14 eggs. Flip a coin for each of the 14 snakes to see which allele is given. If it's heads, write **Aa**. If tails, write **aa**. Then color in the shapes to represent the number of blood pythons in the clutch of 14 snakes.



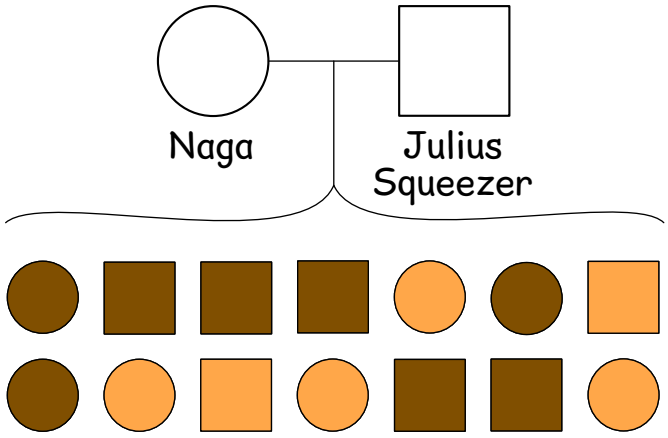
The second time Medusa and Julius Squeezer breed they again have a clutch of 14 eggs. Flip a coin for each of the snakes to see which allele is given. If it's heads, write **Aa**. If tails, write **aa**. Then color in the shapes to represent the number of blood pythons.

Your ratios will be different depending on the coin flip. But overall, it will likely be approximately half orange/albino and half brown/wildtype.



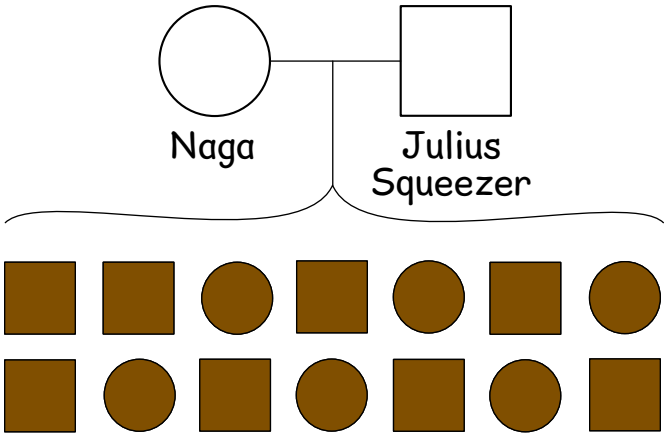
Assuming Naga is heterozygous (**Aa**), flip a coin to see what proportion of this clutch of eggs would be expected to be albinos. Then color in the results.

If Naga is heterozygous, then approximately half of the eggs would hatch albino snakes.



Assuming Naga is homozygous (**AA**), what proportion of this clutch of eggs would be albinos? Do you need to flip a coin here?

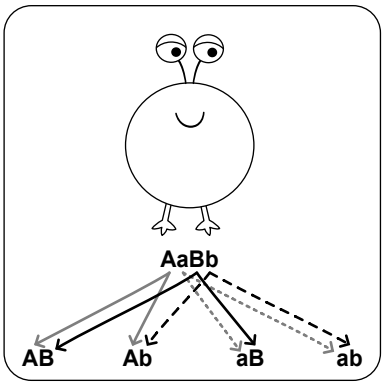
All the offspring will be Aa, so there is no need to flip a coin.

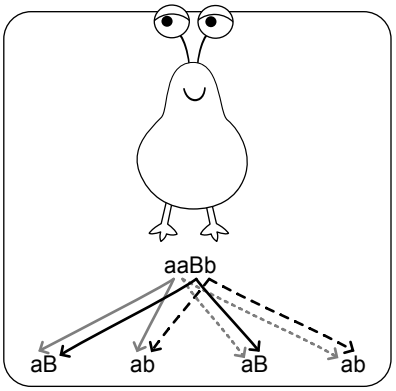


Bigger Punnett Squares!

When we consider two traits at once, we concatenate (or join) the genotypes. For example, an alien that is double heterozygous for roundness (**Aa**) and number of eyes (**Bb**) has the genotype **AaBb.** An pear-shaped alien that is heterozygous for eyes would have the genotype **aaBb.**

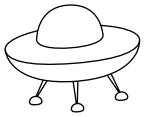
The double heterozygous alien has an equal chance of passing along each of the 4 allele pairs: **AB**, **Ab**, **aB**, and **ab**. The pear-shaped alien also has an equal chance of passing on each of the 4 possible allele pairs.





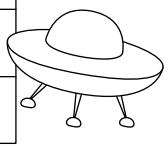
Fill in the punnet square below by drawing the correct number of eyes on each alien for the cross AaBb x aaBb. Remember BB or Bb result in the phenotype of two eyes, and only bb gives the phenotype of one eye.

	aB	ab	aB	ab
AB	**AaBB**	**AaBb**	**AaBB**	**AaBb**
Ab	**AabB**	**Aabb**	**AabB**	**Aabb**
aB	**aaBB**	**aaBb**	**aaBB**	**aaBb**
ab	**aabB**	**aabb**	**aabB**	**aabb**

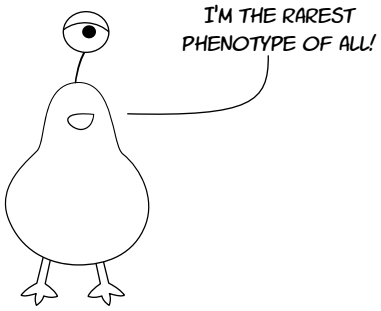


Genotype:	Phenotype:
AA	Round body shape
Aa	Round body shape
aa	Pear body shape

Genotype:	Phenotype:
BB	Two eyes
Bb	Two eyes
bb	One eye



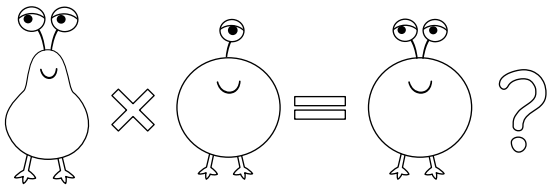
Create a Punnett square for the cross **AaBb×AaBb.** Will you see the rare pear-shaped one-eyed alien (**aabb**) from this cross? If so, what is the chance of seeing it? 1/16, 2/8, 1/4 or 1/2?



Only 1 in 16 will be pear shaped and one-eyed.

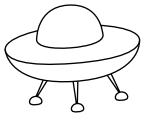
	AB	Ab	aB	ab
AB	AaBB	AABb	AaBB	AaBb
Ab	AAbB	AAbb	AabB	Aabb
aB	aABB	aABb	aaBB	aaBb
ab	aAbB	aAbb	aabB	aabb

Create a Punnett square for the cross **aaBb × Aabb.** What is the chance of seeing a round two-eyed alien (**AaBb**) from this cross?



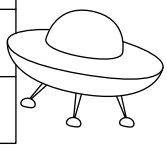
All 4 possible phenotypes occur ¼ of the time with this cross.

	Ab	Ab	ab	ab
aB	aABb	aABb	aaBb	aaBb
ab	aAbb	aAbb	aabb	aabb
aB	aABb	aABb	aaBb	aaBb
ab	aAbb	aAbb	aabb	aabb

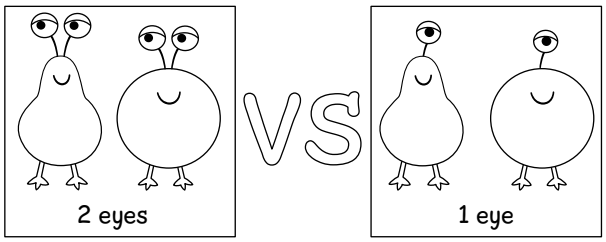


Genotype:	Phenotype:
AA	Round body shape
Aa	Round body shape
aa	Pear body shape

Genotype:	Phenotype:
BB	Two eyes
Bb	Two eyes
bb	One eye

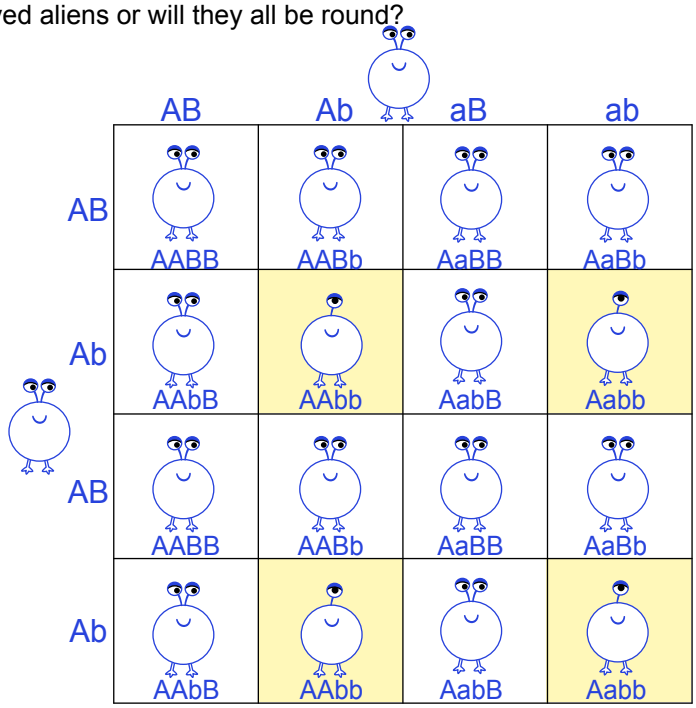


Create a Punnett square for the cross **AABb×AaBb.** How many of the offspring, on average, will have one eye? 1/16, 2/8, 1/4 or 1/2? Will there be any pear-shaped one-eyed aliens or will they all be round?

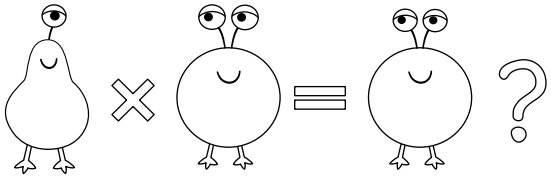


Only 1 in 4 will have one eye.

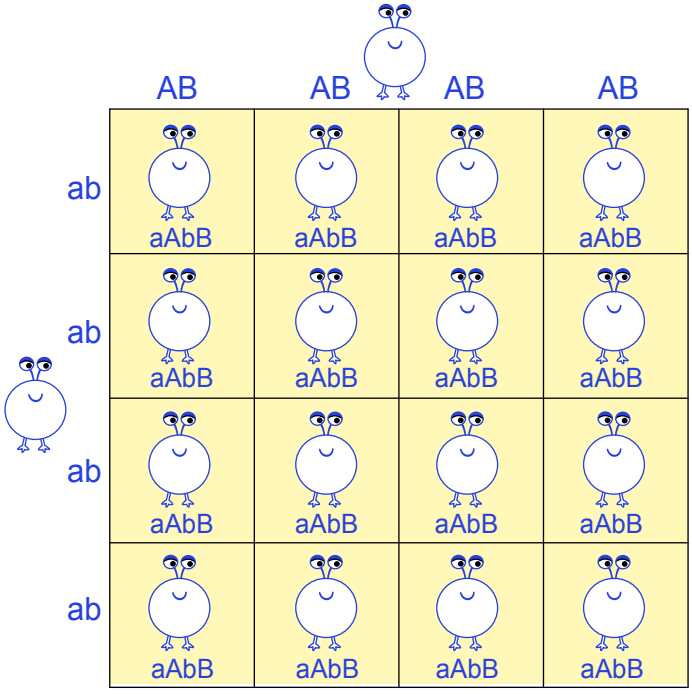
All aliens will be round. There will be no pear-shaped aliens.

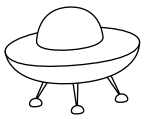


Create a Punnett square for the cross **aabb × AABB.** What is the chance of seeing a round two-eyed alien that is heterozygous for both traits (**AaBb**)?



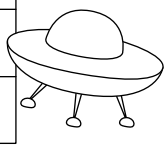
All the offspring will be AaBb because they inherit the dominant alleles form one parent and the recessive alleles from the other.



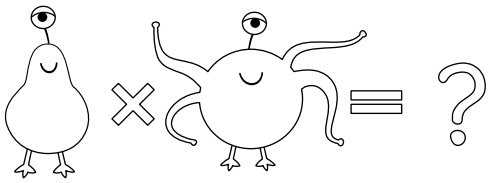


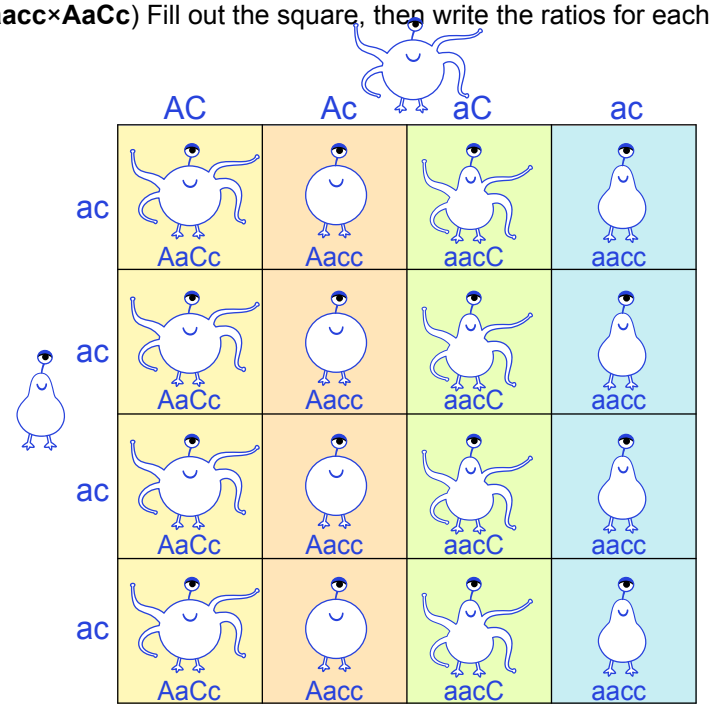
Genotype:	Phenotype:
AA	Round body shape
Aa	Round body shape
aa	Pear body shape

Genotype:	Phenotype:
CC	Tentacle arms
Cc	Tentacle arms
cc	No arms



A new dominant trait of tentacle arms has been discovered. What will be the results of a cross between a heterozygous tentacled round alien and a pear-shaped no-arms alien? (**aacc×AaCc**) Fill out the square, then write the ratios for each of the outcomes.





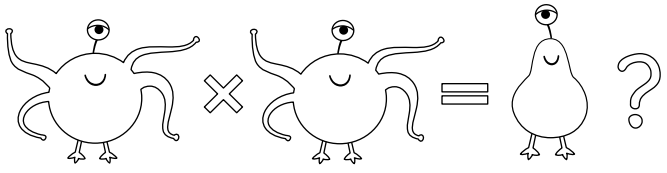
1 in 4 are round with tentacles.

1 in 4 are round without tentacles.

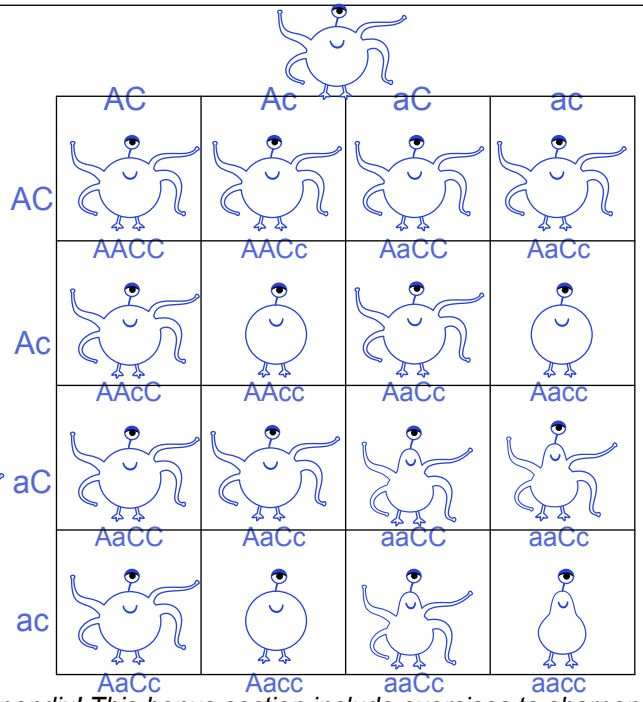
1 in 4 are pear-shaped with tentacles.

1 in 4 are pear-shaped without tentacles.

Can two round-eyed tentacle-arm aliens produce a pear-shaped no-arms alien? If yes, what do the genotypes need to be for this cross, and what is the chance of the pear-shaped no-armed offspring?



AaCc genotype × AaCc genotype = 1/16 Probability of no-arm pear-shaped



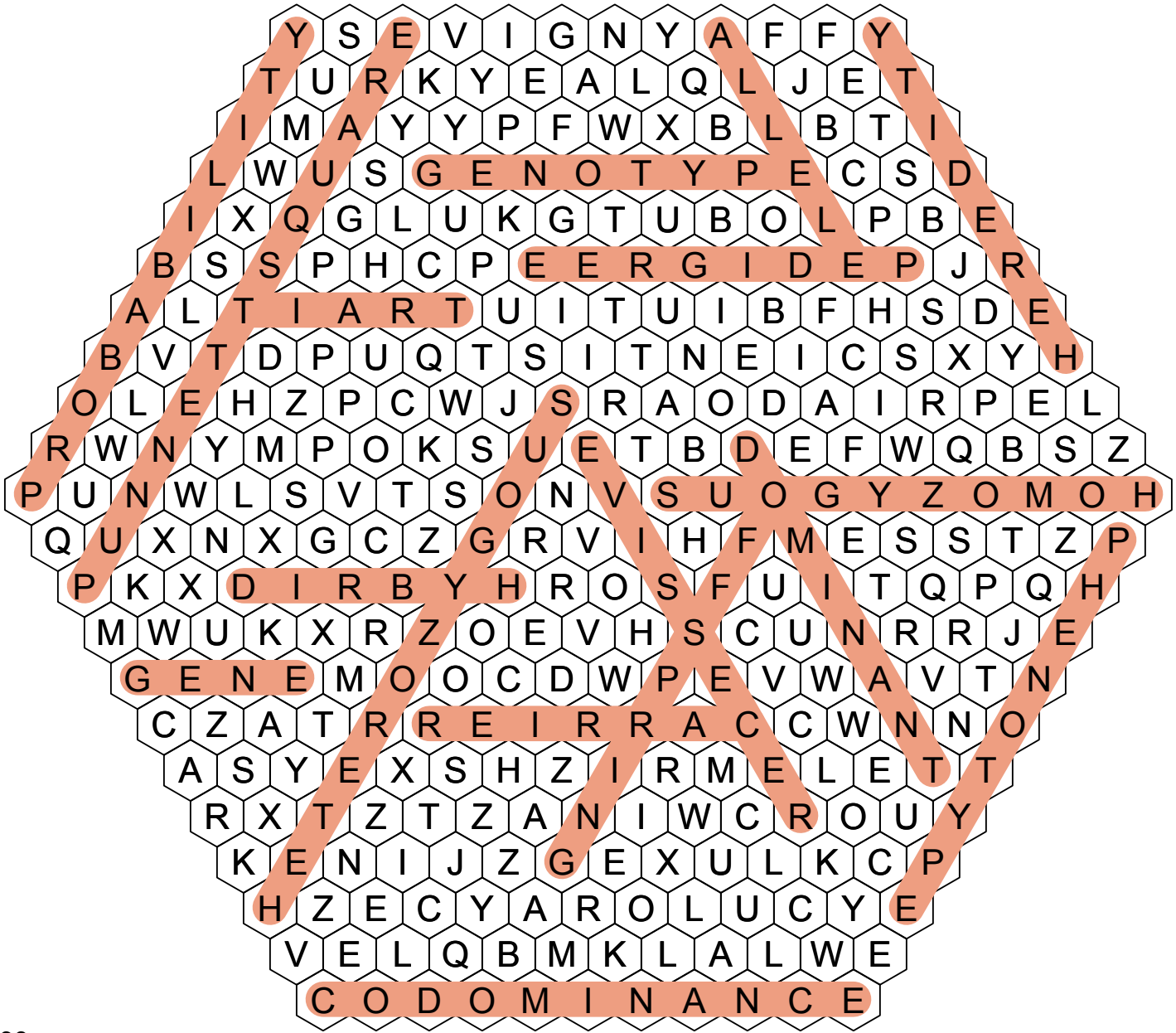
Yes. To get both recessive traits, the parents must be heterozygous (both AaCc). The chance of producing aacc is 1/16.

For more on Punnett squares, check out pages 112-117 in the appendix! This bonus section include exercises to sharpen your skills for calculating probabilities, and templates for a tryhybrid and tetrahybrid cross!

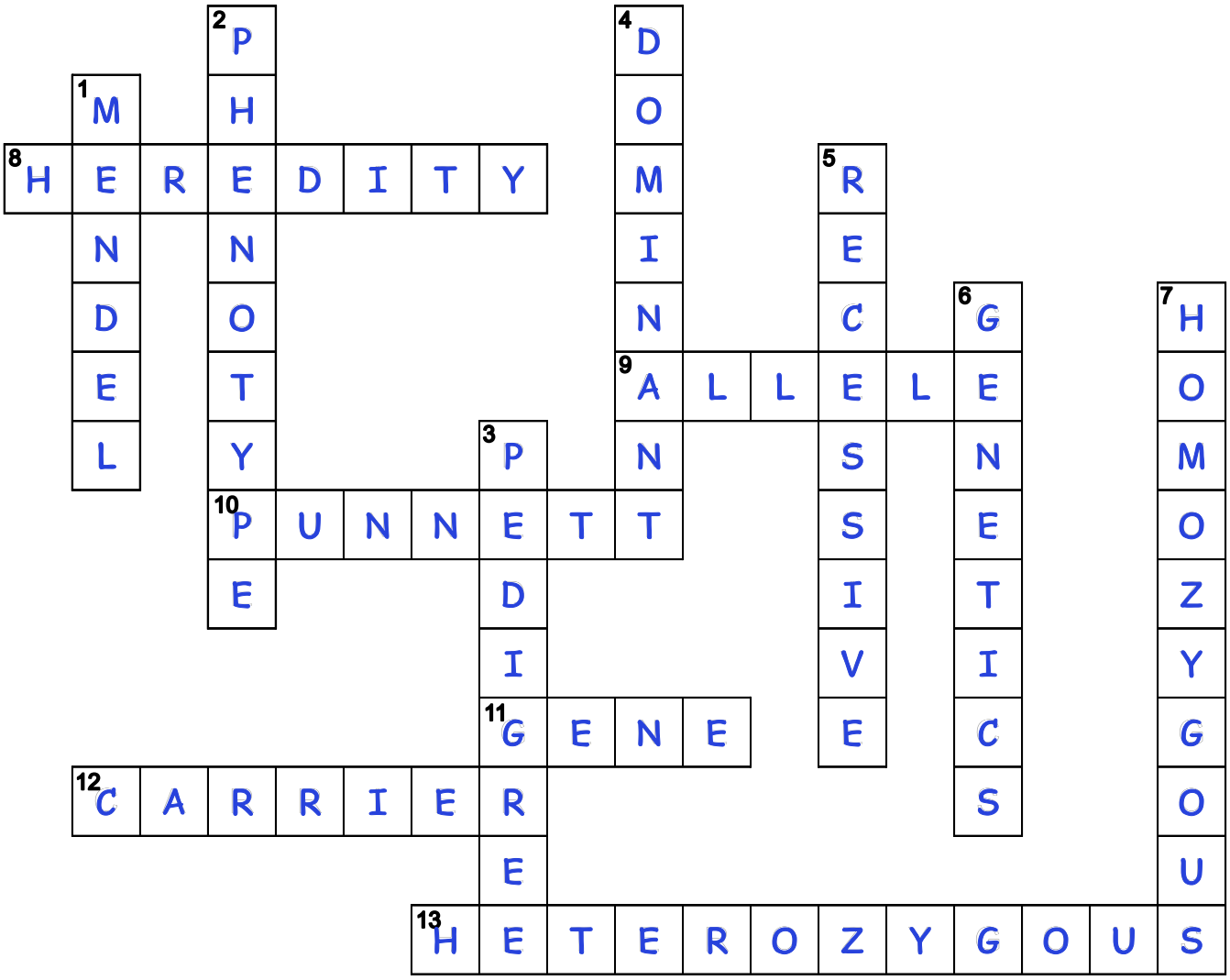
Heredity Word Search

There are a lot of new words to learn when studying biology. Repetition is the best way to learn them, and word games can be part of that! Find each of the hidden words in the word-search. The words can run in any direction: horizontal or diagonal, and the letters might go left to right or right to left!

GENE	RECESSIVE	CARRIER
ALLELE	PHENOTYPE	PROBABILITY
HOMOZYGOUS	GENOTYPE	HEREDITY
HETEROZYGOUS	CODOMINANCE	OFFSPRING
PUNNETTSQUARE	PEDIGREE	TRAIT
DOMINANT	HYBRID	



Heredity Crossword Puzzle

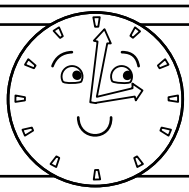


VERTICAL Words

1. What is the name of the father of genetics?
2. What is the term for an organism's physical appearance or visible traits?
3. The name for a chart of the ancestry or heritage of an individual.
4. A trait that will appear in the offspring if one of the parents contributes an allele for it.
5. A trait that will only appear in the offspring if both parents contribute an allele for it.
6. The scientific study of heredity.
7. The term for the condition where both copies of the allele are the same.

HORIZONTAL Words

8. The passing of traits from parents to offspring.
9. The term for a possible form of the gene.
10. A type of square used to keep track of the possible combination of alleles that can result from a cross.
11. A segment of DNA on a chromosome that codes for a specific trait.
12. A person who has one recessive allele for a trait and one dominant allele, but does not have the trait.
13. The term for the condition where there are two different alleles for a trait.



Quiz Time!

ANSWER THE QUESTIONS TO SEE WHAT YOU LEARNED ABOUT HEREDITY!

1. Which statement is true?
   - A. Members of the same species must be approximately the same size.
   - B. Members of the same species can breed with each other and produce offspring.
   - C. Scientists always agree on whether animals are in the same species.
   - D. Only animals have species.

2. Which type of reproduction will result in the most genetic diversity?
   - A. Fragmentation
   - B. Binary fission
   - C. Vegetative propagation
   - D. Spore formation
   - E. Sexual reproduction

3. Every trait is controlled by a single gene, and each gene is determined by two alleles.
   - A. True
   - B. False

4. Select each true statement below.
   - A. A dominant trait can skip a generation.
   - B. A recessive trait can skip a generation.
   - C. When two parents share the same genotype, their offspring will share the same genotype.
   - D. When two parents share the same phenotype, their offspring will share the same phenotype.

5. What does the notation BB mean to a geneticist?
   - A. Two dominant alleles
   - B. Two recessive alleles
   - C. At least one dominant allele
   - D. One dominant and one recessive allele

6. If a homozygous black guinea pig (BB) is crossed with a homozygous white guinea pig (bb), what is the probability that an offspring will have black fur?
   - A. 0%
   - B. 25%
   - C. 50%
   - D. 75%
   - E. 100%

7. If an organism is homozygous dominant for a trait that follows Mendelian inheritance patterns, which of the following must be true?
   - A. Its offspring will also have a homozygous genotype.
   - B. Its offspring will also have a heterozygous genotype.
   - C. Its offspring will exhibit the dominant phenotype for the trait.
   - D. The organism's parent(s) also had a homozygous genotype for the trait.
   - E. None of the above

8. Select each true statement below.
   - A. If you know an organism's genotype for a trait, then you also know its phenotype.
   - B. If you know an organism's phenotype for a trait, then you also know its genotype.
   - C. A parent always has the same genotype as its offspring.
   - D. A parent always has the same phenotype as its offspring.

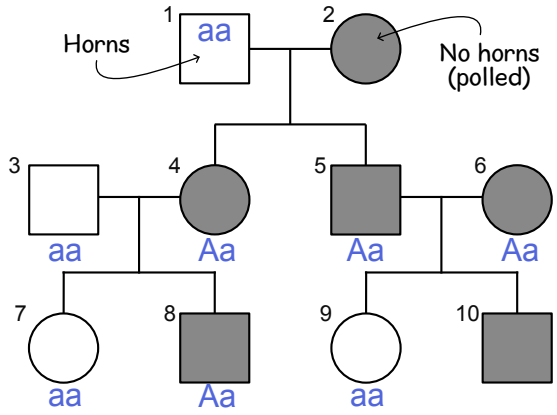
9. An organism that has two different alleles for a single trait is said to be heterozygous for that trait.

10. An organism has a phenotype for a dominant trait while some of its offspring have the phenotype for the recessive trait. What can we conclude about this organism?
    - A. It is heterozygous for the trait.
    - B. It is homozygous dominant for the trait.
    - C. It is homozygous recessive for the trait.
    - D. There is not enough information to tell.

11. True or False: all alleles are either dominant or recessive.
    - A. True
    - B. False

12. What is a Mendelian trait?
    - A. A trait that involves alleles
    - B. A trait that is passed down by dominant and recessive alleles of one gene
    - C. A trait where different alleles are equally and independently expressed
    - D. A trait exhibited by pea plants

Below is a pedigree chart for tracking **hornless cattle**, a Mendelian trait. Cattle without horns are called *polled* cattle and are usually viewed as more desirable than cattle with horns. Each of the cattle is numbered for reference.



13 Is the hornless trait (polling) a dominant or recessive trait in cattle? Explain how you know.

Polling is dominant. Individuals 5 and 6 have the trait, but 9 doesn't. If polled cattle is a recessive trait, then ALL of the offspring from two polled cattle would be polled. If polled cattle is a dominant trait, then two polled cattle can have a calf with horns. This latter case is what we observe in the pedigree.

14 We can assign the alleles A and a to the trait "no horns" exhibited in the pedigree chart. In that case, what is the specific meaning of both A and a?

"A" is the allele for the gene for no horns or polling. "a" is the allele for horns.

15 Label each member of the pedigree chart whose genotype can be fully identified. Are there any that you can't determine? Explain.

The genotype for 1, 3, 7, and 9 is aa because they don't have the trait of polling.
The genotype for 4, 5, 6, and 8 is Aa.
2 and 10 can't be determined. They could be either AA or Aa.

16 List the numbers of each individual that has horns in the pedigree above:

1, 3, 7, and 9 have horns.

17 List the numbers of the individuals that are heterozygous in the pedigree above:

4, 5, 6, and 8 are heterozygous (carriers) for the "no horns" trait.

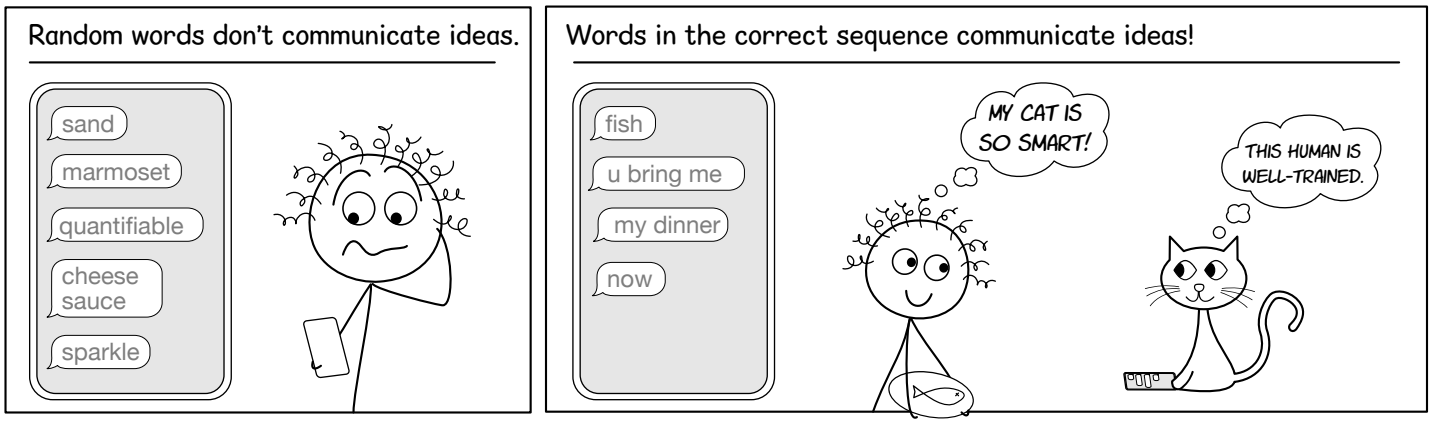
18 If we cross two cattle with horns, could the offspring have no horns? Explain.

No. Having horns is a recessive trait, so two cattle with horns will only pass on recessive alleles causing the offspring to also be recessive. The cross aa x aa can only produce aa.

19 If we cross two cattle with no horns, could the offspring have horns? Explain.

Yes. If both parents are heterozygous, then the cross Aa × Aa can produce aa. In that case, two cattle without horns would have offspring with horns.

The Genetic Code



FILL IN THE BLANKS USING THESE WORDS:

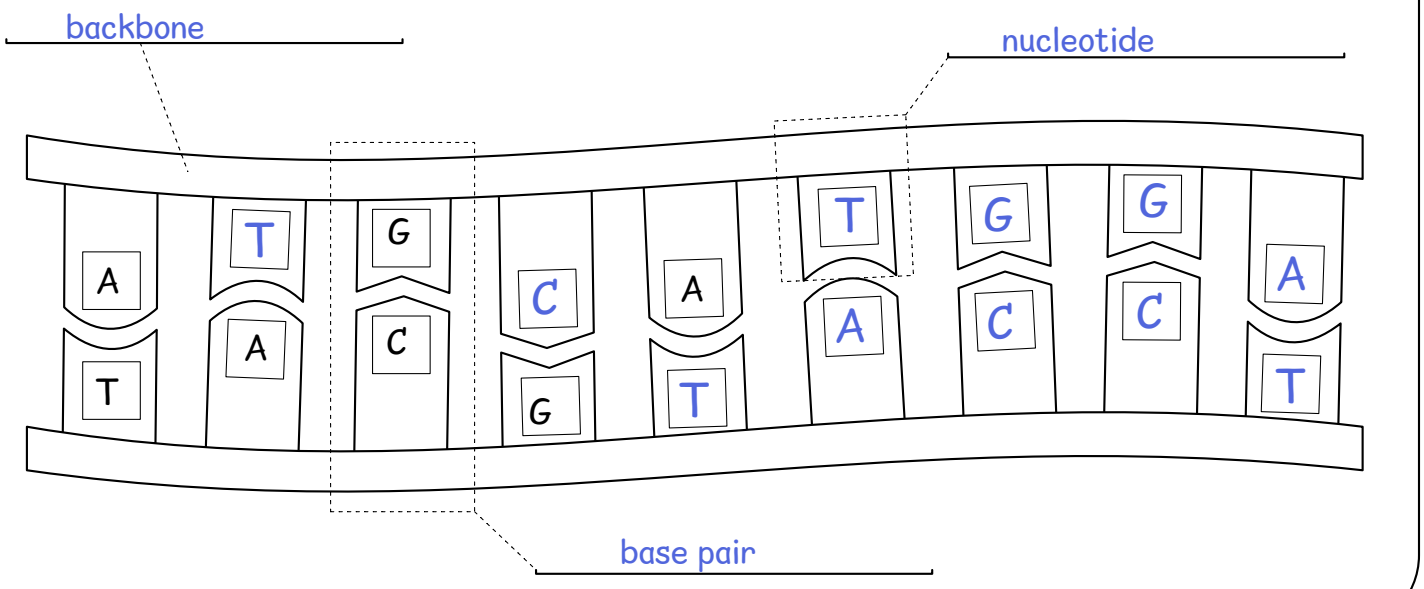
four thymine garage repeating genome trees

DNA stands for deoxyribonucleic acid. It's a long strand of repeating units which are called nucleotides. The complete sequence of DNA within an organism is called its genome.

There are four different nucleotides in DNA: adenine, thymine, guanine, and cytosine. They fit together to form pairs: **adenine** pairs with thymine, and **cytosine** pairs with **guanine**.

These pairings are what's being referred to when we read that the human genome contains approximately 3 billion **base pairs**. If you ever forget which base pairs with another, remember, "Apples grow on trees, park your car in a garage."

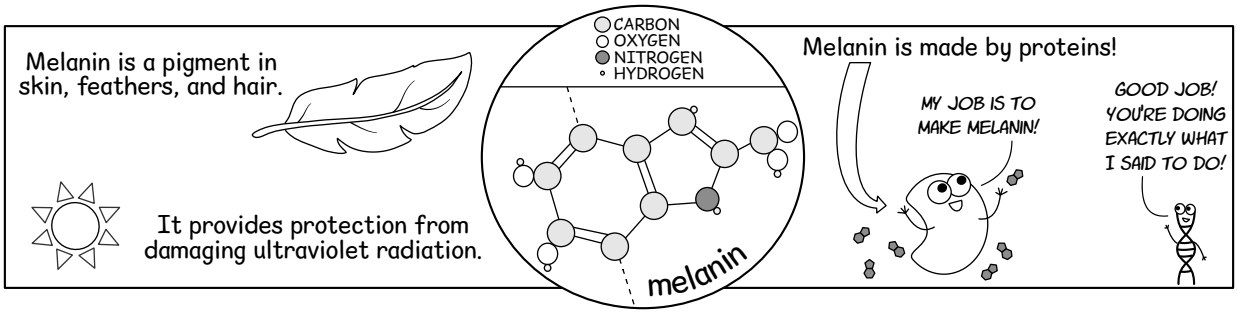
*LABEL THE **BASE PAIR**, **BACKBONE**, AND **NUCLEOTIDE** IN THIS CARTOON REPRESENTATION OF DNA. THEN WRITE **A**, **T**, **C**, OR **G** IN EACH BOX TO FILL IN THE CODE!*



What's a gene?

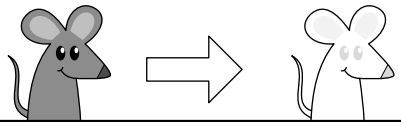
A gene is a specific sequence of DNA that contains information to make a gene product such as a protein. Most organisms have thousands of genes. There are approximately 20,000 genes in the human genome!

To better understand how a gene works, we'll look at two examples with genes that affect a pigment called melanin.



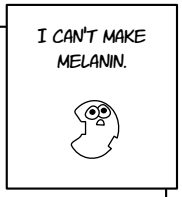
Albinism

Albino rats have completely white hair and pink eyes because they lack the pigment melanin. Blood vessels behind their transparent eyes are the reason for the pink color. The lack of pigment makes albinos much more sensitive to light. They sunburn easily, and their eyes can be damaged by bright lights.



The cause: a mutation in the DNA causes a protein that makes melanin to stop working.

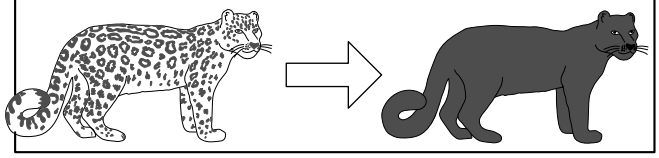
Why would this result in a recessive trait?



Any gene that codes for a working copy of the enzyme will produce melanin and the pigment will be visible in the phenotype. A lack of melanin can only happen when there are two defective genes.

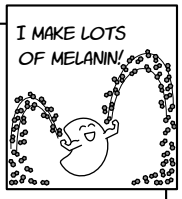
Melanism

Black panthers are actually leopards with melanism. The extra pigment turns their coat completely black, which is not a disadvantage when hunting prey at night! Examples of melanism have been found in many different mammals and reptiles. In each case, the skin, feathers, or fur of the animal is completely black due to the extra pigment.



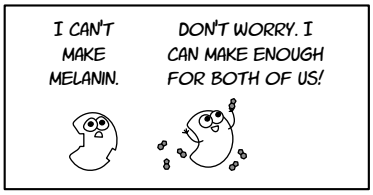
The cause: a mutation in the DNA causes a protein that makes melanin to work overtime!

Why would this result in a dominant trait?

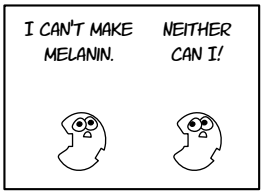


If there is one working copy of the gene, the result will be an over-abundance of melanin pigment.

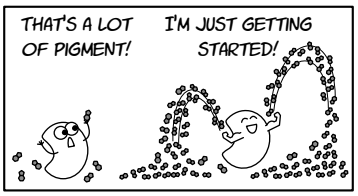
Write the correct phenotype below the cartoon representing each genotype. Possible phenotypes include albino, melanistic, or wild type (average melanin levels).*



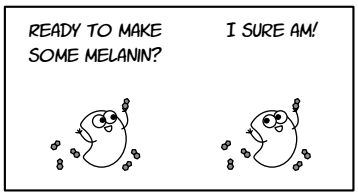
wild type



albino



melanistic



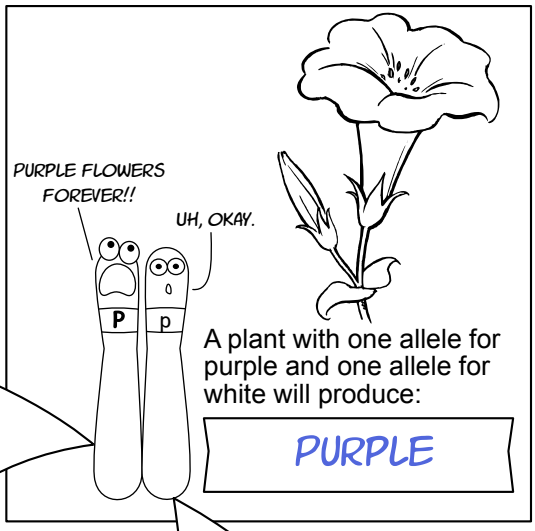
wild type

This example is over-simplified for educational purposes. While melanism in jaguars is a dominant trait, in other animals melanism is often recessive! There isn't just one type of melanin, and there are multiple enzymes and pigments involved in the process. So in the real world, pigmentation is more complex than displayed here.

Flower Color in Mendel's Peas

Remember the example of flower color that Mendel observed, where purple was dominant and white was recessive? The "bossy" **P** allele is representing a piece of DNA that has instructions for an enzyme. The **P** enzyme makes the purple pigment in the flower. It's efficient and fast, and one copy can do just as good a job at making the flower purple as two copies. The recessive allele is representing a piece of DNA with a mutation that makes a non-functional enzyme. It can't make the purple pigment.

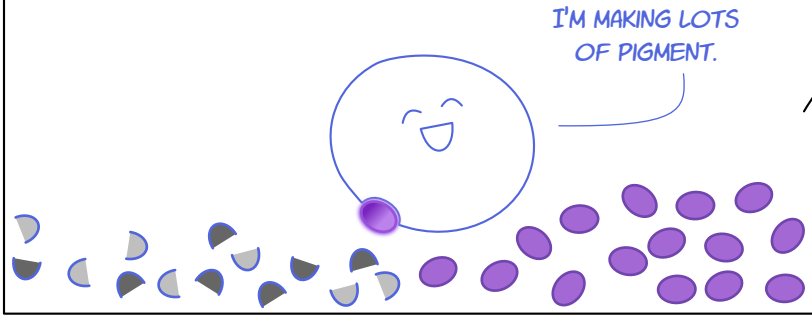
Draw pictures in the boxes below representing the working protein that makes purple pigment and the mutated protein that can't make the pigment:

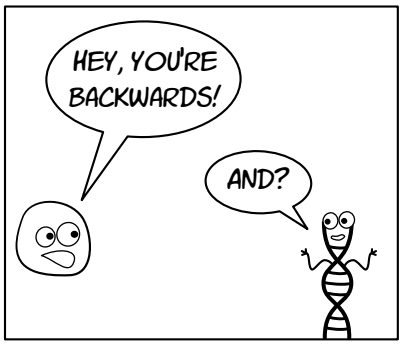


A plant with one allele for purple and one allele for white will produce:

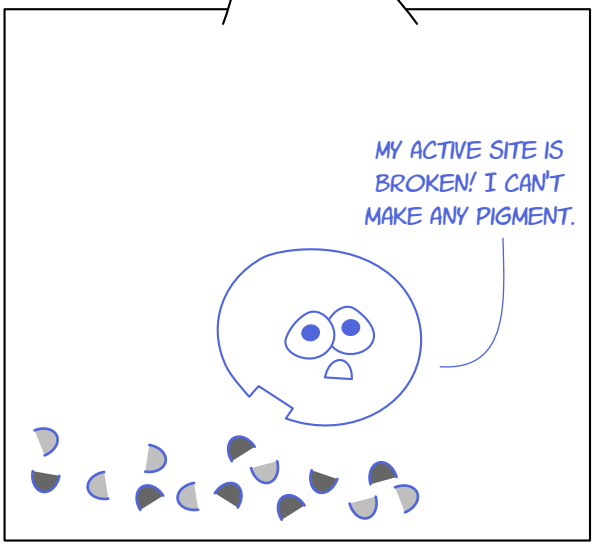
PURPLE

Drawings can be cartoonish and fun or more realistic. The main point is that one drawing shows an enzyme making lots of purple pigment, and the other shows an enzyme that cannot make pigment.



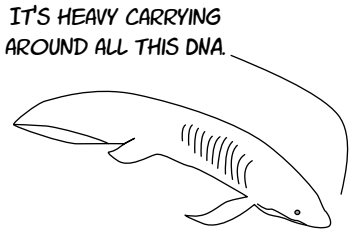


What did the clean DNA say to the dirty DNA?



ARE THESE FACT OR FICTION? *Write your verdict below each statement.*

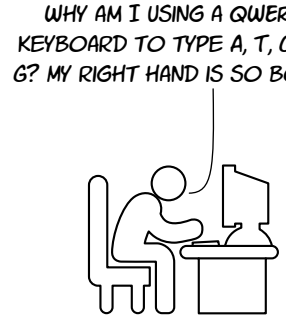
The Australian lungfish has the largest genome of any animal.



FACT - its genome has 43 billion base pairs!

Read more at: https://www.imp.ac.at/news/article/record-breaking-lungfish-genome/

If you type 8 hours a day at 60 words per minute, it would take approximately 2 years to type the human genome!



FICTION - it would take 50 years!

Read more at https://www.yourgenome.org/facts/what-is-a-genome

Identical twins have the same DNA!

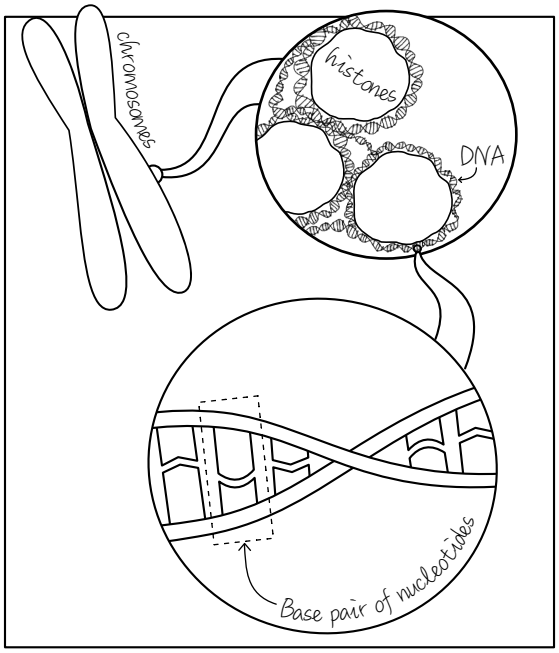
It all depends on what you mean by identical!

It can be argued to be FACT in that monozygotic twins come from a single cell. They will almost always have the same alleles or genes.

It can be argued to be FICTION because there can be mistakes in cell division early on in development that could cause twins to have different chromosomes (ex: one twin could be XY, the other XO). Also, as the twins age there will be a relatively small number of differences due to mutations, as well as epistatic changes to how the DNA is expressed. Even with identical genes, twins will have measurable physical differences between their DNA.

For most cases and for the most common use of the word "identical," we think the best answer is "FACT." This is one reason why identical twins have been and continue to be an important part of in understanding the role genetics plays in different diseases and traits.

Chromosomes



FILL IN THE BLANKS USING THESE WORDS:

number histones chromosome fly 23 karyotype humans

A chromosome is a strand of DNA wrapped around proteins called histones. Each member of the same species will have the same number of chromosomes, but between different species, the number and size of chromosomes can be very different. A fruit fly has 8 chromosomes. The black mulberry tree has more than 300! Humans have 23 pairs of chromosomes for a total of 46 chromosomes. A karyotype is a picture of the complete set of chromosomes that have been sorted by length.

Draw lines to match each organism with its karyotype:

Mulberry Tree	Wheat	Fruit Fly	Human	Cat	Dog
2 copies of 39 chromosomes Total: 78	6 copies of 7 chromosomes Total: 42	2 copies of 19 chromosomes Total: 38	22 copies of 14 chromosomes Total: 308	2 copies of 23 chromosomes Total: 46	2 copies of 4 chromosomes Total: 8

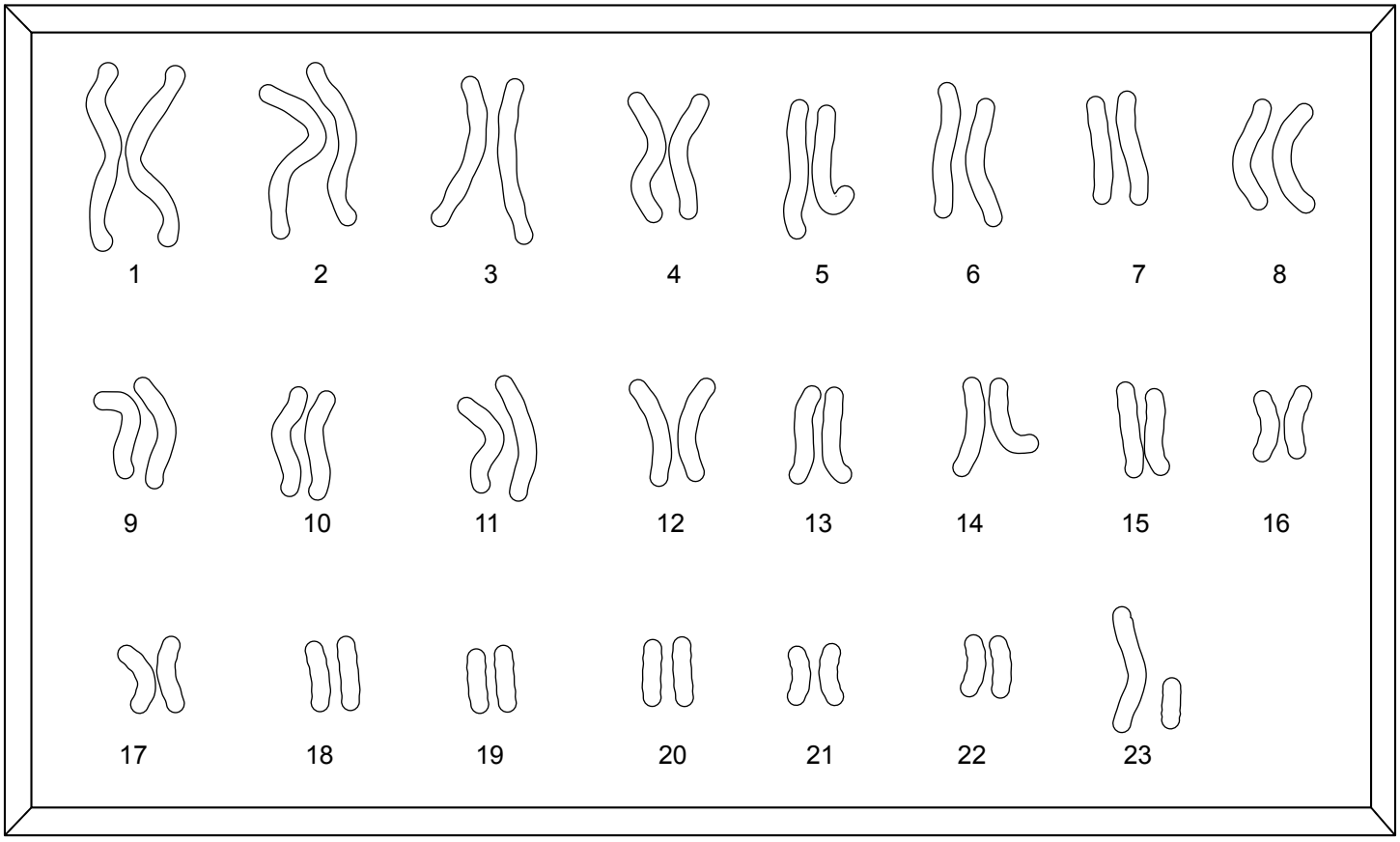
The human genome

There are 23 pairs of chromosomes in the human genome, but what do they all do? Lots of things! Remember each chromosome contains *hundreds to thousands* of different genes. Having only one chromosome or having three copies of a chromosome (trisomy) is usually fatal. There are only a few chromosomes where an extra copy can be tolerated.

Vocabulary review! Fill in the blanks below with the correct term:

The condition of having three copies of a chromosome is called:	Chromosomes contain both DNA and proteins. The proteins are called:	A sequence of DNA that contains information to make a product such as a protein is called:
trisomy	histones	a gene

Arranging chromosomes in a karyotype helps scientists organize them for further study. In the human karyotype, the chromosomes are arranged from longest to shortest, with the XY pair at the end.



Write the number of the corresponding chromosome next to each statement:

1. The longest chromosome in the human genome. It contains thousands of genes.
23. This pair of chromosomes determines biological sex.
21. Three copies of this chromosome causes Down Syndrome.
18. Three copies of this chromosome causes Trisomy 18.
22. It was thought to be the shortest human chromosome, but then chromosome 21 was discovered to be shorter!

Sex Determination

FILL IN THE BLANKS USING THESE WORDS:

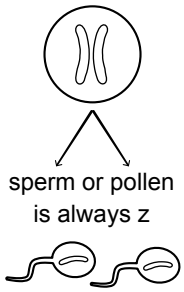
male 50 eyesight 900 females birds

Most organisms that reproduce sexually have two sexes: male and female. In humans, biological sex is determined by chromosome 23. Females have two copies of the X chromosome. The X chromosome is long and has about 900 genes, including important alleles for eyesight, blood clotting, hearing, and nerve and muscle function. The Y chromosome has about 50 genes, and their purpose is to start a cascade of hormone changes that cause the development of the male physical traits.

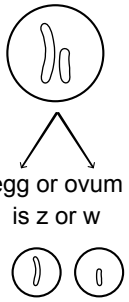
In birds, some fish, and most reptiles, the sex determination is different. Males have two copies of the same chromosome and females have two different sex chromosomes. This system is called the ZW system.

ZW system - birds, some fish, reptiles, and pistachio trees

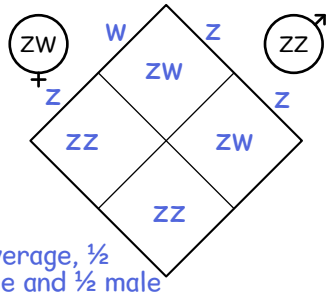
Male bird is ZZ



female bird is ZW



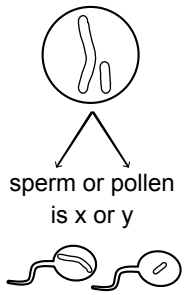
Fill out the Punnett square for ZW. On average, how many birds will be male, and how many will be female?



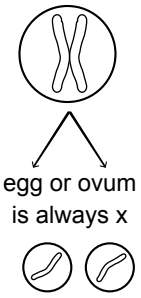
On average, ½ female and ½ male

XY system - mammals, some insects, guppies, and ginkgo trees

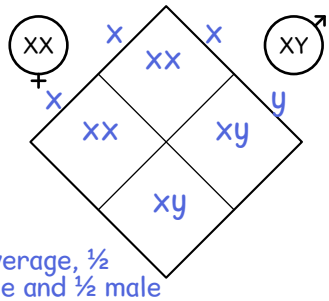
Male mammal is XY



female mammal is XX



Fill out the Punnett square for XY. On average, how many mammals will be male? How many will be female?

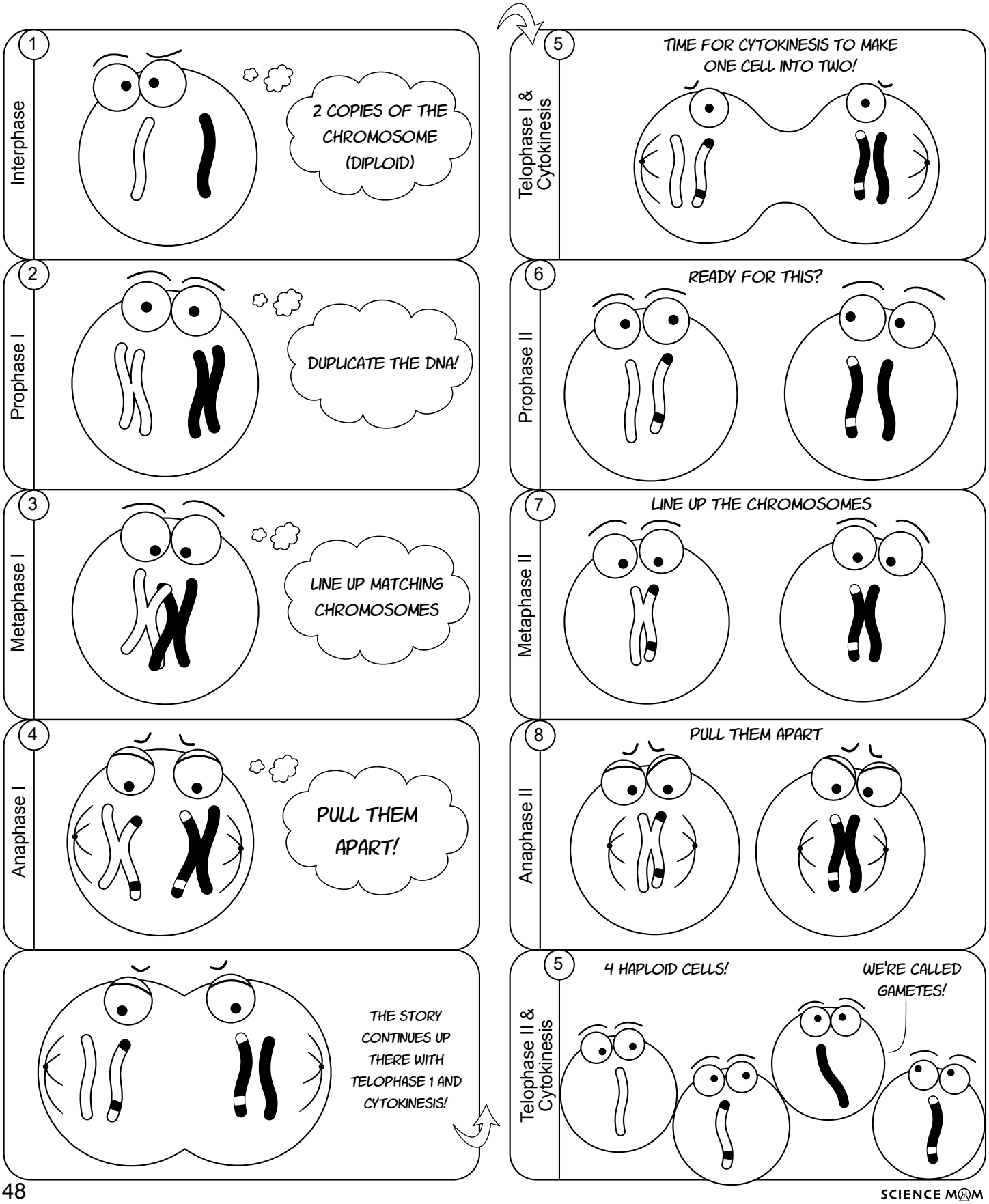


On average, ½ female and ½ male

Female	Male	Intersex	Klinefelter Syndrome	Turner syndrome
XX	**XY**	**XX** or **XY**	**XXY**	**X**
The individual has ovaries that produce eggs through meiosis.	The individual has testes that produce sperm through meiosis.	Physical characteristics don't match traditional definition of male or female. Observed phenotype is sometimes opposite what would be expected from the genotype.	Physical characteristics are usually male. Individual is often infertile. Occurs in about 1 in 1,000 male births.	Physical characteristics are female. Individual is infertile. Higher risk of heart disease, diabetes, and thyroid disorders.

MEIOSIS

Meiosis is a special type of cell division used to produce **gametes**. Gametes have ½ the number of chromosomes as their parent cell and are called **haploid** cells. Combining gametes from two different individuals increases genetic diversity, which is one of the main advantages in sexual reproduction.

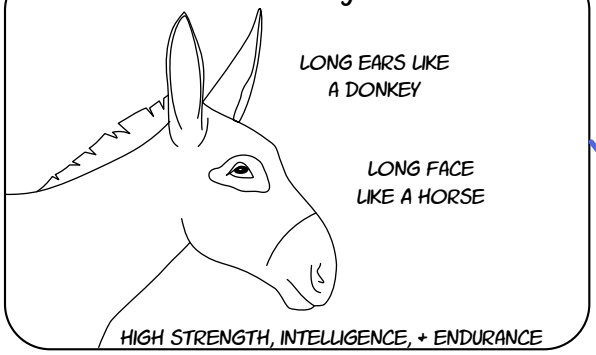


Meiosis Mysteries

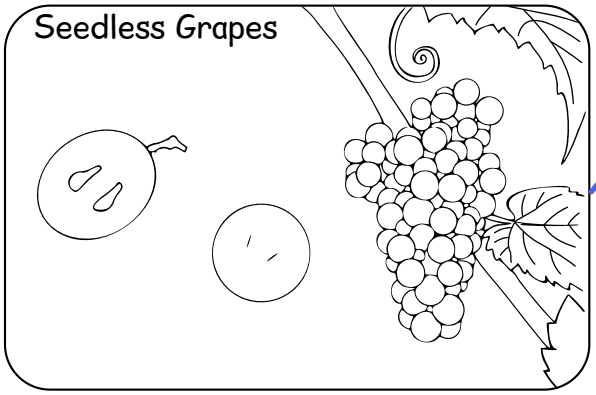
Seedless watermelons, bananas, and mules all have something in common. They can't reproduce!* Match each organism with the corresponding explanation for why it is sterile or infertile.

**The domestic banana (Cavendish) can reproduce asexually through vegetative propagation but does not have seeds and cannot undergo sexual reproduction. There are hundreds of different varieties of bananas. Most of the wild bananas do produce seeds.*

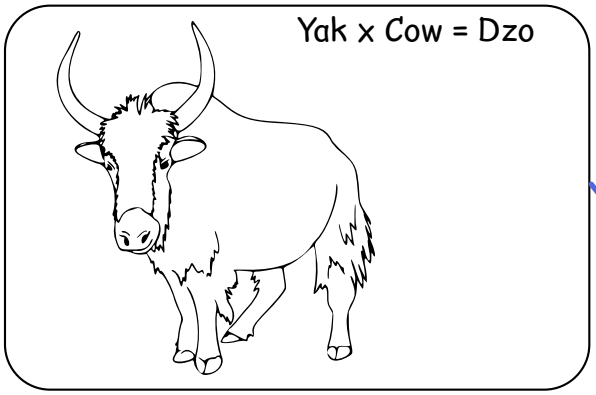
Horse x Donkey = Mule



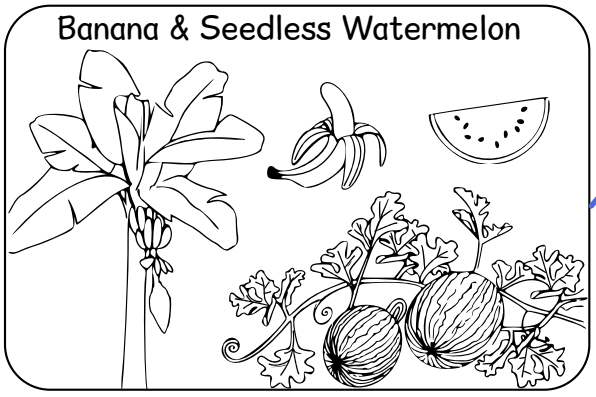
Seedless Grapes



Yak x Cow = Dzo



Banana & Seedless Watermelon



A mutation stopped meiosis from working. People first noticed this mutation several hundred years ago. They liked the result and have been nurturing similar mutations ever since!

One parent has 64 chromosomes. The other parent has 62. The resulting organism has an odd number of chromosomes (63), which causes problems in meiosis.

One parent is diploid (2 copies of each chromosome) and the other parent is tetraploid (4 copies of each chromosome). The resulting triploid organism is infertile or sterile.

Both of the parents have 60 chromosomes. Female offspring are fertile, but males are sterile because of some interesting and complex epigenetic changes to meiosis.

Proteins!

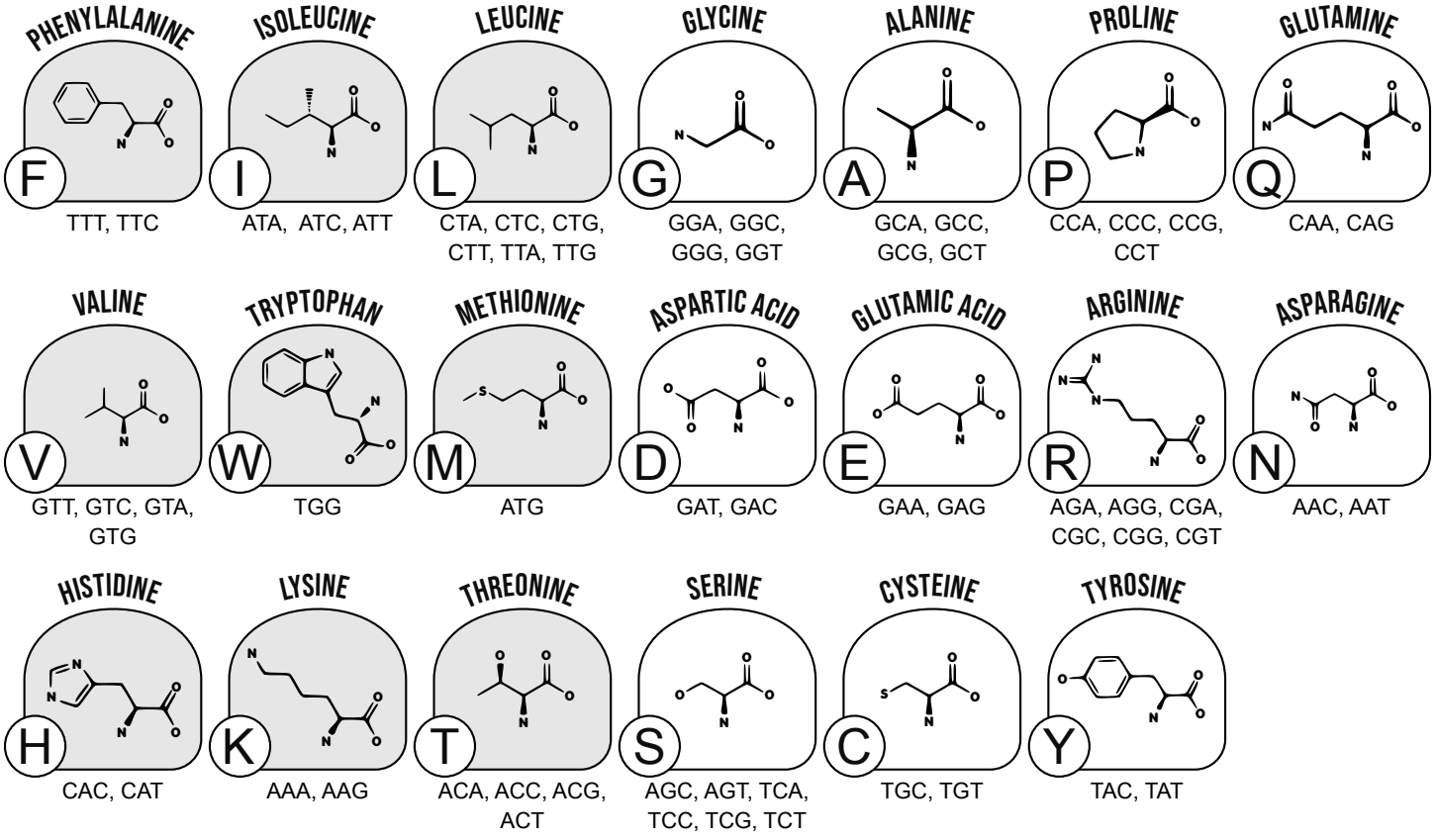
The molecules that run things in the cell

FILL IN THE BLANKS USING THESE WORDS:

acids	proteins	muscles	duplicating
traits	make	amino	structural

Almost all of the traits in animals and plants are ultimately controlled by proteins. Proteins can be enzymes that make things like pigments or perform tasks like duplicating DNA. Proteins can also be structural; they're the main ingredients in the muscles, skin, and bones of all animals. All proteins are polymers made of amino acids.

Below are the 20 amino acids used to make proteins. Each amino acid has a 1-letter abbreviation.
The 9 dietary essential amino acids are shaded grey.



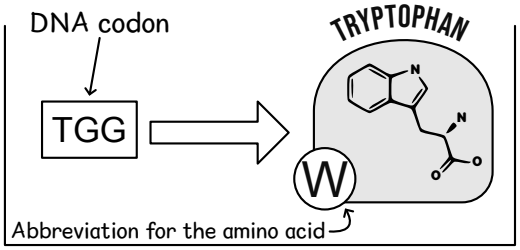
Label Hunt: *Check some food labels. Can you can find amino acids listed in the ingredients?*

FOOD ITEM:	AMINO ACID IT CONTAINS:
Sugar-free gum	phenylalanine
Diet soda	phenylalanine

Hint: check sugar-free products such as chewing gum. You'll find one!

A Code of Triplets

A **codon** is a sequence of 3 nucleotides such as adenine, thymine, and cytosine (ATC). Each codon represents an amino acid or an instruction like “start” or “stop.” On the previous page, you can see the amino acid tryptophan is specified by the triplet TGG and abbreviated with the letter W. Some amino acids can be specified by multiple codons. For example, both AAA and AAG code for the amino acid lysine.



Can you decipher a secret message from the letters below?

...YRTQUNYOUCANEATPIEANYDAYMMETBK...

It helps if we break up the phrase into triplets:

...YRT QUN YOU CAN EAT PIE ANY DAY MME TBK...

Now what happens if we shift our starting position by just one letter?

...RTQ UNY OUC ANE ATP IEA NYD AYM MET BK...

The secret message is lost!

The genetic code is similar. Adding or taking away one base pair can have disastrous effects!

DNA Decipher Challenge

Break up the letters below into groups of three nucleotides (codons). Match each codon with the abbreviation letter of the associated amino acid by referring to the previous page. Can you finish deciphering the secret message? Use the chart on the previous page OR use the DNA decoder wheel from the appendix.

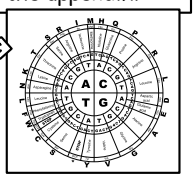
AGTTGCATTGAAAACTGTGAGATCTCAATAAACATGTATGATAACGCG

S C I E N C E I S I N M Y D N A

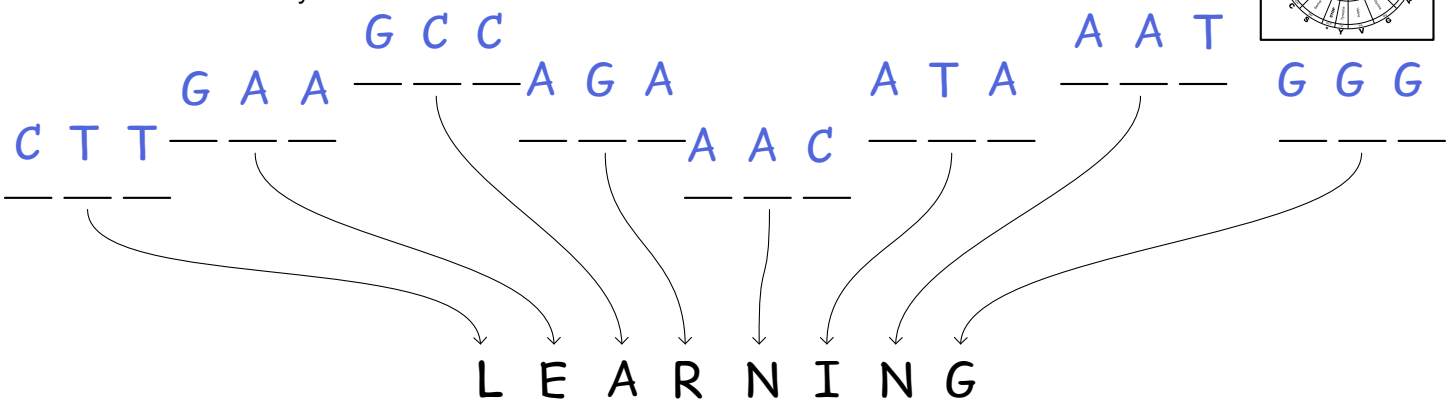
What did one chromosome say to the other? Do these genes look good on me?

DNA Encryption Challenge

Tip: For faster code deciphering, use the codon wheel in the appendix!



Write out the DNA codons that will code for the word “LEARNING.” Use the abbreviation letters for the amino acids. For example, “L” can be coded for by “CTC” or “CTT.” Then give the sequence to someone and see if they can decode it!

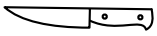


There are multiple correct answers. The letters below show just one possible code.

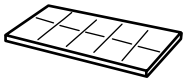
Hands-on Science Project

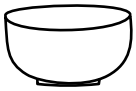
GUMMY WORM KARYOTYPES

MATERIALS:


knife or scissors


gummy worms


chocolate

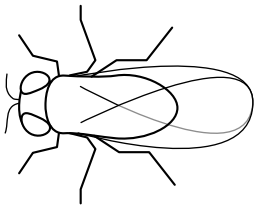

Small bowl for melting chocolate

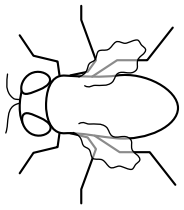
Make a fruit fly karyotype

The common fruit fly is used as a model organism for biological research because it has a quick life cycle and a relatively small genome with just 4 pairs of chromosomes.

The first pair of chromosomes in the fruit fly karyotype is the X/Y pair that determines biological sex or the female/male trait. The other chromosomes are named 2, 3, and 4. But chromosome 4 is so small that it only has a handful of genes compared to the others!

Fruit fly with full-sized wings





Flightless fly with vestigial wings

SPECIES NAME: *Drosophila melanogaster*
GENOME SIZE: 0.139 billion base pairs (or 139 million base pairs)
NUMBER OF GENES: 14,000
NUMBER OF CHROMOSOME PAIRS: 4

Instructions:

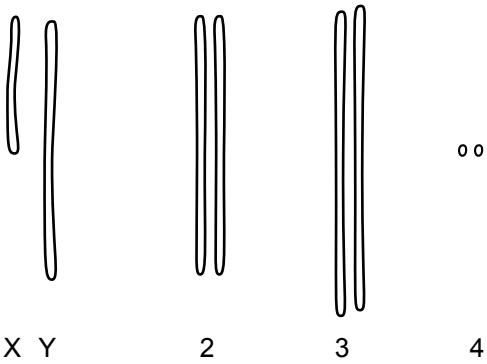
1. Using the picture on the right as a guide, cut the gummy worms to the appropriate relative lengths. Make multiple copies of each chromosome type.

2. Carefully melt chocolate in a microwave, and dip about half of chromosomes 2, 3, and X into chocolate. It is not necessary to coat chromosome 4 or the Y chromosome with chocolate since we will not be evaluating genes on those chromosomes. After dipping, let the gummy worms cool.

3. Arrange two of each chromosome type on paper to make a fruit fly karyotype. If the chromosome is dipped in chocolate, this indicates that it contains a dominant trait. If the chromosome is not dipped in chocolate, this indicates a recessive trait.

4. See if another person can use the key below to decipher the traits that your gummy worm karyotype represents! Then color in the fly correctly.

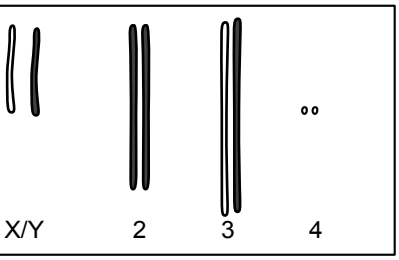
5. Rearrange the gummy worms to create another karyotype. Repeat the exercise again.



Karyotype Key

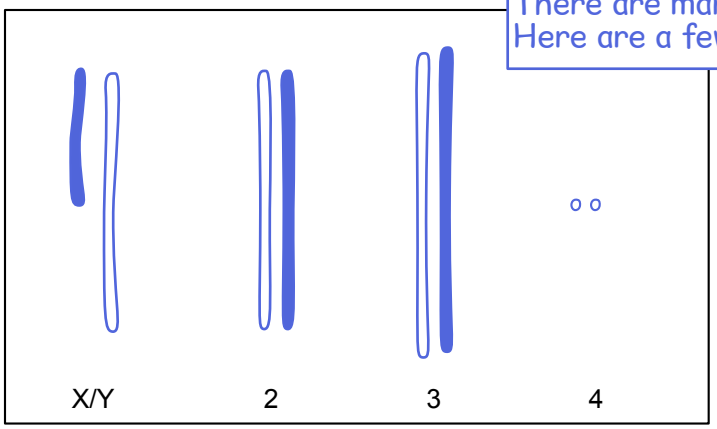
XX chromosomes = female
XY chromosome pair = male
Dominant trait in X = red eyes
Recessive trait in X = white eyes
Dominant trait in 2 = functional wings
Recessive trait in 2 = miniature wings (flightless)
Dominant trait in 3 = yellow body color
Recessive trait in 3 = ebony or black body color

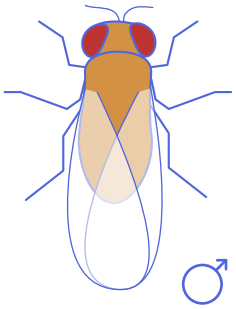
FOR EXAMPLE:

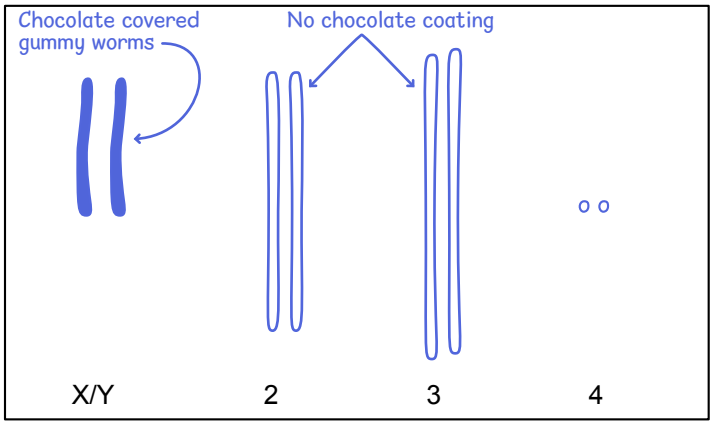


This karyotype matches a female red-eyed, flying, yellow fruit fly.

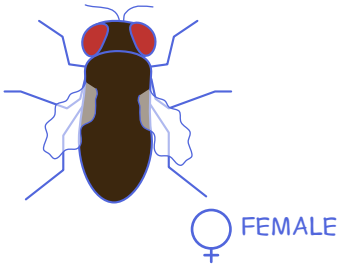
There are many different ways to arrange a fruit fly puzzle!
Here are a few examples of potential karyotypes and answers.

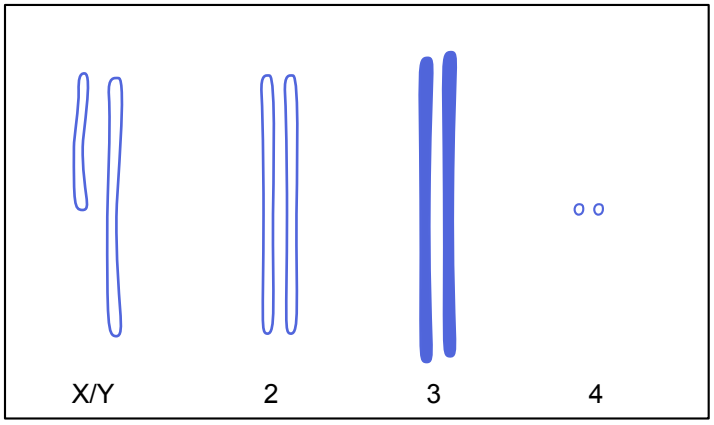




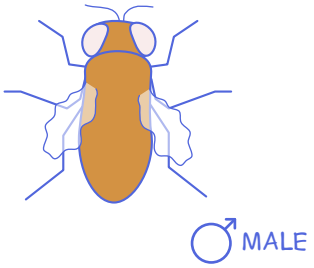


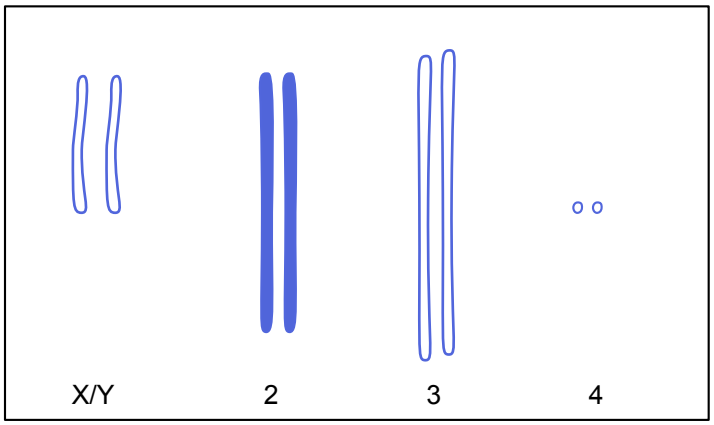
Color and describe the fruit fly that matches this karyotype!
Don't forget to draw in the wings.



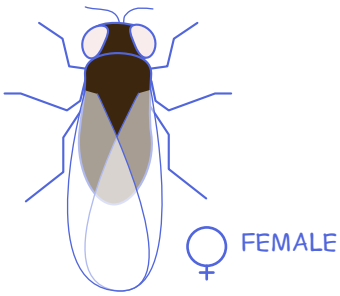


Color and describe the fruit fly that matches this karyotype!
Don't forget to draw in the wings.





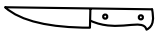
Color and describe the fruit fly that matches this karyotype!
Don't forget to draw in the wings.



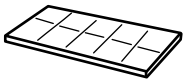
Hands-on Science Project

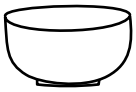
GUMMY WORM MEIOSIS

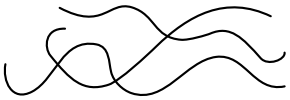
MATERIALS:


knife or scissors


gummy worms

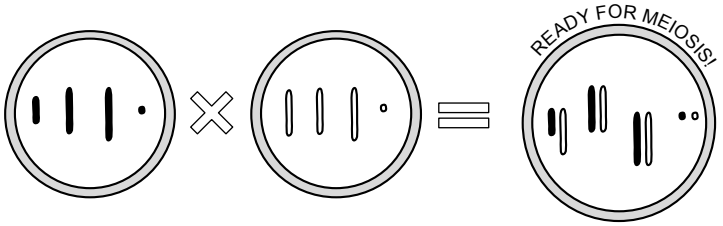

chocolate


Small bowl for melting chocolate


Cooked spaghetti noodles or yarn for the spindle fibers


Jelly beans or other cylindrical objects to represent centrioles

*In this activity, the cell inherited **chocolate-covered** gummy worm chromosomes from one parent and **non-chocolate** chromosomes from the other parent.*



Meiosis with gummy worms

1. Interphase: Arrange 4 pairs of gummy worms on a plate just as in the karyotype activity. One set of gummy chromosomes should be covered in chocolate. The others should be uncovered. Prepare for duplication by making sure you have an exact match for each gummy worm on the plate.

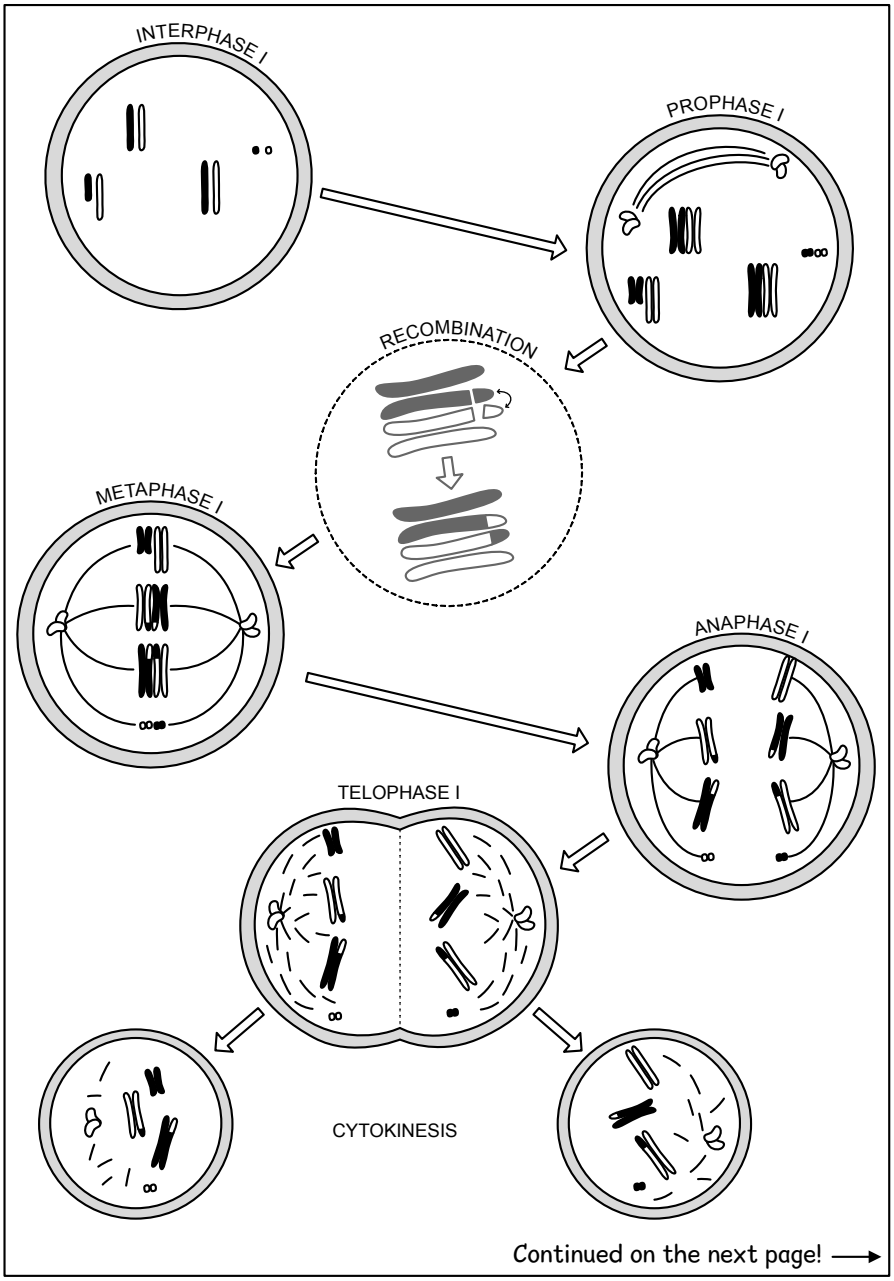
2. Prophase I: When duplicated, the identical chromosomes are linked together and called sister chromatids. Represent this step by adding an identical gummy worm to each gummy worm on the plate.

3. Recombination: During prophase one, the matching chromosomes (homologous pairs) come together to form a tetrad. While they're together, they swap pieces of DNA! With your knife, cut pieces from two matching chromatids and trade them!

4. Metaphase I: Line up all of the tetrads in a straight line and lay out the yarn or noodles and candies to represent the spindle fibers and centrioles!

5. Anaphase I: The spindle fibers pull the homologous chromosomes apart. Each side should have 8 gummy worms in total.

6. Telophase I and cytokinesis: The cell splits to become two cells, each with 8 gummy worm pieces in total. Notice that now there is more variety with the chromosomes due to recombination.



Continued on the next page! ⟶

7. Prophase II: A new set of spindle fibers are prepared.

8. Metaphase II: The chromosomes line up in a straight line. Centrioles form and spindle fibers attach.

9. Anaphase II: The spindle fibers pull the sister chromatids apart to opposite sides of the cell.

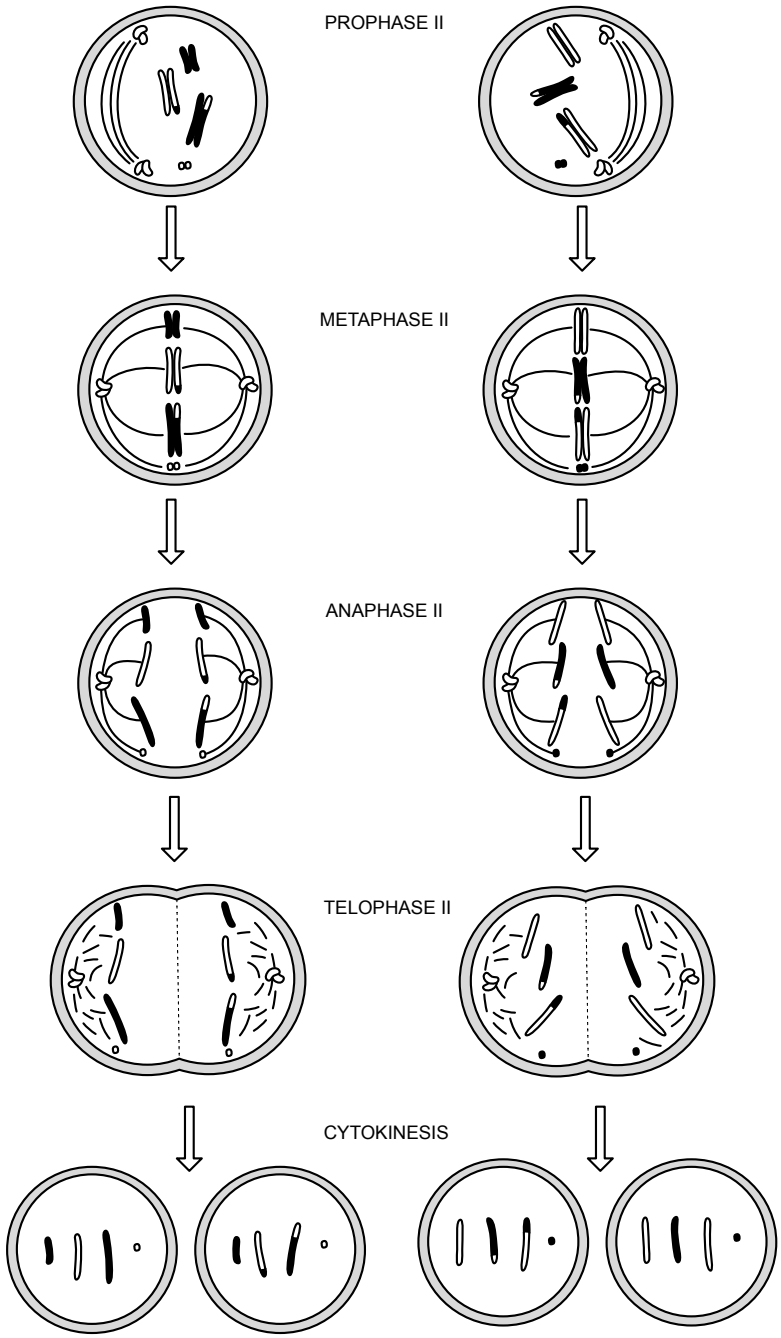
10. Telophase II and cytokinesis: Each cell splits into two cells, with one copy of each chromosome. Notice how the cells produced (gametes) have half the number of chromosomes as the starting cell.

Why do the gametes have half the number of chromosomes? What is the purpose?

The gametic cells are haploid (½ the number of chromosomes) so that they can combine with another haploid cell to produce a new diploid cell.The purpose is to increase genetic diversity!

Can any of the 4 daughter cells or gametes produced by meiosis be identical? Why or why not?

The daughter cells of a single mitotic division will not be identical. Recombination and the random orientation of the chromosomes in metaphase I and II create a high amount of diversity in the daughter cells/gametes.



What happens if, during anaphase II, a spindle fiber pulls two chromatids to one side instead of pulling the chromatids apart?

One of the gametes will have an extra chromosome. During the reproductive process, this cell would result in a trisomy (3 copies of one chromosome). In most cases, trisomy is fatal. There are only a few chromosomes where a trisomy can develop and then be born.

The Genetics of PKU

Most people have an enzyme that can change the amino acid phenylalanine into tyrosine. But some people inherit a rare genetic disease called phenylketonuria or PKU. This disease is recessive. It's caused by a mutation that codes for a non-functional copy of an enzyme called phenylalanine hydroxylase. The working enzyme converts the amino acid phenylalanine to tyrosine. If phenylalanine cannot be converted, it can build up to toxic levels in the blood and cause permanent damage to nerve cells.

PKU *GALACTOSEMIA* *HYPOTHYROIDISM* *MAPLE SYRUP DISEASE* *SICKLE CELL ANEMIA*

BEFORE NEWBORN SCREENING
A person born with PKU was healthy at birth, but as they grew up they developed permanent damage to brain tissue and experienced intellectual disability, psychiatric disorders, and seizures.

AFTER NEWBORN SCREENING
A person born with PKU is put on a special low-protein diet that restricts the amount of phenylalanine. As long as the diet is followed, they do not experience the negative effects of PKU.

Some people think the mutations responsible for PKU originated in Europe. Does this data support or contradict that idea?

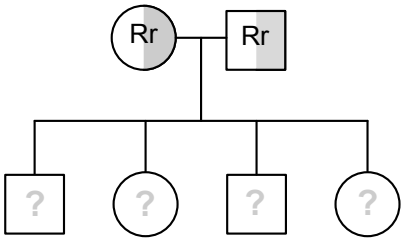
COUNTRY	*INCIDENCE OF PKU**
United States	*1 in 25,000*
Austria	*1 in 5,764*
Finland	*1 in 112,000*
France	*1 in 9,091*
Italy	*1 in 4,000*
Japan	*1 in 125,000*
Philippines	*1 in 116,006*
Thailand	*1 in 227,273*

☑ supports

☐ contradicts

** From The Genetic Landscape and Epidemiology of Phenylketonuria by Alicia Hillert et al. Published in the American Journal of Human Genetics. Vol 107, Aug 6, 2020.*

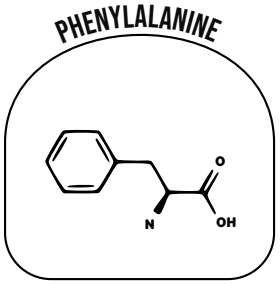
If both parents are carriers for PKU, what are the probabilities of their offspring experiencing the following outcomes?

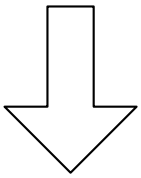


25 % CHANCE UNAFFECTED (RR)

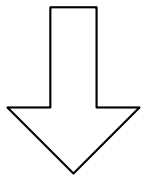
50 % CHANCE CARRIER (Rr)

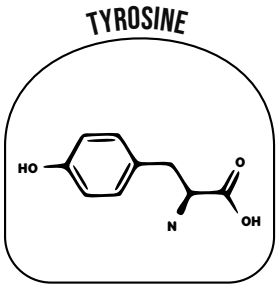
25 % CHANCE PKU (rr)

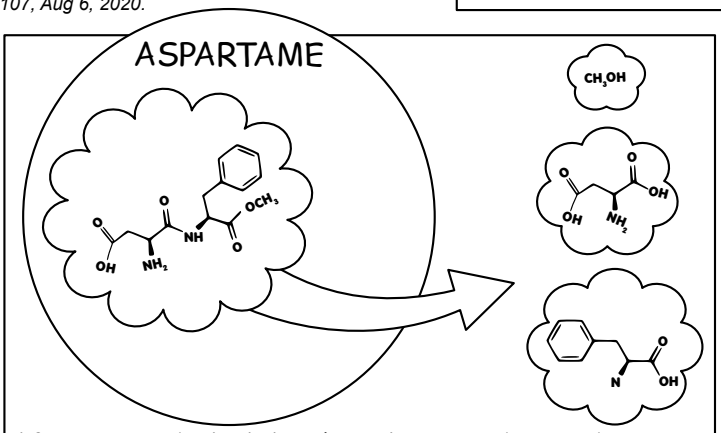




PHENYLALANINE HYDROXYLASE







After eating, the body breaks it down into these 3 things. Do you recognize the largest molecule?

Aspartame is an artificial sweetener that is 200 times sweeter than sucrose. Why are food products with aspartame required to contain a warning label about phenylalanine?

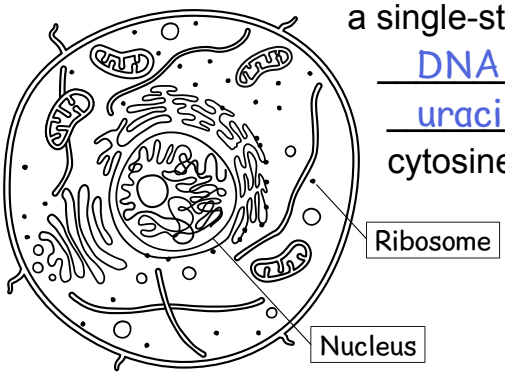
Because foods containing aspartame will be broken down into phenylalanine. High amounts of phenylalanine are dangerous to people with PKU. Because they cannot convert it into tyrosine, it can build up to toxic levels in the bloodstream.

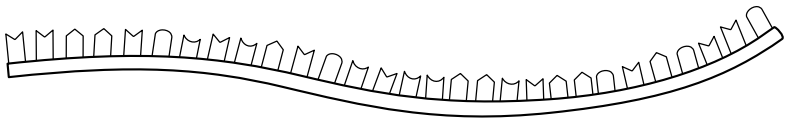
Transcription - from DNA to RNA

FILL IN THE BLANKS USING THESE WORDS:

membrane DNA adenine transported uracil

In human cells, DNA is kept in the nucleus. Because it is surrounded by the nuclear __membrane__, other parts of the cell (like ribosomes) can't access it directly. The information in DNA is __transported__ between the nucleus and the rest of the cell by a single-stranded molecule called RNA. RNA is very similar to __DNA__, but instead of thymine, it contains a nucleotide called __uracil__. The four units of RNA are __adenine__, uracil, cytosine, and guanine, or A,U,C, and G.





Translation

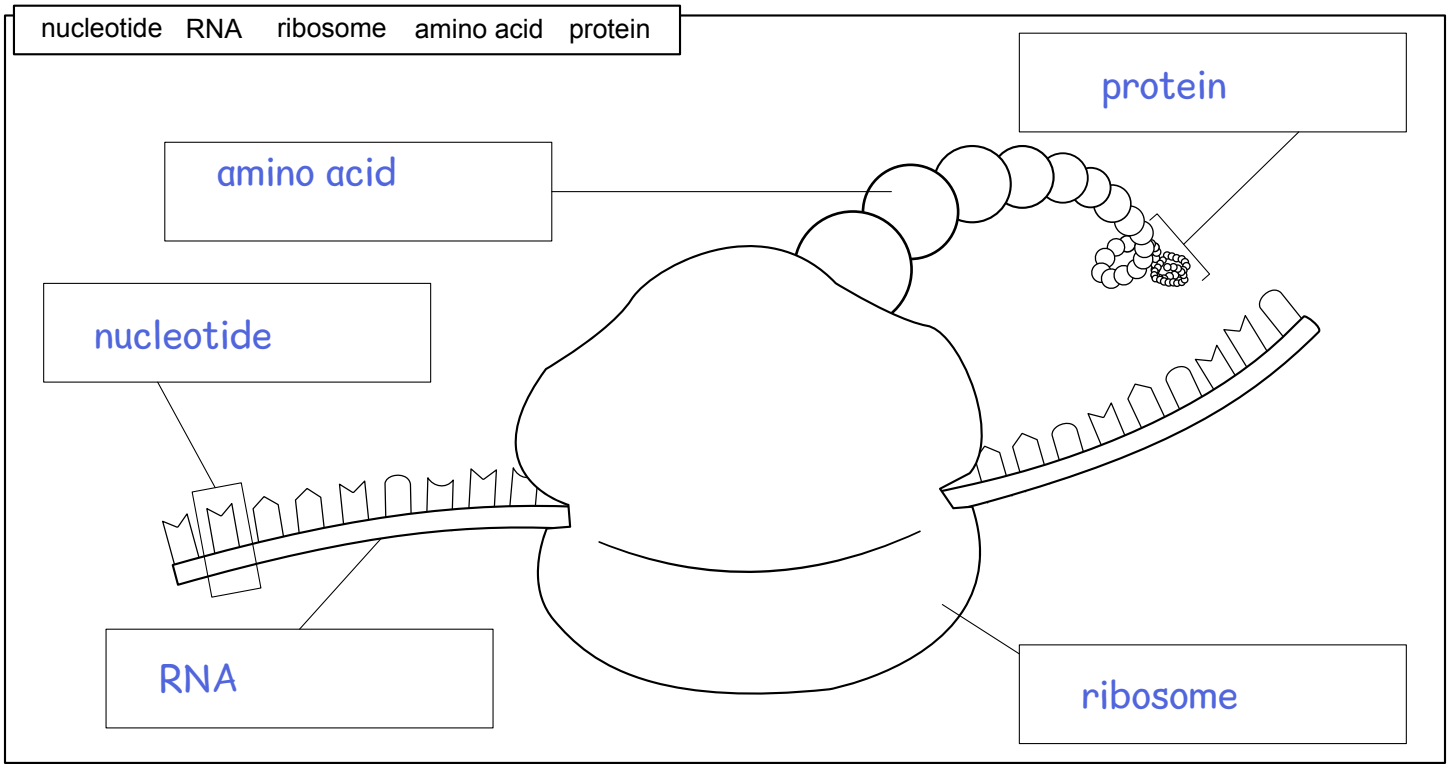
FILL IN THE BLANKS USING THESE WORDS:

translation RNA ribosomes codons protein

RNA molecules called mRNA are used by __ribosomes__ to make protein. The ribosome reads every three nucleotides from the strand of __RNA__ and matches them to an amino acid. These three-letter segments of RNA are called __codons__. For example, if the ribosome reads a codon of three guanines (GGG), it will add the amino acid glycine to the __protein__ it is making. Since the sequence of nucleotides is being translated into a sequence of amino acids, this process is called __translation__.

LABEL EACH BOX IN THE DRAWING BELOW USING THESE WORDS:

nucleotide RNA ribosome amino acid protein

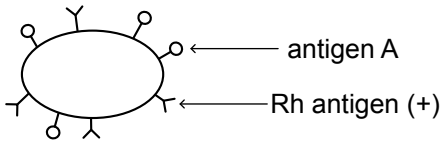


Blood Types

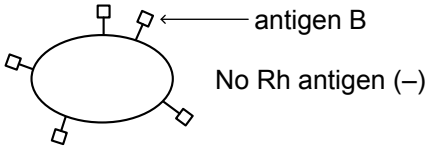
FILL IN THE BLANKS USING THESE WORDS:

recessive | codominant | type | proteins | antigens | AB

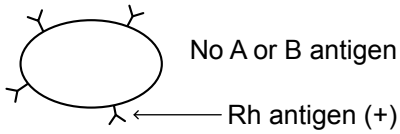
Blood Type A+



Blood Type B-



Blood Type O+



Red blood cells have small __proteins__ and carbohydrates on the surface of their cells, which are called antigens. Different __antigens__ result in different blood types.

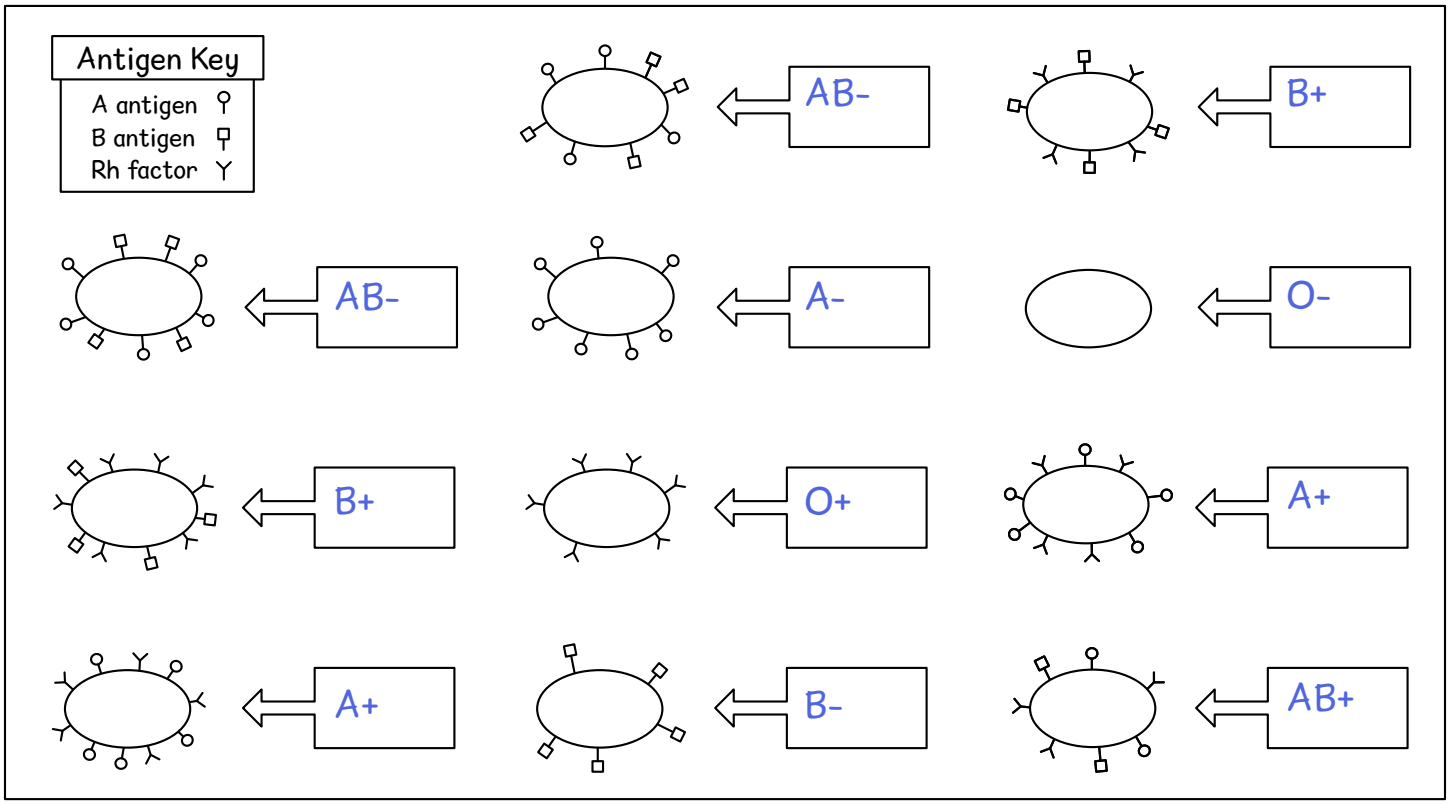
Blood type is essential to know for performing surgery and other medical procedures. The most well known blood __type__ systems are ABO and Rh.

The ABO phenotype is controlled by one of three alleles: A, B, or O. The A and B alleles are __codominant__. Someone with both alleles has blood type __AB__. The A and B alleles are both dominant over O.

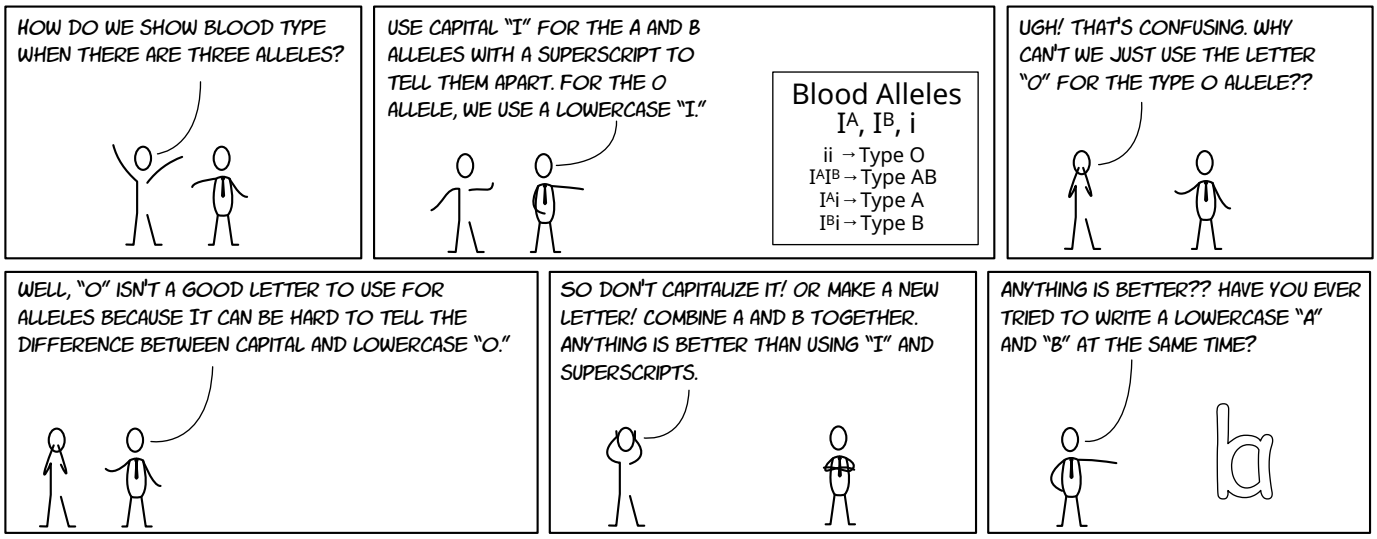
The Rh gene has a dominant allele (+) and a recessive allele (-). The dominant allele produces a small protein on the surface of the blood cells. Someone with this protein is called “Rh positive.” Two copies of the __recessive__ allele results in cells with no Rh protein on their surfaces, a condition which is called “Rh negative.”

Decipher the blood type!

Use the information in the antigen key to label each blood type.

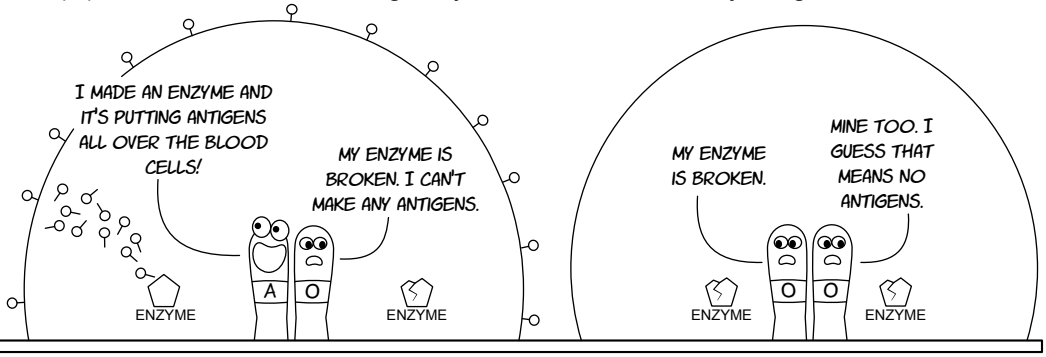


Genotype & Phenotype

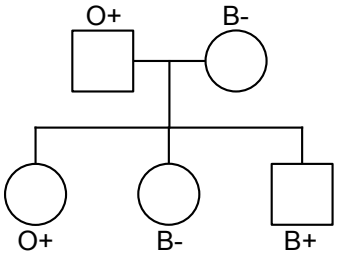


We are using A, B, and O to represent the ABO blood types. Someone with type A blood can either be homozygous (AA) with two alleles that code for enzymes that make the A antigen or they can be heterozygous (AO) with one functional allele. The recessive allele (O) creates a non-functioning enzyme that can't make any antigens.

Phenotype	Genotype
Type A	AA or AO
Type B	BB or BO
Type AB	AB
Type O	OO
Rh +	++ or +–
Rh –	– –



The *phenotypes* of a family are displayed below. What are the *genotypes* of the parents?



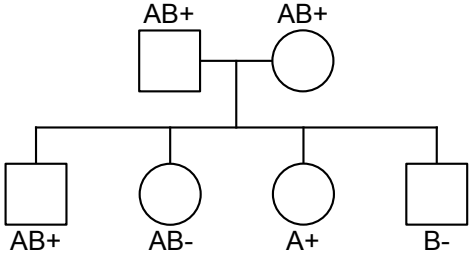
The genotype of parent with O+ blood is:

- ☐ OO++
- ☑ OO+-
- ☐ Something else

The genotype of parent with B- blood is:

- ☐ BB ++
- ☐ BB +-
- ☐ BB - -
- ☐ BO ++
- ☐ BO +-
- ☑ BO - -
- ☐ Something else

The *phenotypes* of a family are displayed below. What are the *genotypes* of the parents and the child with A+ blood?



The parents are:

- ☐ Both homozygous for the Rh factor (both AB++)
- ☐ One homozygous, one heterozygous (AB++ and AB+-)
- ☑ Both heterozygous for Rh factor (both AB+-)
- ☐ We are unable to determine genotype with the given information.

The genotype of the child with A+ blood is:

- ☐ AA++
- ☐ AO+-
- ☐ AO++
- ☑ Either AA++ or AA+-
- ☐ AA+-
- ☐ Something else

Fill out the Punnett square below for the cross AO+– × BO+–. Include both the genotype and the phenotype. Two squares have been completed as examples. Then answer the questions.

	B+	B–	O+	O–
A+	AB+ AB++	AB+ AB+-	A+ AO++	A+ AO+-
A–	AB+ AB+-	AB- AB--	A+ AO+-	A- AO--
O+	B+ BO++	B+ BO+-	O+ OO++	O+ OO+-
O–	B+ BO+-	B- BO--	O+ OO+-	O- OO--

Phenotype

Genotype

How many different blood types could result from this cross?

Eight different blood types: AB+, AB-, A+, A-, B+, B-, O+, O-

Which blood type is most likely from this cross?

AB+, A+, B+, and O+ are all equally likely (3/16 chance of each)

What is the chance of heterozygous A+ / B+ parents producing a child with O- blood?

1/16

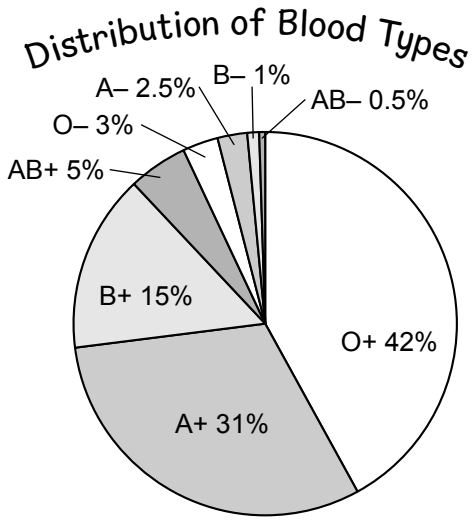
Not all blood types are equally likely! Use the distribution chart for human blood types to fill in the blanks below. As a bonus question, do you know what blood type is called the "universal donor?"

The most common blood type is O+.

The least common blood type is AB-.

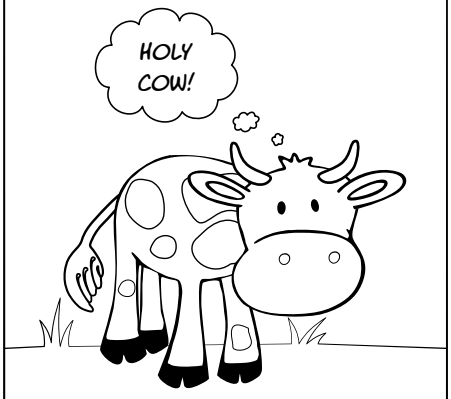
Rh positive blood types are more common than Rh negative blood types.

The universal donor blood type is O-.



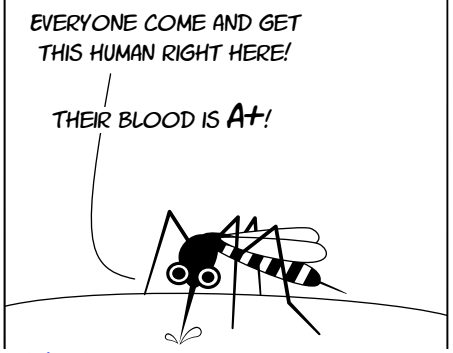
ARE THESE FACT OR FICTION? *Write your verdict below each statement:*

Cows can have more than 800 possible blood types.



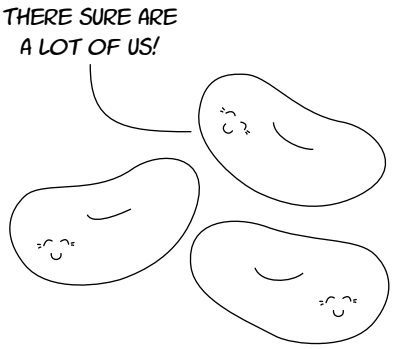
FACT

Mosquitoes prefer type A blood over all other types.



FICTION - they prefer type O or B, depending on the species. One study found that mosquitos were 2x more likely to bite someone with type O blood than type A. In another study, a different species showed a strong preference for type B. See this article for more: https://www.nature.com/articles/s41598-021-03765-z

One pint of blood contains 2.4 TRILLION red blood cells!



FACT- For more general reading on blood cells, see: https://sciencetrek.org/sciencetrek/topics/blood/facts.cfm

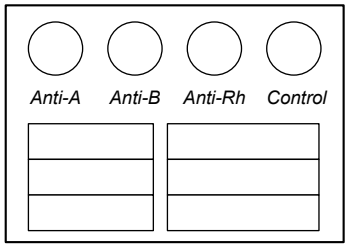
Hands-on Science Project

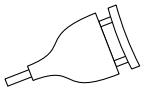
WHAT'S YOUR BLOOD TYPE?

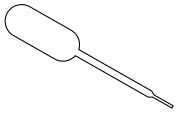
SAFETY FIRST!

Using a blood type kit requires the use of a lancet to provide a blood sample, so this should only be done while supervised and with an adult's permission. Be sure to follow the directions of the blood typing kit used. If not using a blood type kit, decipher the results on the following page to determine the mystery blood types.

MATERIALS:

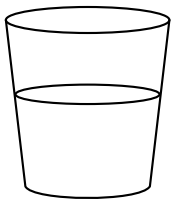



lancet


dropper or pipet


sticks for mixing samples

Blood type kit
Kits typically contain a card, antiseptic, lancet, dropper, sticks or swabs for mixing, and instructions.


Glass of water

A clock or timer

INSTRUCTIONS:

Always follow the directions from your blood typing kit! Most likely, they will look something like this:

1. Place a drop of water on each circle located on the card to activate the serum.

2. Prep your finger by sterilizing it with an alcohol wipe.

3. Prick your finger using the lancet. Then gently massage your finger to allow a drop of blood to form.

4. Touch one of the provided sticks to the blood. Then rest it on one of the circles on the card. Stir gently to mix.

5. Using a new stick each time, repeat until all circles are filled.

6. Gently mix the blood sample with the water on each serum circle.

7. Let the card sit for at least 1 minute. The circle(s) that have agglutinates or clumping indicate your blood type. No clumping in the A or B circles means you are type O. The "Anti-D" or "Anti-Rh" space will clump if you are Rh positive.

8. Using the alcohol wipe, clean your finger and apply a bandaid.

9. Write your name and blood type on the card. Then, when the blood has dried, place the protective sheet on top to save your results.

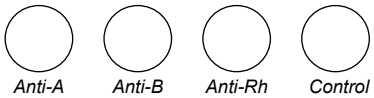
WHY IS THERE A 'CONTROL' CIRCLE?

If a person is careless, they can cross-contaminate their sample. This might give a result of AB+ when in reality, the blood type should be A-, B-, B+, or A+. To help avoid this error, a control spot is added. If agglutination is visible in the control circle, the results are invalid! The test must be run again to determine blood type.

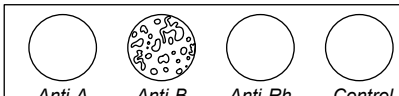
HOW IT WORKS

The serum on the card in the testing kit contains A, B, and Rh antibodies. When blood is mixed with these antibodies, the antigens attempt to find their match.

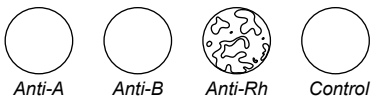
When you see the agglutination in your sample, you are witnessing the antigens and antibodies bonding together, thus making it visible what the blood type is.



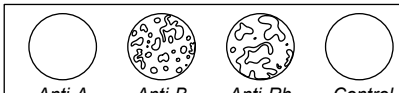
No agglutinates = type O-



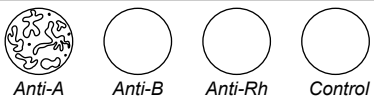
Only agglutinates in B = type B-



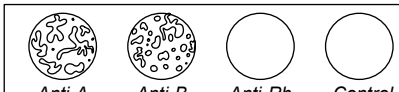
Only agglutinates in Rh = type O+



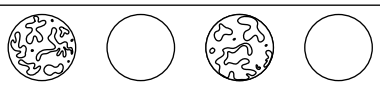
Agglutinates in B and Rh = type B+



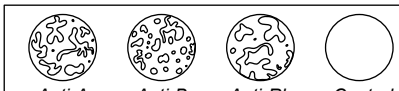
Only agglutinates in A = type A-



Agglutinates in A and B = type AB-

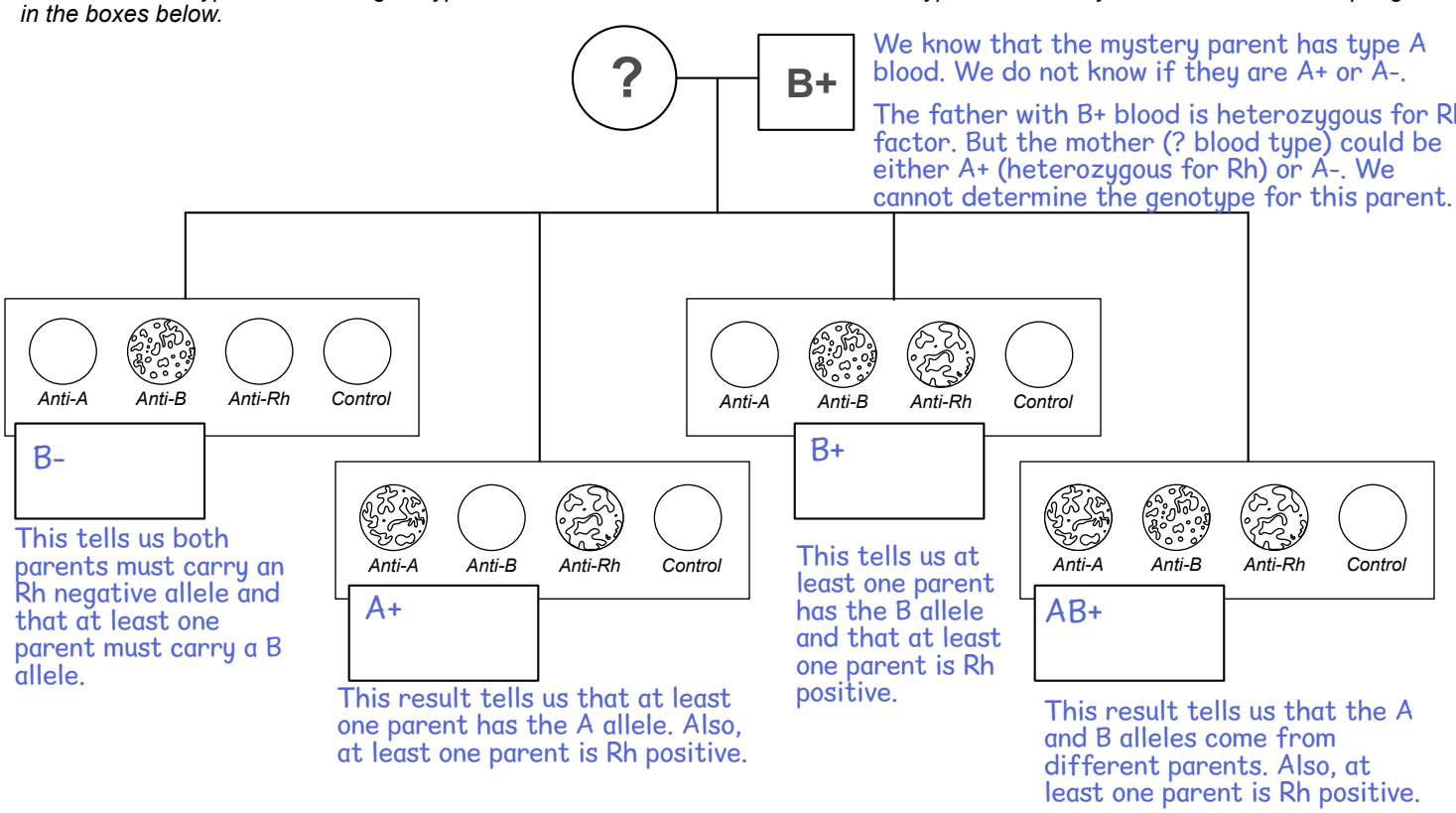


Agglutinates in A and Rh = type A+



Agglutinates in A, B and Rh = type AB+

One of the parents in this family does not know their blood type. Is there enough information from the other individuals to determine what their blood type is? Can the genotype be determined as well? Record the blood types indicated by the cards for each offspring in the boxes below.



We know that the mystery parent has type A blood. We do not know if they are A+ or A-.

The father with B+ blood is heterozygous for Rh factor. But the mother (? blood type) could be either A+ (heterozygous for Rh) or A-. We cannot determine the genotype for this parent.

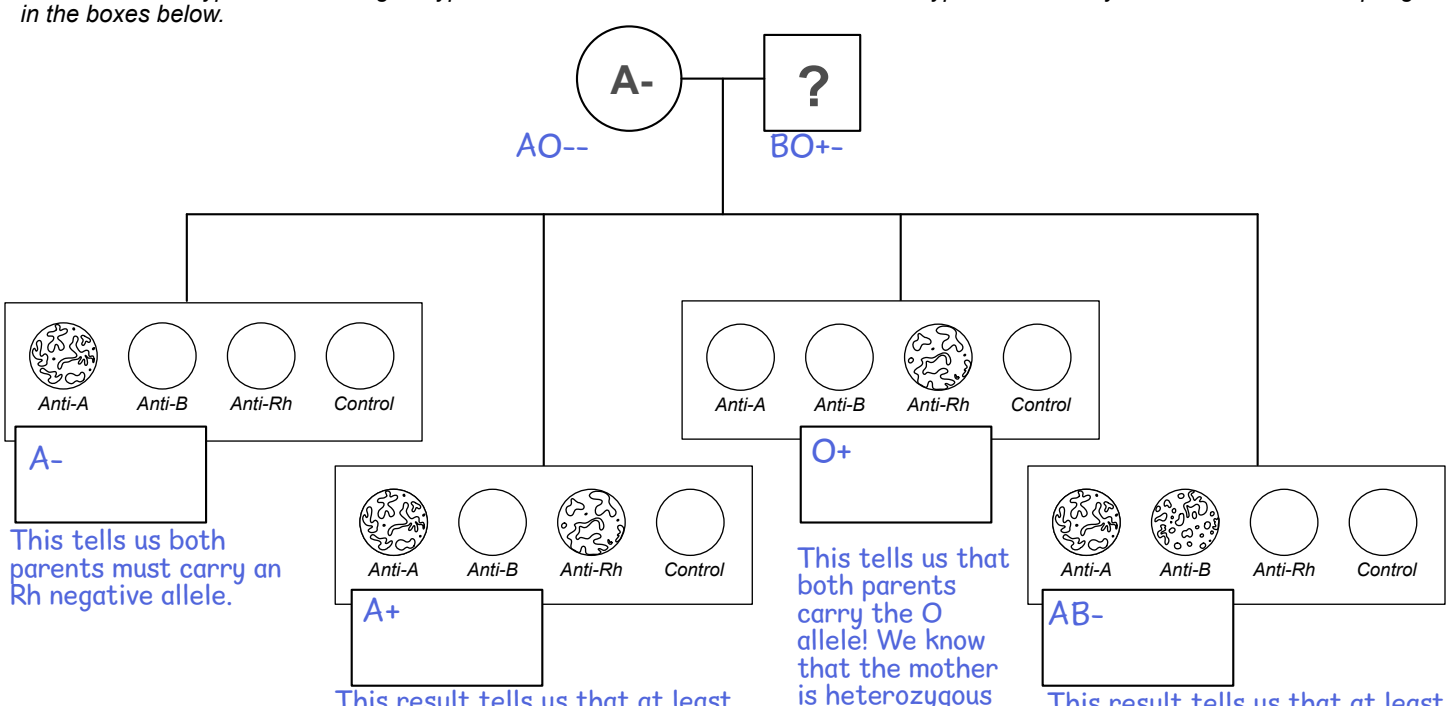
This tells us both parents must carry an Rh negative allele and that at least one parent must carry a B allele.

This result tells us that at least one parent has the A allele. Also, at least one parent is Rh positive.

This tells us at least one parent has the B allele and that at least one parent is Rh positive.

This result tells us that the A and B alleles come from different parents. Also, at least one parent is Rh positive.

One of the parents in this family does not know their blood type. Is there enough information from the other individuals to determine what their blood type is? Can the genotype be determined as well? Record the blood types indicated by the cards for each offspring in the boxes below.



This tells us both parents must carry an Rh negative allele.

This result tells us that at least one parent has the A allele and that at least one parent is Rh positive.

Since the mother is type A-, we know the father is Rh positive.

This tells us that both parents carry the O allele! We know that the mother is heterozygous (AO).

This result tells us that at least one one parent carries the B allele and that both have an Rh negative allele.

Complete a Punnett square of blood genotypes for each cross below. Then write a summary of what blood types you could expect in the offspring. Use language that would be understandable to a non-scientist.

AB+– × OO+–

	O+	O+	O-	O-
A+	AO++	AO++	AO+-	AO+-
B+	BO++	BO++	BO+-	BO+-
A-	AO+-	AO+-	AO--	AO--
B-	BO+-	BO+-	BO--	BO--

3/8 (or 6/16) will have A+ blood.

3/8 (or 6/16) will have B+ blood.

1/8 (or 2/16) will have A- blood.

1/8 (or 2/16) will have B- blood.

AO – – × BO+–

	B+	B-	O+	O-
A-	AB+-	AB--	AO+-	AO--
A-	AB+-	AB--	AO+-	AO--
O-	BO+-	BO--	OO+-	OO--
O-	BO+-	BO--	OO+-	OO--

Each blood type (AB+, AB-, A+, A-, B+, B-, O+, and O-) will show up 1/8 (or 2/16) of the the time.

AO+– × BB– –

	B-	B-	B-	B-
A+	AB+-	AB+-	AB+-	AB+-
A-	AB--	AB--	AB--	AB--
O+	BO+-	BO+-	BO+-	BO+-
O-	BO--	BO--	BO--	BO--

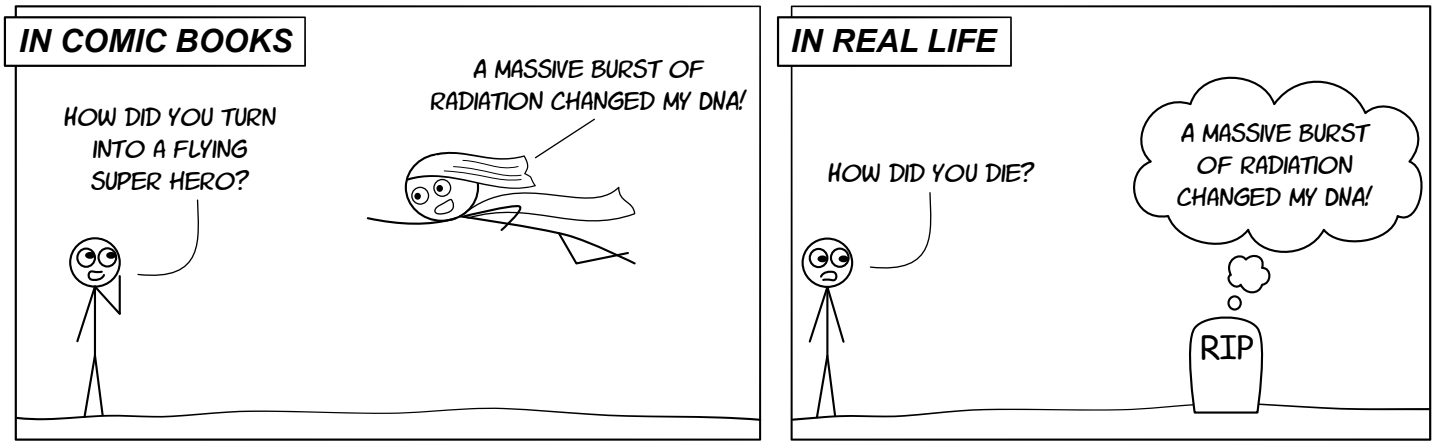
1/4 (or 4/16) will have AB+ blood.

1/4 (or 4/16) will have AB- blood.

1/4 (or 4/16) will have B+ blood.

1/4 (or 4/16) will have B- blood.

MUTATIONS

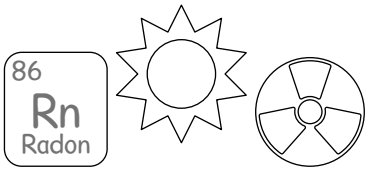


FILL IN THE BLANKS USING THESE WORDS:

growing replicates enzymes sequence

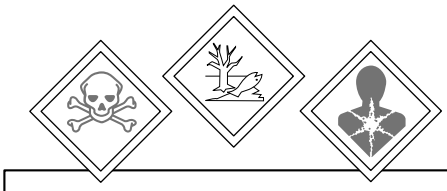
DNA replication is an essential part of living and ___growing___. It is happening right now inside millions of cells in your own body! Every time a cell ___replicates___, DNA polymerase and other enzymes are there to duplicate the DNA. If something damages or breaks the DNA, repair enzymes are there to fix it. These ___enzymes___ are incredibly accurate, but sometimes they make mistakes. When that mistake causes a change to the DNA ___sequence___, we call it a **mutation**.

CAUSES OF MUTATIONS



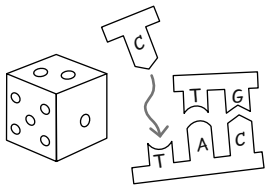
Radiation

High energy particles from sun, x-rays, and radioactive materials cause damage to DNA.



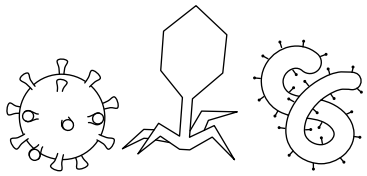
Mutagens

Chemicals that damage DNA or increase the likelihood of mutations



Random Chance

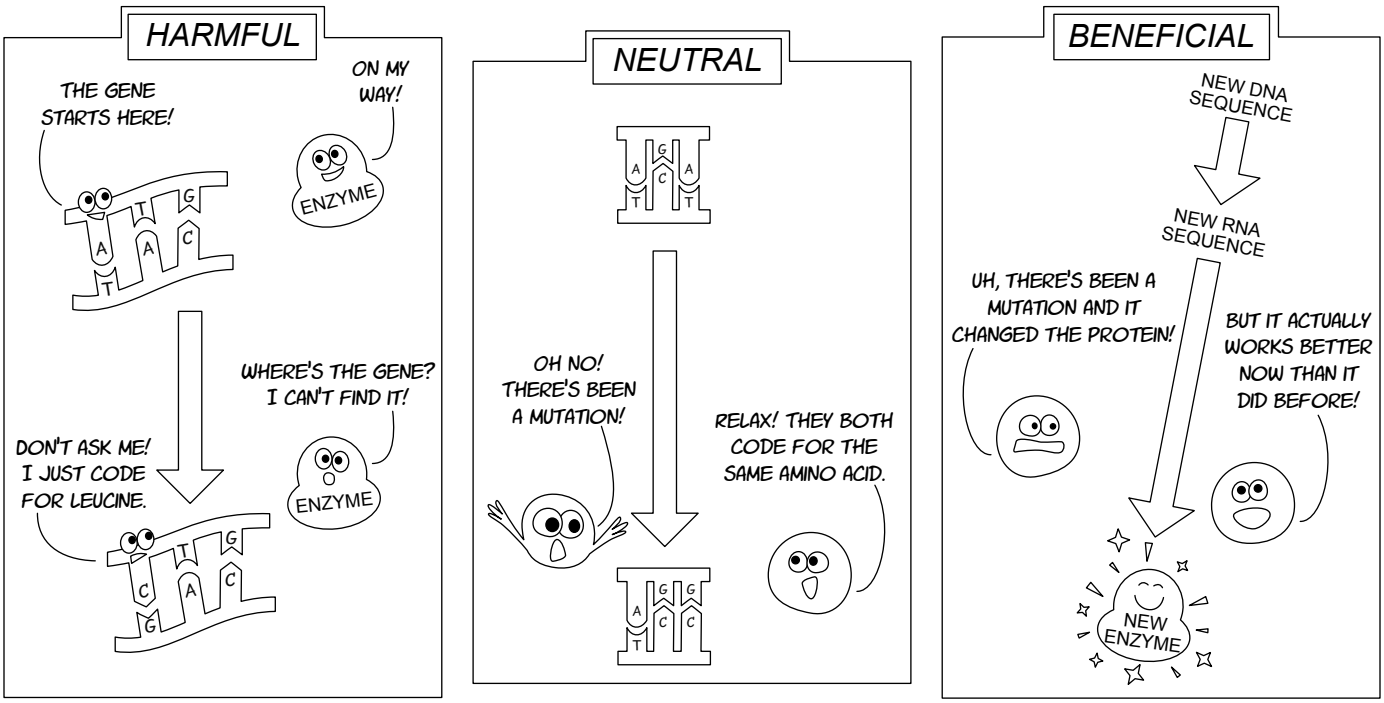
Something goes wrong in the copying process without getting corrected.



Viruses

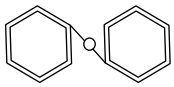
Some viruses insert their own DNA into the genome of host cell. (This DNA then becomes part of the host DNA and is passed on to the next generation.)

EFFECTS OF MUTATIONS

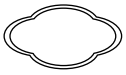


Is the mutation that causes lactase persistence harmful, neutral, or beneficial? Support your answer with an example.

The ability to digest lactose is beneficial. It allows people to consume another food source that would not otherwise provoke gastrointestinal distress. During a famine, lactase persistence provides a survival advantage.



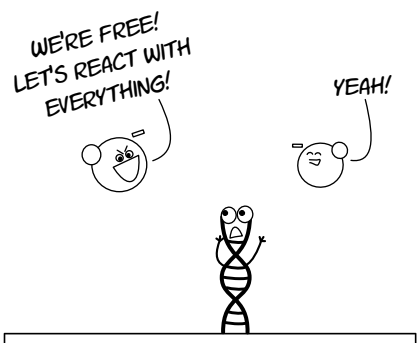
Lactose - the sugar in milk! (galactose + glucose)



Lactase - the enzyme that can cut lactose in half

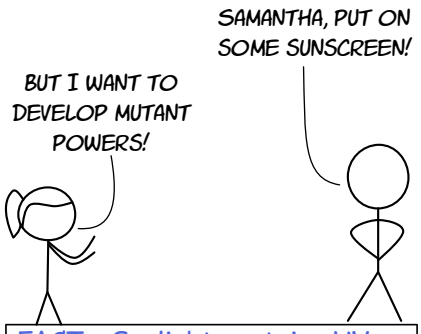
ARE THESE FACT OR FICTION? *Write your verdict below each statement:*

Hydrogen peroxide produces molecules called free radicals that damage DNA.



FACT

Getting a sunburn increases the number of mutations in your DNA.



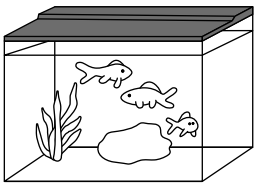
FACT - Sunlight contains UV-radiation that can harm skin cells and DNA.

Some people have genes that let them smell chemicals in urine after someone has eaten asparagus.

We'll say FACT, but recent research shows it's more complicated than we previously thought. https://udel.edu/~mcdonald/mythasparagusurine.html

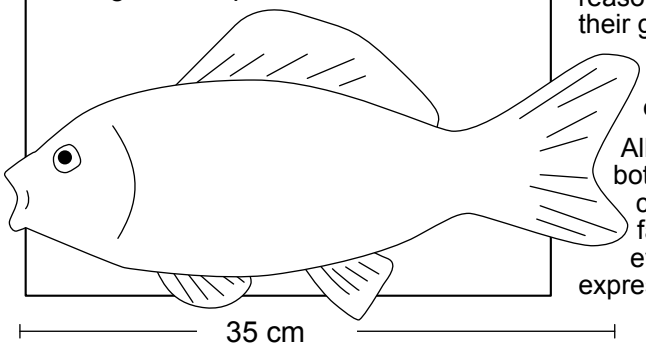
Nature & Nurture

Goldfish in a tank



3-5 cm long

Same goldfish species in Lake Tahoe



35 cm

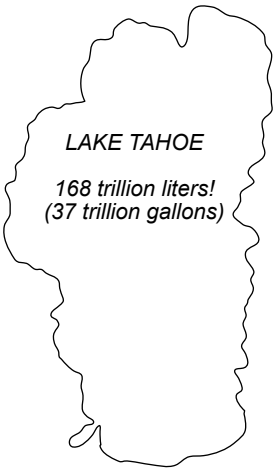
Several years ago, someone dumped a tank of goldfish into Lake Tahoe. They probably thought the goldfish would become food for another fish. But instead, the goldfish became an invasive species!

Goldfish in an average-size fish tank typically grow to be about 3-5 cm long. But the same goldfish in Lake Tahoe grow to be more than 10× bigger. The reason they grow so big is not because their genes have changed – they're still the same species of goldfish. They're big because their environment has changed.

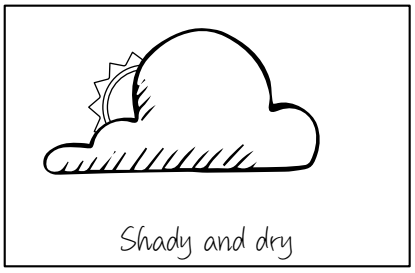
All living organisms are affected by both their genetics and the conditions in their environment. In fact, environmental factors can even influence how genes are expressed!

STANDARD FISH TANK

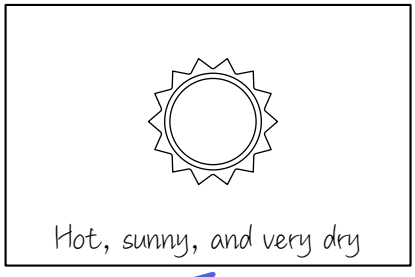
37 liters (10 gallons)



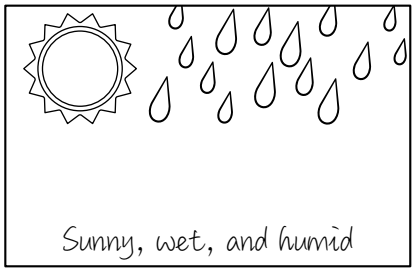
Three genetically identical dandelion seeds landed in three different environments. Match each plant to its environment. Then note one or two characteristics that gave clues to the match.



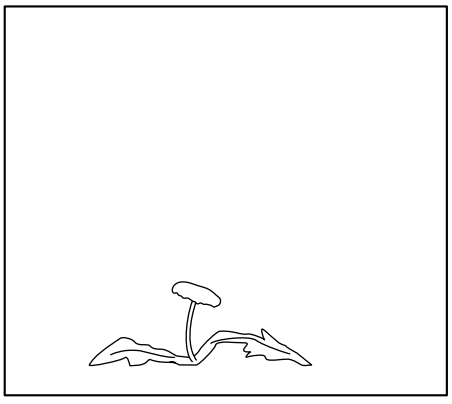
Shady and dry

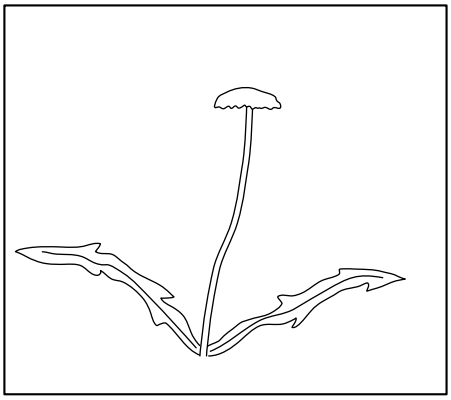


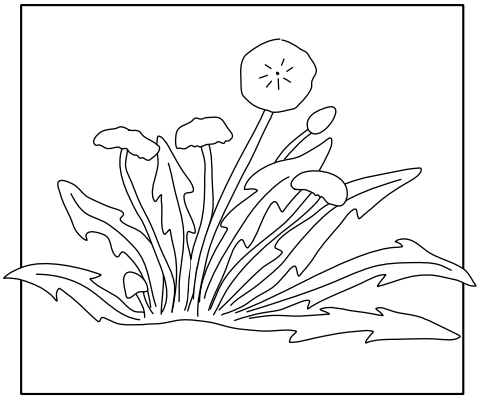
Hot, sunny, and very dry



Sunny, wet, and humid







This plant is the smallest.

Drought is a stress for plants.

Plants in shady locations often grow taller and have elongated stems.

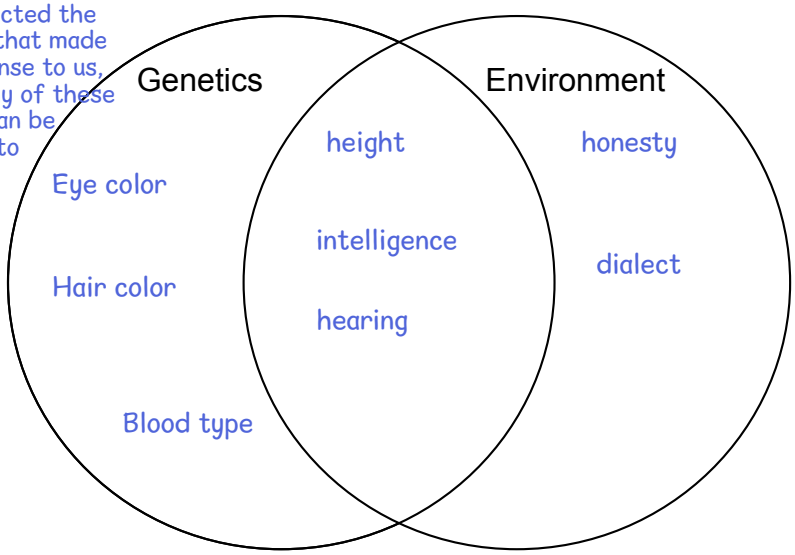
This plant is the largest.

It should match with the environment that has the most water.

Write each attribute in the Venn diagram below to classify it as being primarily the result of genetics, environmental conditions, or both. There may not be a clear answer for every trait. Be able to justify your classifications.

eye color	dialect	blood type	intelligence	height	hearing	hair color	honesty

We selected the circles that made most sense to us, but many of these traits can be argued to be the result of both!



List five examples of how the growth of an organism can be influenced by its environment:

There are many possible correct answers!

1. Good nutrition helps organisms grow larger.
2. Low levels of light cause plants to grow taller with elongated stems.
3. Fluoride in the water supply can make teeth stronger
4. Poor soil will stunt the growth of plants.
5. Lack of calcium in the diet can lead to weaker bones.

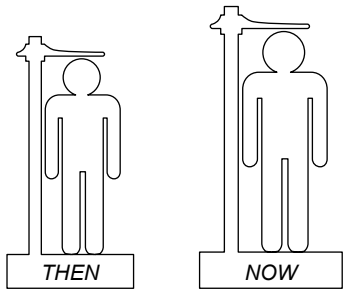
FILL IN THE BLANKS USING THESE WORDS:

dandelions	epigenetics	both	genetic

The traits plants, animals, and other life forms have are often influenced by __both__ their genetics and their environment. Genetic clones such as __dandelions__ can be almost unrecognizable when grown in drastically different environments. Some traits, like perfect pitch, need a combination of __genetic__ factors and experience to develop the trait. And sometimes the environment can directly influence how genes are expressed! The study of how environmental conditions impact gene expression is called __epigenetics__.

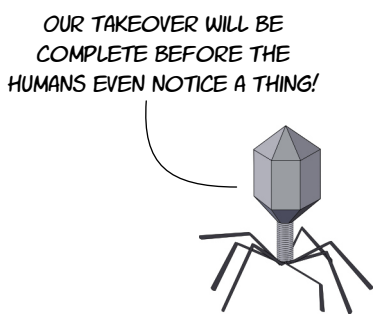
ARE THESE FACT OR FICTION? *Write your verdict below each statement:*

Over the last 150 years, the average height of humans in developed countries has increased by 20 cm! (7.8 inches)



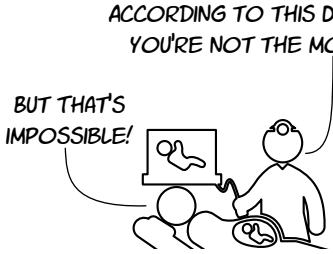
FALSE - but average height has increased by half that amount. For more, see https://ourworldindata.org/human-height

Around 8% of your DNA isn't human – it's viral.



FACT - Cold Spring Harbor Laboratory has a good article with more information: https://www.cshl.edu/the-non-human-living-inside-of-you/

Some people have two different sets of DNA.

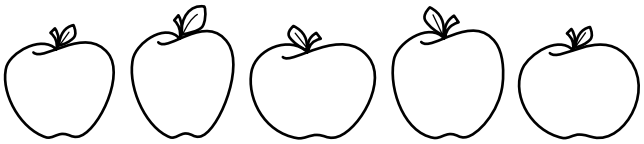


FACT - They're called human chimeras. This rare condition can occur when a dizygotic twin dies in utero and the other embryo absorbs the cells. Recipients of organ transplants are another example of a person who contains two different sets of DNA. For more information see: https://www.sciencedirect.com/science/article/pii/S1769721220302895

Hands-on Science Project

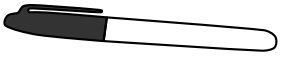
APPLE VARIETY TASTE TEST

MATERIALS:

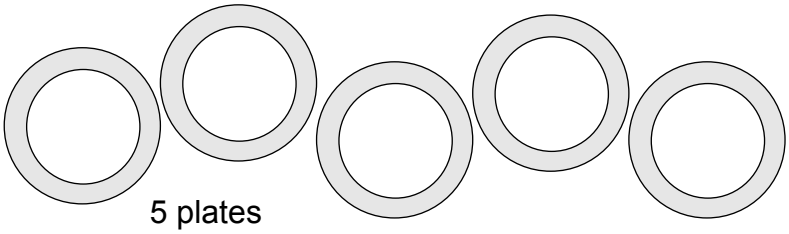


5 apples of different varieties

knife



marker



5 plates

Prepare the taste test

1. Go to the store and pick out 5 apples that are different varieties, including one Red Delicious. If possible, choose apples that have stickers or mark them in some way to differentiate which variety is which.

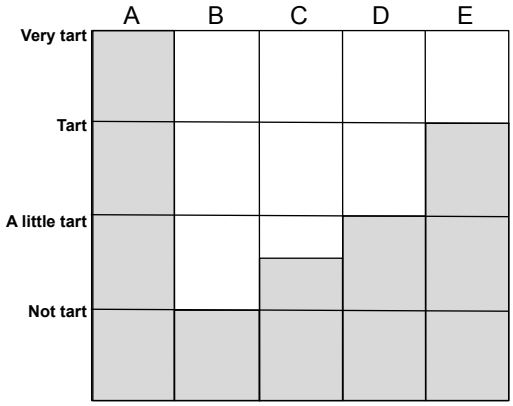
2. At home, use a marker or paper to label each plate with a letter: A,B,C,D,E. Place the sticker from each apple or a label with the name of each apple on the bottom of each plate to help keep track of which apple is which. Be sure the label with the apple variety is not visible to the person taste-testing the apples.

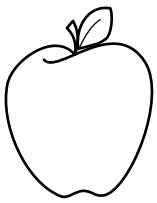
3. For the browning test, cut each apple in half. Place one half face-down on the plate for future taste testing. Cut a piece from the other half and leave it face up and exposed to the air. Then set a timer. Rate each apple variety for browning at 1, 5, 15, and 30 minutes. The taste test can proceed while the apples are being tested for browning.

4. For the taste test, locate volunteers to taste the apples. Cut additional slices from each apple and present the samples to each taste tester. Each apple sample should be identified by letter (A, B, C, D, and E) not by variety name. If possible, give each taste tester their own paper and have them rate all apples for tartness, sweetness, crispness, and overall flavor.

6. If multiple taste testers evaluated the apples, average their results and then record them on the next page.

For example, if apple A was very tart, B had no tartness at all, C was barely tart, D a little tart, and E was tart, then you would fill out your chart like this:





For BEST results

Remove the peel from the apple samples so taste testers don't have peel color as a clue about which variety is which!

The Red Delicious - Beautiful but bland

The Red Delicious apple was created in 1872 at an orchard in Iowa. It debuted as a sweet, round, red and yellow fruit named Hawkeye. When Stark Nurseries bought the rights to the apple in the 1890s, they changed the name to Stark Delicious and then later Red Delicious to match another Stark Nursery apple named Yellow Delicious. As the apple became more popular in grocery stores, growers increasingly selected genes for longer shelf life and appearance over flavor, which resulted in a less appetizing fruit. The selection of redder skin caused deselection of flavor because the genes that produced yellow stripes on the original fruit were on the same chromosomes as those of the flavor-producing compounds. Breeding for uniform appearance and shelf life resulted in a thicker skin. One hundred years later, in the 1980s, demand for the Red Delicious declined as other varieties of more flavorful apples entered the market.

TARTNESS
how sour the apple is

	A	B	C	D	E
Very tart					

Results will vary! For a more scientific approach, we recommend having 5 volunteers participate in the taste test and then averaging their results. Be sure to remove the stickers or labels from the apples and just call them by their letter designation (A, B, C etc.). You don't want the name of the variety doesn't influence the taster as they rank the apple.

Individual apples can vary in their texture and taste. In general, Granny Smith will be the most sour or tart apple, and Honey Crisp, Fuji, or Gala will be the sweeter varieties.

Red Delicious, Macintosh, and Golden Delicious will be less crisp, or softer, than other varieties. They also typically rate less tart than the aforementioned varieties.

SUGAR CONTENT
how sweet the apple is

	A	B	C	D	E
Very sweet					
Sweet					
A little sweet					
Not sweet					

CRISPNESS
how crisp the apple is

	A	B	C	D	E
Very crisp					
Crisp					
A little crisp					
Not crisp					

OVERALL FLAVOR
the most subjective rating of all

	A	B	C	D	E
Delicious flavor					
Good flavor					
Okay flavor					
Poor flavor					

BROWNING
how quickly the apple turns brown after being cut

	A	B	C	D	E
Browning visible at 1 min					
Browning visible at 5 mins					
Browning visible at 15 mins					
Little to no browning visible at 30 min					

How did the Red Delicious variety compare to the others? Was it ranked below or above average?

Our prediction is that Red Delicious will rank the lowest for crispness, overall flavor, sweetness, and tartness. Is this what you found in your taste test?

DID YOU KNOW? *Apples turn brown after being cut because of a reaction between oxygen in the air and enzymes in the apple called polyphenol oxidases. Applying vitamin C to apple slices (such as with lemon juice) will stop this reaction. But different apple varieties have different amounts of polyphenol enzymes. The Opal variety has such low levels, it's known as a "non-browning" apple.*

X-linked traits

FILL IN THE BLANKS USING THESE WORDS:

more	inherited	chromosomes	linked	recombination

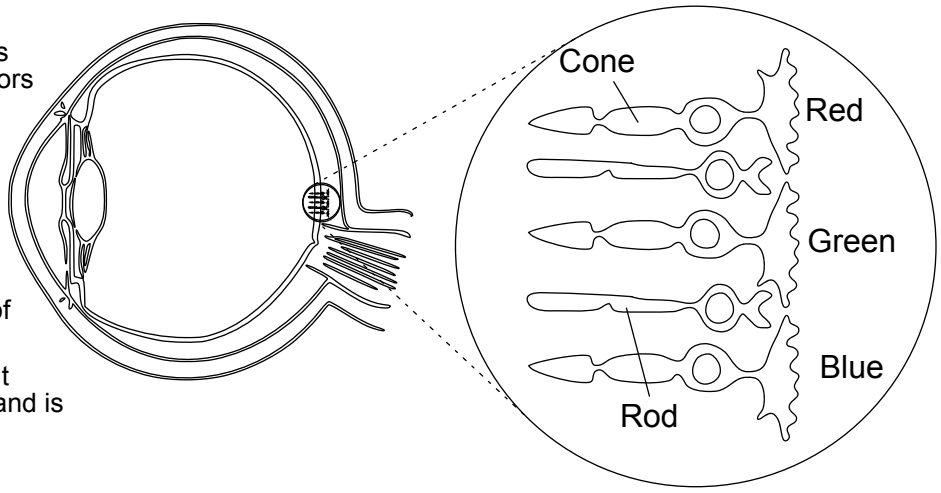
Genes located on different chromosomes are inherited independently. Genes that are further apart on the same chromosome are also inherited independently because of recombination. But if genes are close together on a chromosome, there's a very good chance they'll be inherited together. We call them linked traits. There's one chromosome pair in particular where linked traits are rather famous: that's pair 23. Genes on the X chromosome are called X-linked traits, and they are more likely to be expressed in men than in women.

Red-green colorblindness

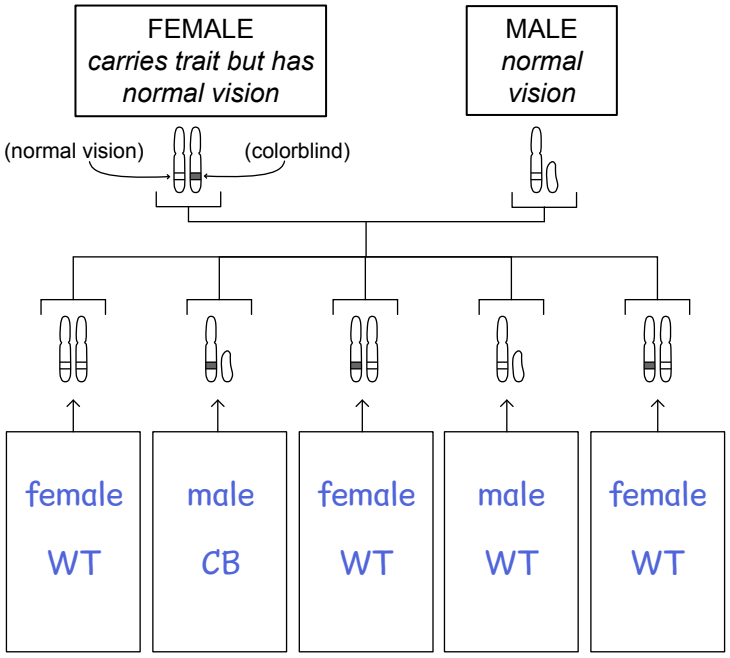
Human vision comes from specialized cells called rods and cones. These photoreceptors work by detecting specific wavelengths of light. The genes with the information to create the color-sensitive red and green cones are located on the X-chromosome.

In people of Northern European ancestry, red-green colorblindness, also called protanopia (no red cones) or deuteranopia (no green cones), is present in about 8% of males and 0.6% of females.

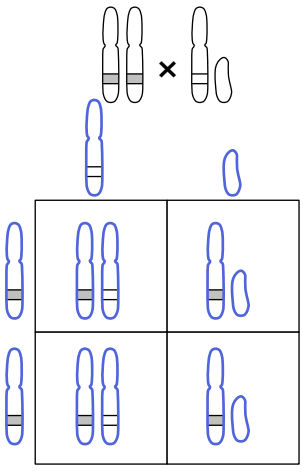
Tritanopia (no blue cones) is not x-linked. It arises from a mutation on chromosome 7 and is much rarer than red-green colorblindness.



Identify the biological sex and color vision status for each of the children below. Write "male" or "female" and either "WT" for wild type (normal vision) or "CB" for colorblind.



What proportion of the offspring will be colorblind from a colorblind mother and trichromat (normal vision) father?



On average, 1/2 of the offspring will be colorblind (the male half). All of the females will have trichromat vision but be carriers for colorblindness.

About Calico Cats

In cats, the genes that control orange or black fur color are on the X chromosome. Orange is dominant, and black is recessive. Because it can be difficult to distinguish between upper and lowercase versions of the letter "o," the alleles are typically represented by X^B (orange) and X^b (black).

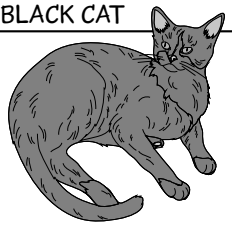
In females with an XX genotype, early in development, one of the X chromosomes is inactivated and supercoiled into a dense structure known as a Barr body. None of its genes will ever be expressed!

The random inactivation of half of the X chromosomes early in development is called X-inactivation. As a result of this inactivation, some of the cells in XX females express genes from one chromosome while others express entirely different genes!

With calico cats, you can see where the Barr bodies formed because the black fur is from one X chromosome and the orange fur is from another. Calico cats are always female, except in the rare case of Klinefelter syndrome (XXY).

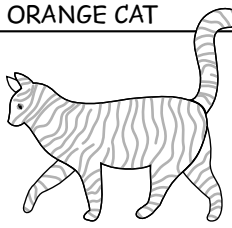
The white fur in a calico cat is caused by the recessive piebald gene, which is located on a different chromosome. It creates unpigmented (white) patches of fur.

BLACK CAT



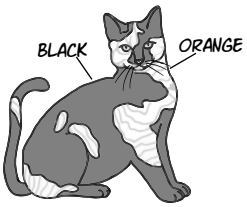
Female X^bX^b
Male X^bY

ORANGE CAT



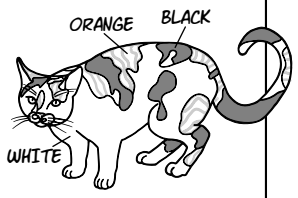
Female X^BX^B
Male X^BY

TORTOISESHELL CAT



Female X^BX^b

CALICO CAT



Female X^BX^b
Plus S (piebald) gene

What will be the outcomes of the following crosses? Will any of them produce a calico cat? All cats carry the piebald gene and have patches of white fur.

Black and white "tuxedo" male (X^bY) with an orange and white female (X^BX^B).

All the female cats will be calico (about ½ the cats, on average).

	X^b	Y
X^B	X^BX^b CALICO	X^BY ORANGE
X^B	X^BX^b CALICO	X^BY ORANGE

Orange and white male (X^BY) with a calico female (X^BX^b).

¼ chance of a calico kitten

	X^B	Y
X^B	X^BX^B ORANGE	X^BY ORANGE
X^b	X^BX^b CALICO	X^bY BLACK

Black and white male (X^bY) with a calico female (X^BX^b).

¼ chance of a calico

	X^b	Y
X^B	X^BX^b CALICO	X^BY ORANGE
X^b	X^bX^b BLACK	X^bY BLACK

Orange and white male (X^BY) with a black and white female (X^bX^b).

All females will be calico, so, on average, ½ of the kittens will be calico.

	X^B	Y
X^b	X^BX^b CALICO	X^bY BLACK
X^b	X^BX^b CALICO	X^bY BLACK

Genetically Modified Organisms

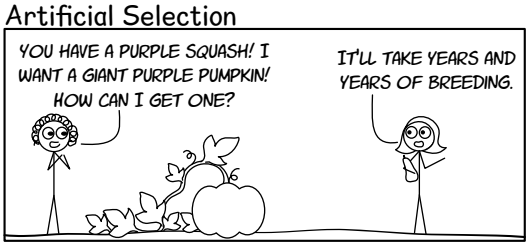
WHAT THEY ARE

The genetics of organisms are changing all the time due to natural factors such as mutations and sexual reproduction. But these changes have a high degree of randomness. Genetically modified organisms, or GMOs, have had their genetic code changed in a more deliberate way. They have either had a specific piece of DNA inserted or removed from the genetic code.

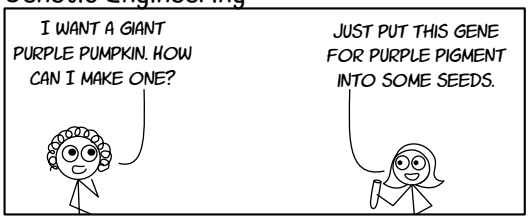
Sometimes this piece of new DNA is from the same species. For example, a pumpkin could be genetically engineered to have another trait by taking the gene from a different breed of squash and inserting it into the pumpkin genome. This would be faster than achieving the same result through artificial selection or breeding.

More often, the piece of new DNA is from a different species, such as when human beings engineered bacteria to produce the protein insulin to treat diabetes.

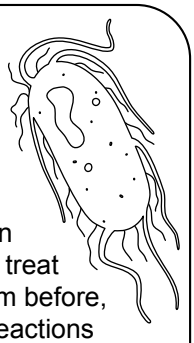
Artificial Selection



Genetic Engineering



EXAMPLE 1: Insulin-producing bacteria



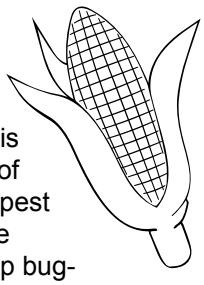
Insulin is a hormone that regulates the amount of glucose in the bloodstream. Someone with diabetes is unable to produce enough insulin. Before 1922, diabetes was a fatal illness. After the discovery of insulin, doctors used insulin from the pancreases of pigs or cattle to treat diabetes. This was an improvement from before, but it would sometimes cause allergic reactions because the insulin in humans is different from the insulin from pigs and cows. In 1978, the bacteria *E. coli* was modified by inserting the human gene for insulin into its DNA. When this bacteria reproduces, it transfers the insulin production gene to its millions of offspring. The insulin protein is then purified and used as medicine.

Benefits: The new insulin is the same as human insulin and easier to produce.

Drawbacks or concerns: Almost none

Alternatives: The only alternatives are to use the insulin produced by the pancreases of other mammals. But pig and cow insulin is slightly different than human insulin and can cause allergic reactions.

EXAMPLE 2: Bt corn



Bacillus thuringiensis (Bt) is a common bacteria that has natural insecticidal abilities. It makes a protein known as the **Bt toxin** which is poisonous to most insects. Because of this ability, Bt has been an important pest control tool for nearly a century. In the 1990s, scientists were able to develop bug-resistant plants by moving some of the genes from the bacteria into corn and cotton. Bt crops have been highly effective at combating pests such as European corn borer, rootworm, corn earworm, tobacco budworm, and bollworm. They are the predominant varieties planted in North America. But now the bugs are starting to develop resistance!

Benefits: The crops are able to fight off insects without the application of pesticide.

Drawbacks or concerns: Bugs are becoming resistant to Bt. Corn pollen can negatively impact other beneficial insects.

Alternatives: Farmers can spray insecticides on their crops, apply a slurry of Bacillus thuringiensis, or do crop rotation and mixed planting (not a monoculture) to reduce insect pests.

EXAMPLE 3: GURT or Terminator Seeds

Genetic use restriction technology (GURT), also known as terminator seeds or suicide seeds, involves a genetic switch that will be activated to produce a non-viable seed. Advocates of GURT technology say it would benefit farmers by reducing volunteer plants that come up from the previous year after crops have been rotated. Opponents of GURT technology say the only benefit is that a seed company would earn more money because farmers could not save seeds to plant again the following year. Higher food prices and the risk of the terminator gene impacting other populations of plants were of strong enough concern that the United Nations recommended a moratorium on the sale of terminator seeds. India and Brazil have both passed laws banning GURT technology.

Benefits: The seed producing company makes more money. There will not as many volunteer crops during rotation.

Drawbacks or concerns: Increased food prices, loss of biodiversity.

Alternatives: Don't develop terminator seeds! Harvest crops in a timely manner to discourage seeds falling the field.

EXAMPLE 4: Genetically Modified Mosquitos

The *Aedes aegypti* mosquito spreads diseases such as malaria, dengue fever, Zika, and chikungunya. But only female mosquitoes bite. They need a blood meal in order to produce eggs. Scientists developed genetically modified *A. aegypti* mosquitoes that had a **self-limiting gene**. This gene prevents female mosquitoes from growing to adulthood. The genetically modified mosquitoes also have a fluorescent marker gene that glows under a specific light so that they can be identified in the wild. These mosquitoes have been successfully used in Brazil and Panama to reduce the number of *A. aegypti* mosquitoes and the diseases they cause.

Benefits: Fewer mosquitoes means fewer diseases.

Drawbacks or concerns: Other animals depend on mosquitoes for food.

Alternatives: Draining marshy land, nets, spray, and treating sick people to reduce disease. Other GMO efforts focus on making it so the mosquitoes can no longer carry certain diseases.

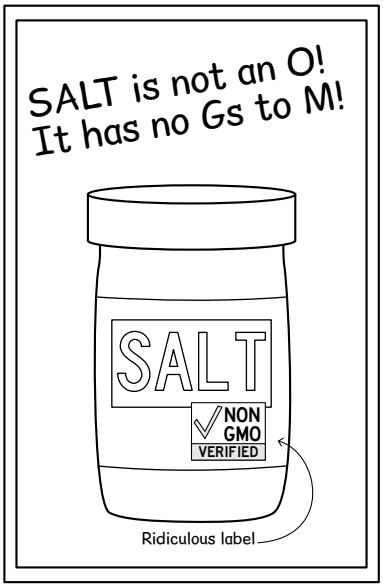
If you could design a genetically modified organism, what would you design and why?

Answers will vary!

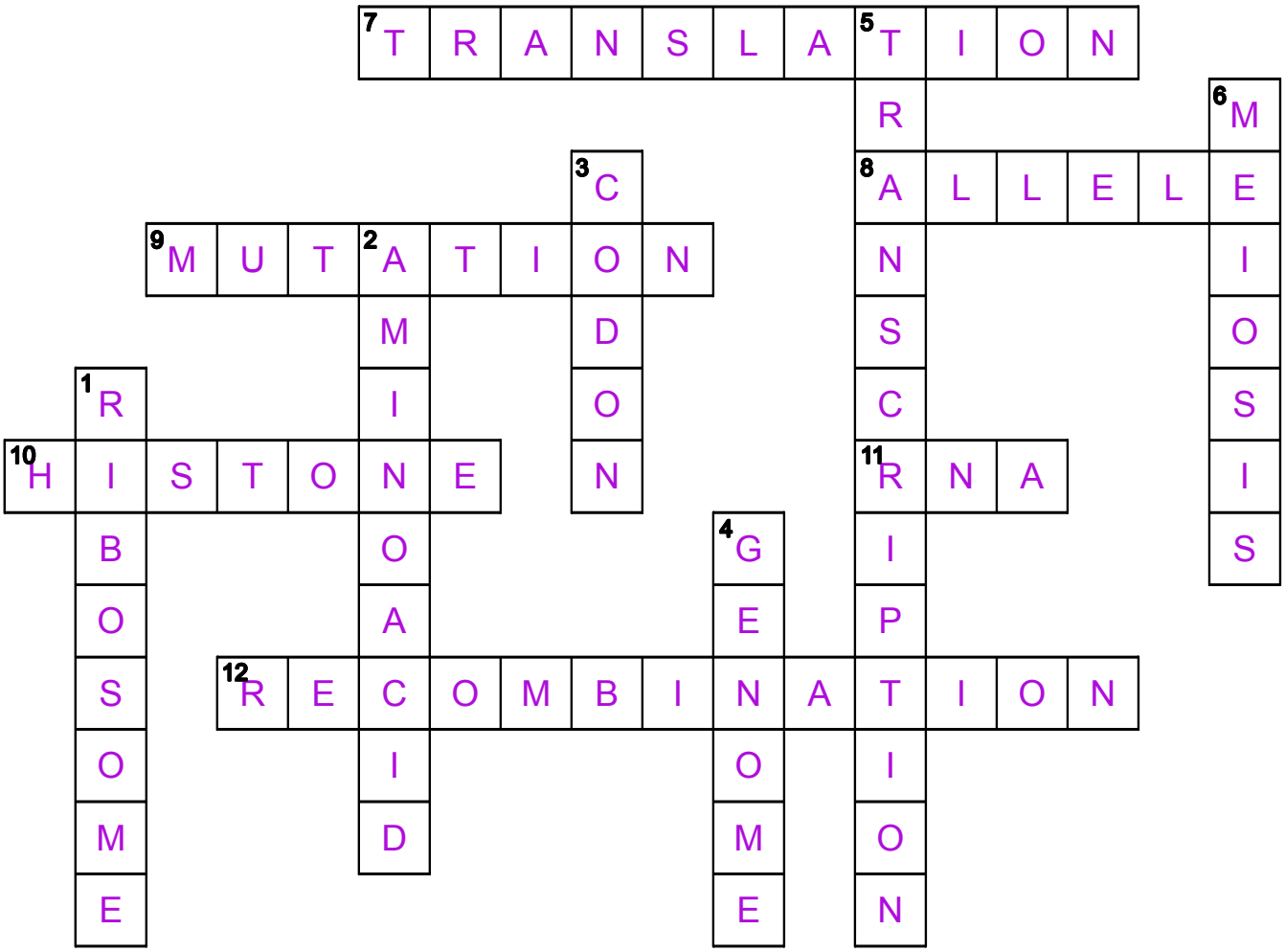
I would design a type of algae that would digest microplastics to help remove microplastics from the oceans.

THINK ABOUT IT: One of the biggest questions of the upcoming century is whether or not human beings should modify their own genetic code. Using CRISPR and gene therapy, it is possible to alter genes to make a person taller, smarter, or less susceptible to disease.

Should people experiment with this technology, or should genetic modification to human beings be restricted? What do you think?



Genetics Crossword Puzzle



VERTICAL Words

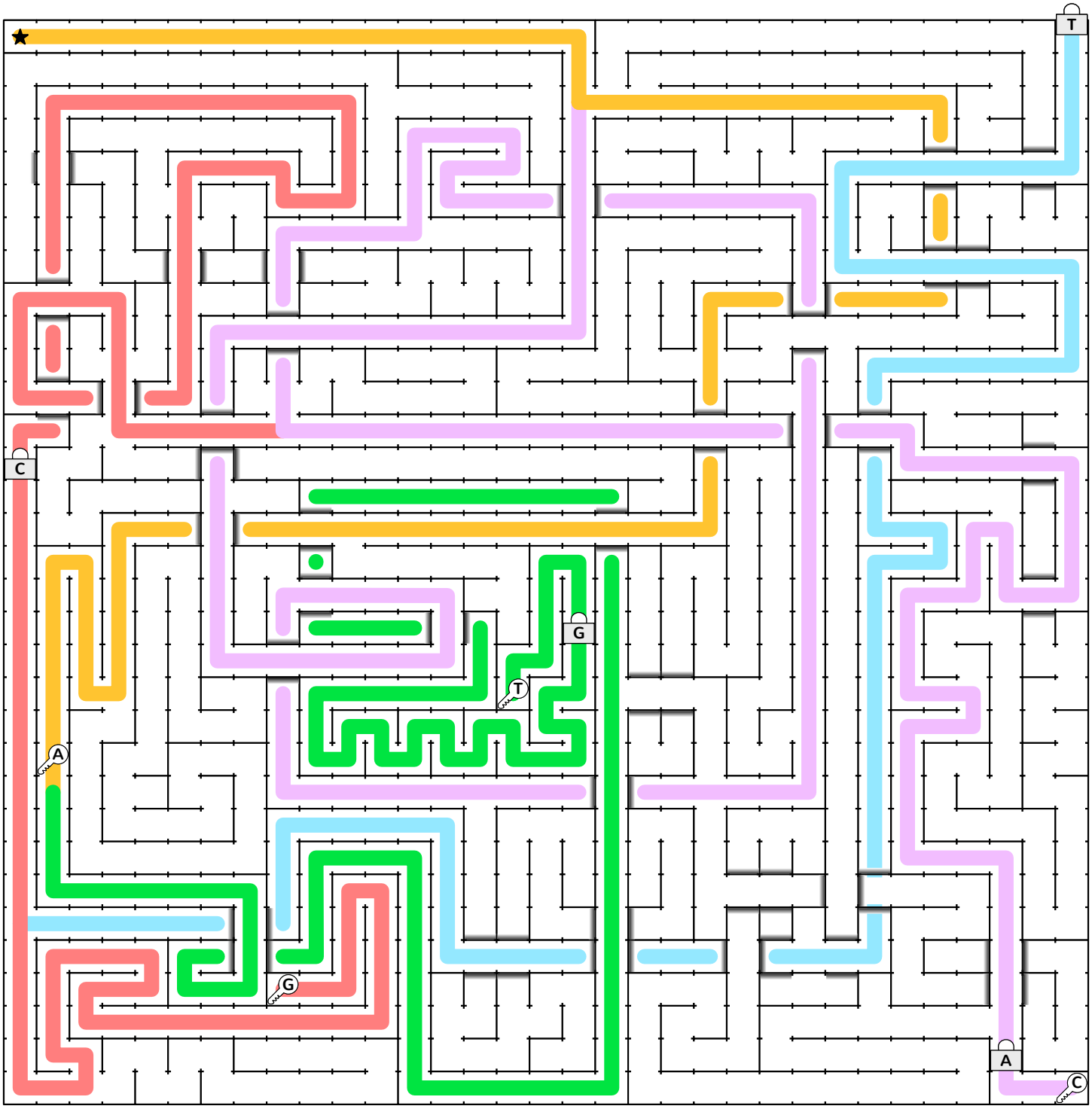
1. A cell organelle where protein synthesis occurs
2. A type of molecule that combines to form proteins
3. A sequence of three nucleotides
4. The complete set of genes or genetic material present in a cell or organism
5. The process of making an RNA copy of a DNA sequence
6. The process of creating haploid cells containing half of the genetic information

HORIZONTAL Words

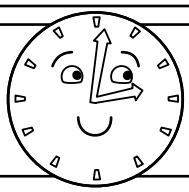
7. The process of converting messenger RNA to a sequence of amino acids
8. A version of a gene inherited from a parent
9. When the sequence of a gene changes
10. A protein that provides structural support to a chromosome
11. Ribonucleic acid
12. The rearrangement of genetic material by crossing over in chromosomes

DNA MAZE

Collect all the building blocks of DNA to escape the maze. Start at the star and work your way through the maze to escape in the upper right corner. You can only pass through a lock T if you have the corresponding key T.
Keep an eye out for overpasses and underpasses!



Follow the yellow path to get the **A key**. Then backtrack to the pink path to unlock the **A lock** and get the key labeled **C**. Then follow the pink back to where it intersects with the salmon-red color to access the **C lock**. Continue following the path to get the **G key.** Then turn around and backtrack to the pink and then to the yellow path from the beginning. Go past the A key to get on the green path, which will take you to the **G lock**. Right after the G lock, you'll get the **T key.** Then backtrack all the way back to the yellow and then the pink. Next, get back on the salmon-red color path to access the blue path. The blue path will take you to the **T lock** so you can escape the maze!



Quiz Time!

ANSWER THE QUESTIONS TO SEE WHAT YOU LEARNED ABOUT GENETICS!

1. Which individuals will have identical or near-identical genes?
   A. Siblings
   B. Identical twins
   C. Fraternal twins
   D. Parents and their offspring

2. How many pairs of chromosomes does the human genome have?
   A. 23
   B. 46
   C. 15
   D. 52

3. A strand of DNA reads 'GATACTACT'. The complementary (paired) strand reads
   A. CTATGATGA
   B. CATAGTAGT
   C. ADGCTDCT

4. How does RNA differ from DNA?
   A. RNA contains deoxyribose, and DNA contains ribose.
   B. RNA contains uracil, and DNA contains thymine.
   C. RNA is double stranded, and DNA is single stranded.

5. Is it possible for a man and a woman, each with Type A blood, to have a child that is Type O?
   A. Yes, if the man is heterozygous
   B. Yes, if the woman is heterozygous
   C. Yes, if both parents are heterozygous
   D. No, it is impossible

6. In cells, long pieces of DNA are wrapped up with proteins to form
   A. microtubules
   B. RNA
   C. nuclei
   D. chromosomes

7. DNA is made up of which repeating subunits?
   A. RNA
   B. nucleotides
   C. genes
   D. bases

8. The sequence of DNA in the skin cells of your hand is significantly different in sequence from the DNA in your heart cells.
   A. True
   B. False

9. Down Syndrome results from
   A. an extra copy of chromosome 21
   B. a missing copy of chromosome 21
   C. a specific gene mutation
   D. changes to DNA that occur after birth

10. Who are more likely to suffer from X-linked diseases and why?
    A. females, because they have two X-chromosomes and are therefore more likely to inherit one with a disease
    B. males, because they have only one X-chromosome and it, alone, determines whether they have the disease.
    C. females, because one of their X-chromosomes is deactivated
    D. males, because the Y-chromosome already carries the gene for the disease.

11. Crossing over or recombination takes place during_____.
    A. meiosis
    B. mitosis
    C. segregation
    D. linkage

12. A sequence of 3 consecutive nucleotides that codes for a specific amino acid or signals the start or termination of gene is called a(n)
    A. gene
    B. allele
    C. codon
    D. gamete

13. Two parents have 8 kids, and all 8 kids have different phenotypes for their blood type. Their blood types are A+, A-, B+, B-, AB+, AB-, O+, and O-.

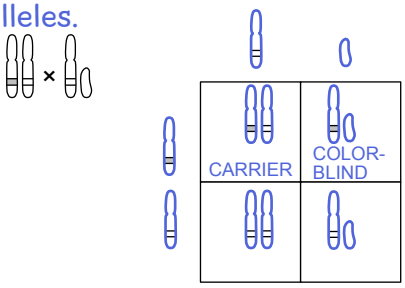
    What genotypes do the parents have for blood type?

    One parent must have blood type AO+- and the other has type BO+-. No other combinations can yield all eight blood types as offspring.

14 Can two orange cats produce a calico kitten? Why or why not?

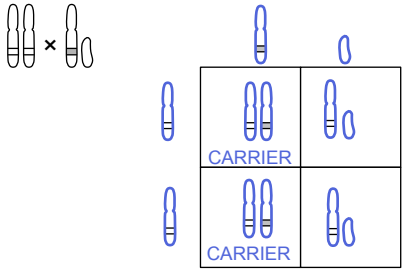
They cannot. Both black and orange alleles are needed for a calico kitten. An orange male cat only carries the orange allele. An orange female cat has two orange alleles.

15 If the mother carries the allele for red-green colorblindness and the father has normal vision, what proportion of their offspring will be colorblind?



A. Half the males, all the females
B. Half the males, none of the females
C. All the males, half the females
D. All the males, none of the females
E. None of the males, none of the females

16 If the father has red-green colorblindness and the mother has normal vision and is not a carrier, what proportion of the offspring will be colorblind?



A. Half the males, all the females
B. Half the males, none of the females
C. All the males, half the females
D. All the males, none of the females
E. None of the males, none of the females

17 True or false: in a living organism, mutations are always occurring.

A. True
B. False

18 Lactase persistence is an example of a _____ mutation.

A. beneficial
B. neutral
C. harmful

19 If the parents are A+ and B+ and are both heterozygous for both alleles, what are the chances of their child having the universal donor blood type of O-?

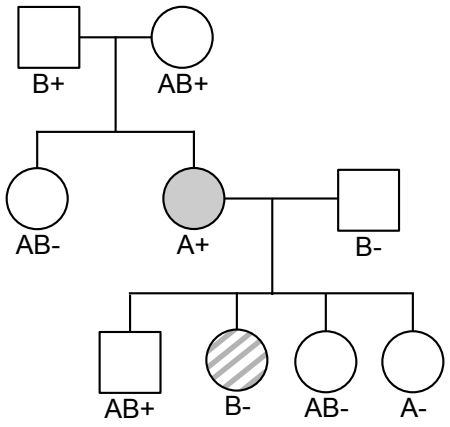
A. 1/2
B. 1/4
C. 1/8
D. 1/16
E. 1/32

To answer this question you can draw a Punnett square or multiply the individual probabilities:
For the A+ parent, there is ½ chance of giving O allele and ½ chance of giving Rh- allele
½ * ½ = ¼ chance of the child inheriting O- from the first parent.
For the B+ parent, there is ½ chance of them giving the O allele and ½ chance of them giving the Rh- allele.
½ * ½ = ¼ chance of the child inheriting O- from the second parent.
To obtain the chance of the offspring having the genotype OO--, multiply the two probabilities: ¼ * ¼ = 1/16.

20 What is the genotype of the shaded individual in the pedigree?

A. AO+-
B. AO++
C. AA++
D. AA+-

We know they are heterozygous for both alleles because of the B- offspring.



21 What is the genotype of the striped individual in the pedigree?

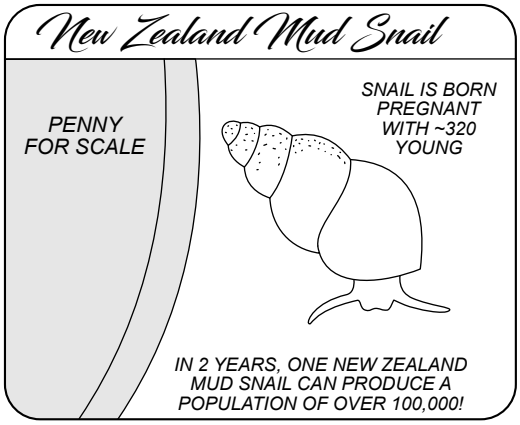
A. BO+-
B. BO- -
C. BB+-
D. BB- -

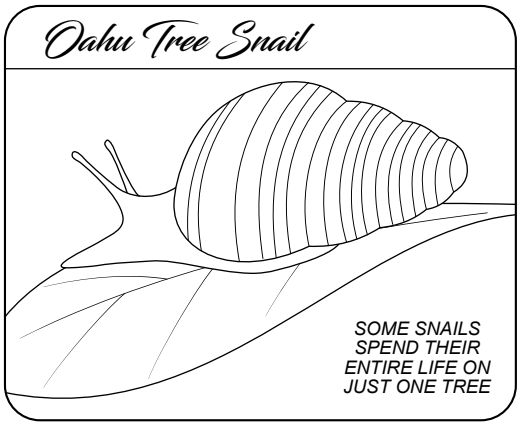
The phenotype of Rh negative is always homozygous recessive (--). The B allele came from the father. If the mother (blood type A+) and had given the A allele, the blood type would have been AB-. Since the blood type is B-, the mother must have given the O allele.

Invasive vs Endangered

FILL IN THE BLANKS USING THESE WORDS:

fungus | adaptable | species | traits | clone | seven





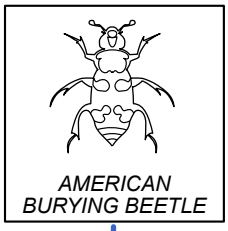
Invasive species like the kudzu vine or the New Zealand mud snail have specific **traits** that make them more prolific and adaptable than other **species**. These traits are why they are so successful at taking over.

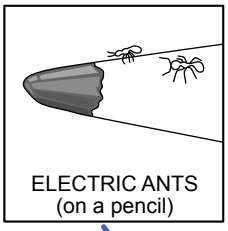
Endangered species like the white fringeless orchid or Oahu tree snails have traits that make them less **adaptable** or slower to reproduce.

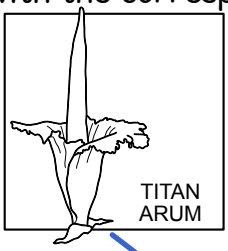
While a kudzu seed can germinate in virtually any soil, orchid seeds can only germinate by bonding with a specific species of **fungus**. The fungus they need often depends on old growth forests.

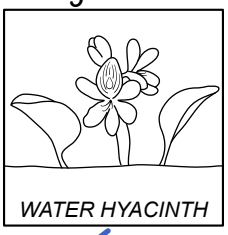
A single New Zealand mud snail can **clone** itself to start a new population, and each of its offspring is born pregnant! The Oahu tree snail, on the other hand, must be almost **seven** years old before it is mature enough to mate. When it does reproduce, it needs a partner snail, and the pair will only have one to four offspring.

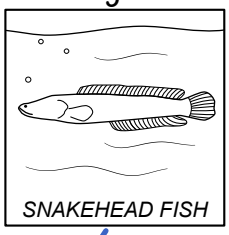
Draw lines to match each trait with the corresponding invasive or endangered organism:











This animal only eats carrion. It needs to lay its eggs in a dead bird or rodent in order to reproduce.

Each plant produces thousands of seeds per year. Seeds can remain viable for 28 years.

This animal can eat almost anything. Its venom allows it to attack and eat prey 1,000 x larger than itself!

This animal can produce 150,000 eggs a year. It lives underwater but can survive on land for up to 4 days.

This plant flowers once every 2 to 7 years and is pollinated by nocturnal beetles and flies.

This animal only lives in rivers and lakes in the Andes that are 3,800 meters (12,500 feet) above sea level.

What about in YOUR climate?

Research the ecology of where you live to discover if there are any invasive or endangered species near you. If there are none in your area, research one invasive and one endangered species for a similar climate.

TROPICAL	DRY	TEMPERATE	CONTINENTAL	POLAR
				
Every month of the year averages 18°C / 64° F or warmer. Lots of rain.	Low precipitation. At least one month warmer than 10°C / 50°F.	Temps in coldest month do not average below freezing. The warmest is above 10°C / 50°F.	Coldest month is below freezing, warmest is above 10°C / 50°F.	Temperatures for every month of the year average below 10°C / 50°F.

INVASIVE SPECIES

Common name: _____

Scientific name: _____

Average number of offspring produced in one year: _____

Preferred diet or growing conditions: _____

What native species is it competing with? _____

What traits or characteristics contribute to this species being invasive?

There are many different options to choose from! Research a species specific to where you live. A few invasive species in the US and Canada include: Zebra Mussels, Asian Carp, Burmese Python, Purple Loosestrife, Fire Ants, Argentine Ants, Kudzu Vine, Cane Toad, Rusty Crayfish, Tamarisk, Sea Lampreys, Emerald Ash Borer, and Leafy Spurge.

ENDANGERED SPECIES

Common name: _____

Scientific name: _____

Average number of offspring produced in one year: _____

Preferred diet or growing conditions: _____

What traits or characteristics contribute to this species being endangered?

There are also several options to choose from in this category! Research a species specific to your area.

A few endangered species in the US and Canada include: Devil's Hole Pupfish, Oahu Tree Snail, Kemp's Ridley Sea Turtle, Florida Panther, Dusky Gopher Frogs, California Condor, and Ozark Hellbender (a salamander)

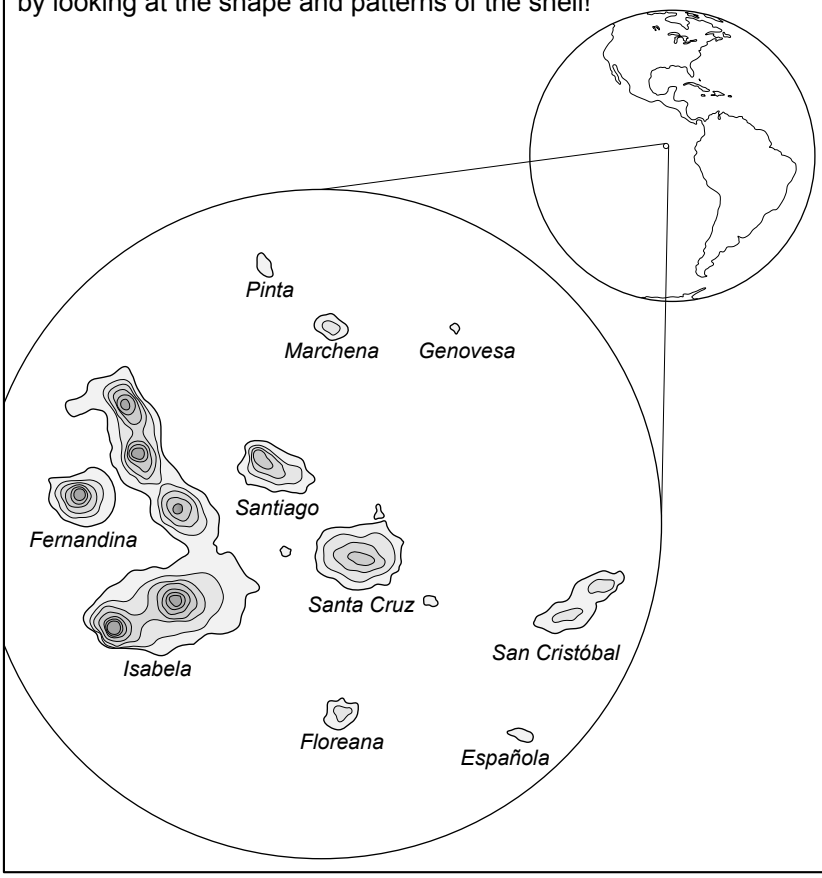
Darwin and a journey around the world

In 1831, Charles Darwin secured passage on a ship conducting a mapping expedition that would circle the globe. The captain was interested in science and had more than 400 books onboard.

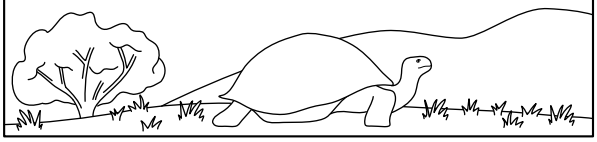
After visiting South America, the ship sailed to the Galapagos Islands.

In a few days' time, the Beagle will sail for the Galapagos Islands. I look forward with joy and interest to this, both as being somewhat nearer to England and for the sake of having a good look at an active volcano!
- Charles Darwin

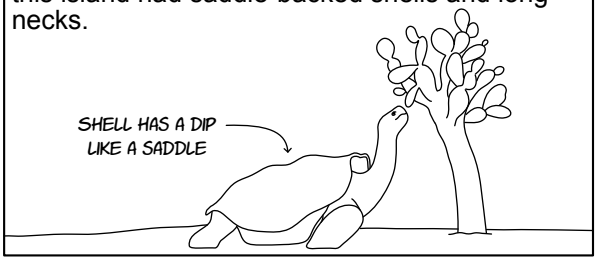
Darwin was fascinated by the diversity of life between the different islands. It was possible to tell which island a tortoise came from just by looking at the shape and patterns of the shell!



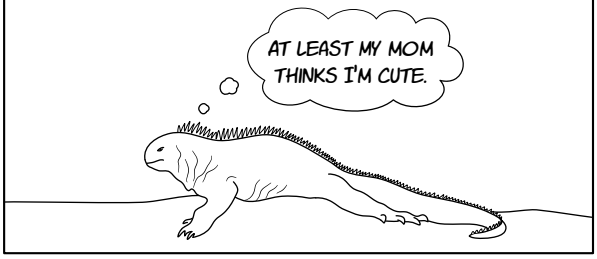
Santa Cruz was a green island with abundant food for tortoises such as grasses. The tortoises on this island had domed shells.



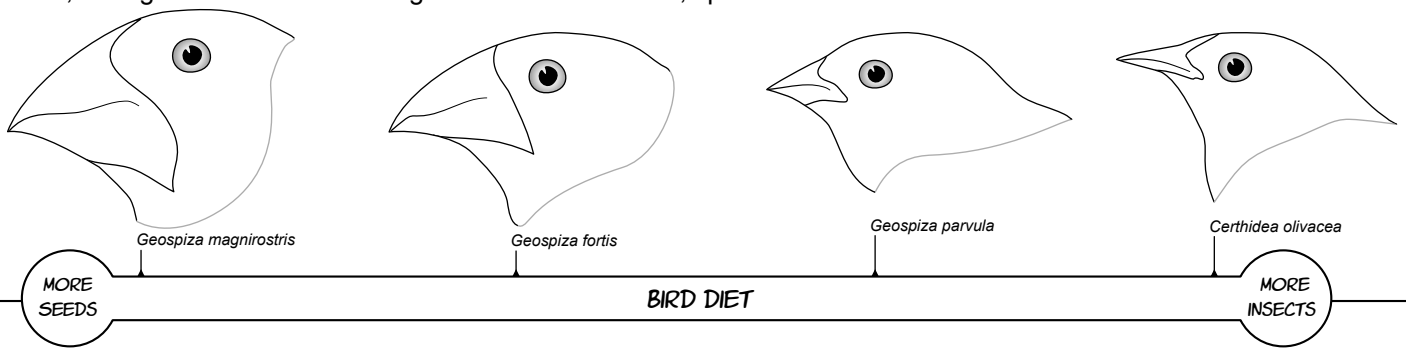
Española was an arid island. The tortoises on this island had saddle-backed shells and long necks.



The islands also had iguanas, which Darwin described as "disgusting imps of darkness."



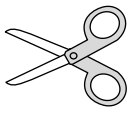
Darwin noticed that the finches on different islands had differently-shaped beaks. Finches that primarily ate seeds had thicker, stronger beaks. Insect-eating finches had narrower, spear-like beaks.



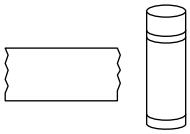
Hands-on Science Project

MAP THE JOURNEY OF THE H.M.S. BEAGLE

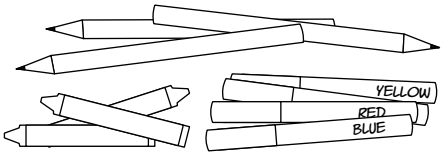
MATERIALS:



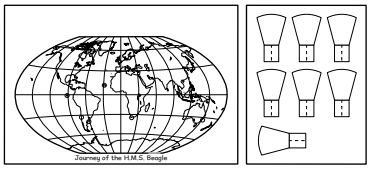
scissors



tape or glue



crayons, colored pencils, or markers



world map and 3-D labels (templates in appendix)

The Beagle had made one previous trip to South America to survey and map the area. A second journey was planned that would circumnavigate the globe. Charles Darwin secured passage as the ship's naturalist. The journey took 5 years and included many extended stops with exploration expeditions. Darwin wrote frequent letters and kept a detailed diary as they traveled. His observations were instrumental in the famous book he published years later: *On the Origin of Species.*

Map the journey

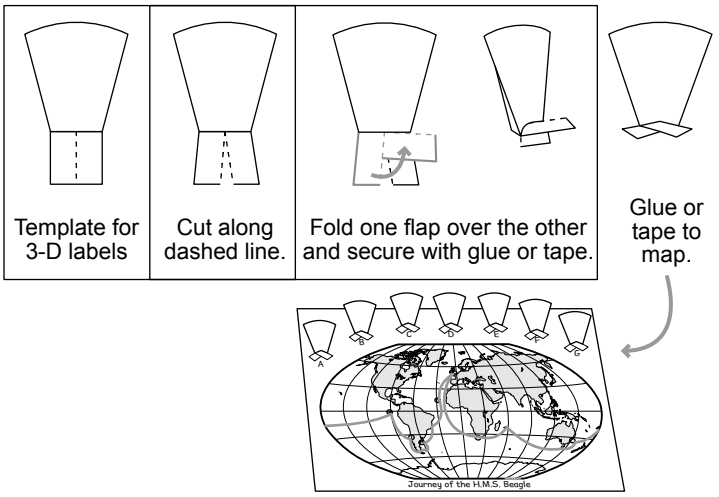
1. Print and color the world map (pg 120 in the appendix). Then draw the 1831-1836 journey of the H.M.S. Beagle on the map. Use the list of stops and example map below to help chart the course.

2. Match each of the clues on the following page to the circled locations on the world map template.

3. Color the 3-D pop up labels. You can use either the pre-drawn cutouts or create your own (instructions in appendix).

4. Cut and fold each cutout, securing the flaps with glue so that they stand upright.

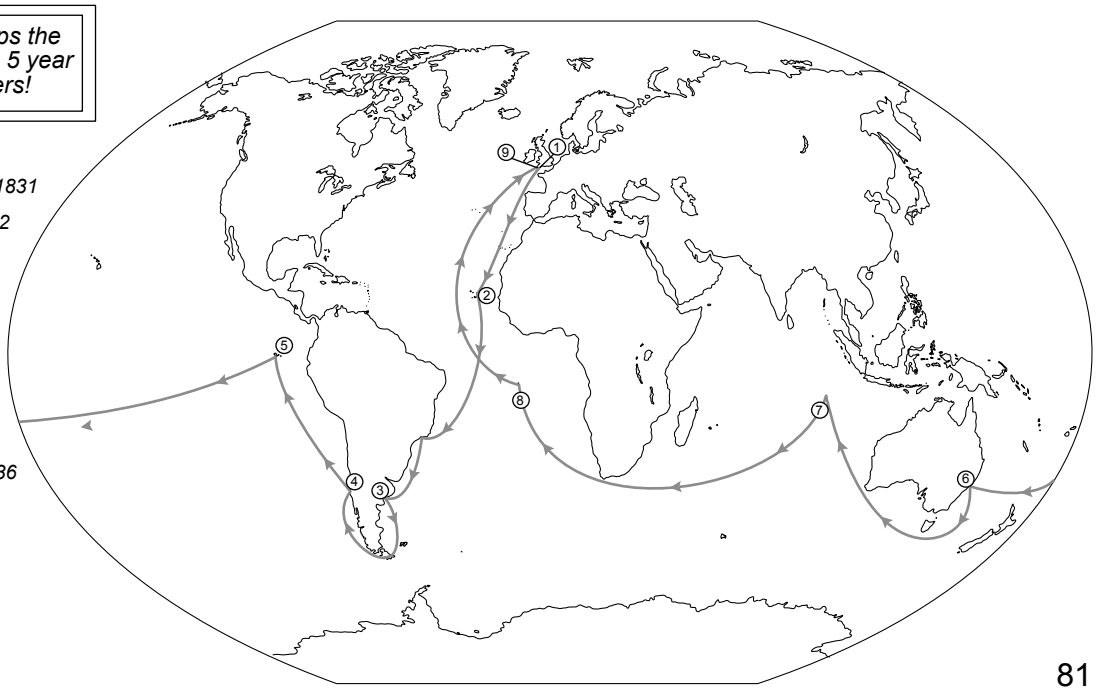
5. Arrange the 3-D cutouts across the top of the map. Glue them in place and write the corresponding letter or place name next to each cutout.



Selected stops along the way

These are just a few of the stops the H.M.S. Beagle made during its 5 year journey. There were many others!

1. Plymouth, England *Dec 27, 1831*
2. Cape Verde Islands *Jan 1832*
3. Punta Alta *Sep 1832*
4. Concepción *Mar 1835*
5. Galápagos *Sep-Oct 1835*
6. Wallerawang *Jan 1836*
7. Keeling Islands *Apr 1836*
8. Ascension Island, *Jul 1836*
9. Falmouth, England *Oct 2 1836*



7 STOPS MADE BY THE H.M.S. BEAGLE

Draw lines between each description to match it with the correct location. Each description matches a stop made by the H.M.S. Beagle. The pictures on the next page provide additional clues.

It was here Darwin found the fossilized skull of an extinct megatherium (giant ground sloth), which was about the size of an elephant! This skull allowed scientists to assemble a full megatherium skeleton for the first time.

CLIMATE: SUBTROPICAL
CLOSEST OCEAN: ATLANTIC
CLOSEST CONTINENT: SOUTH AMERICA

Darwin encountered marine iguanas, birds, land tortoises, and many other creatures. While studying finches, he noticed distinct differences in their beaks that correlated with the differences in their available food.

CLIMATE: HOT AND DRY
CLOSEST OCEAN: PACIFIC
CLOSEST CONTINENT: SOUTH AMERICA

After a large earthquake, Darwin found mussel beds had been raised above the water level. He also found marine shells in the mountains that proved the land had risen over time.

CLIMATE: SUBTROPICAL
CLOSEST OCEAN: PACIFIC
CLOSEST CONTINENT: SOUTH AMERICA

Concepción

Punta Alta

Galápagos Islands

Though the black and red volcanic island had been described as “hell with the fire put out,” Darwin saw potential.

He later convinced the British Admiralty to plant trees on the island. A century and a half later, the island is covered in trees and vegetation with a National Park called, “Green Mountain.” The forest of planted trees didn’t just change the soil on the island, it changed the weather too!

CLIMATE: HOT AND DRY
CLOSEST OCEAN: ATLANTIC
CLOSEST CONTINENT: AFRICA

Ascension Island

Cape Verde Islands

Wallerawang

Keeling-Cocos Islands

Here Darwin saw a platypus and many other marsupials. Despite how different these marsupials were from the animals in England, he observed that they had similar behaviors and filled the same ecological niche as the mammal species back home.

CLIMATE: TROPICAL
CLOSEST OCEAN: PACIFIC
CLOSEST CONTINENT: AUSTRALIA

At these islands, Darwin saw rock made from shells and coral sandwiched between layers of volcanic rock.
The sedimentary rock could only form at the beach or underwater, yet here it was high above sea level.

CLIMATE: TROPICAL
CLOSEST OCEAN: ATLANTIC
CLOSEST CONTINENT: AFRICA

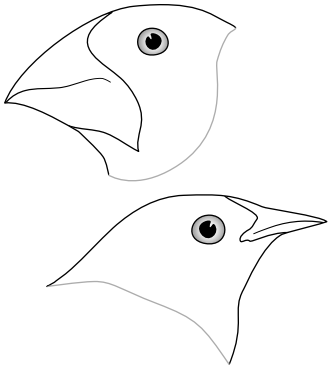
Darwin created a theory that coral reefs are formed as volcanic islands gradually subside into the ocean. At these islands, he was able to find evidence to support this theory as he collected many geological, plant, and animal specimens.

CLIMATE: TROPICAL
CLOSEST OCEAN: INDIAN
CLOSEST COUNTRY: INDONESIA

7 STOPS MADE BY THE H.M.S. BEAGLE

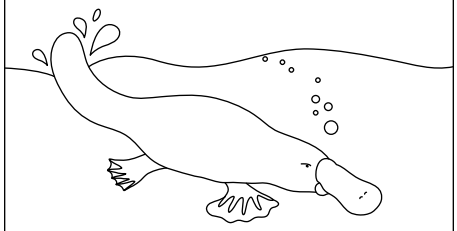
Circle the two locations you would most like to visit!

GALAPÁGOS ISLANDS



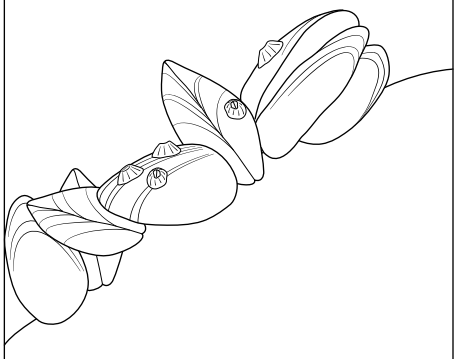
The Galapagos are part of the country of Ecuador. 97% of the islands belong to a national park and wildlife preserve.

WALLERAWANG



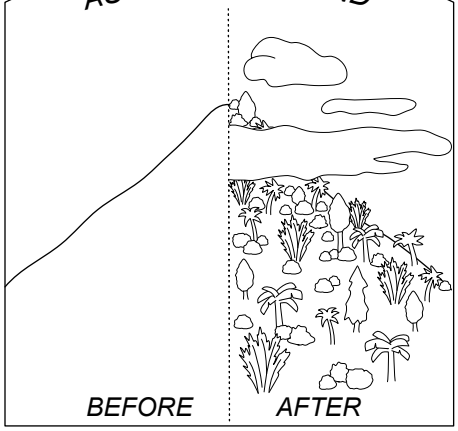
Wallerawang is located 150 kilometers northwest of Sydney near the Blue Mountains.

CONCEPCIÓN



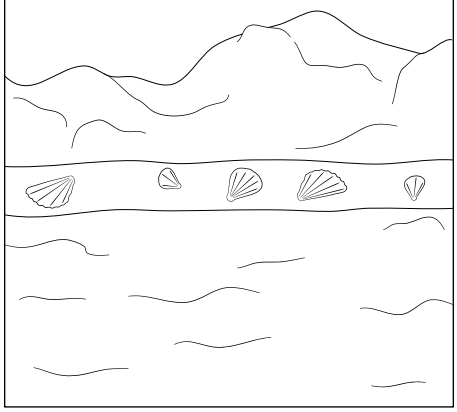
Of the world's known earthquakes of over 8.5 magnitude, nearly 1/3 have occurred in Chile.

ASCENSION ISLAND



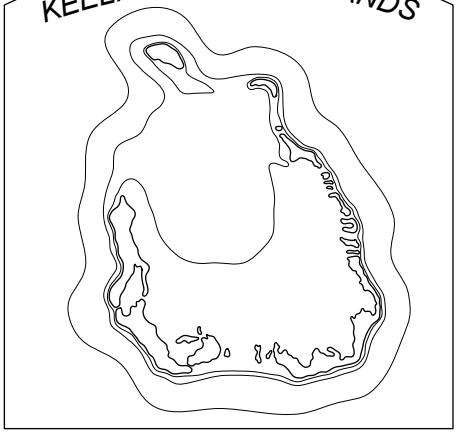
This British territory is a remote Atlantic island located about 1,600 km (1,000 miles) from the coast of Africa and 2,300 km (1,400 miles) from the coast of Brazil.

CAPE VERDE ISLANDS



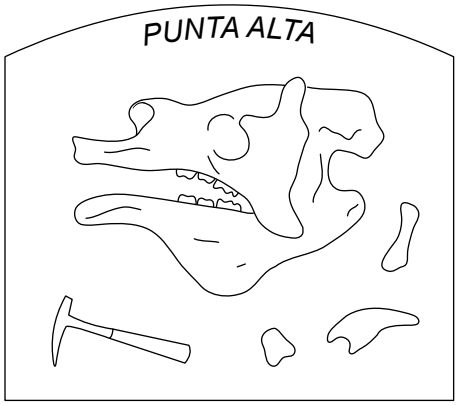
The Cape Verde Islands (officially named the Republic of Cabo Verde) is a group of volcanic islands located approximately 580 kilometers (360 miles) west of the westernmost point of Africa.

KEELING-COCOS ISLANDS



The Territory of Cocos (Keeling) Islands are an Australian territory located in the Indian Ocean. Only 2 of the 27 islands are inhabited.

PUNTA ALTA

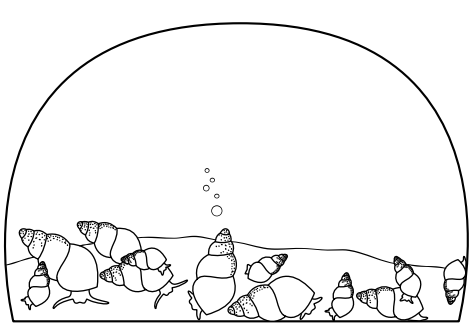


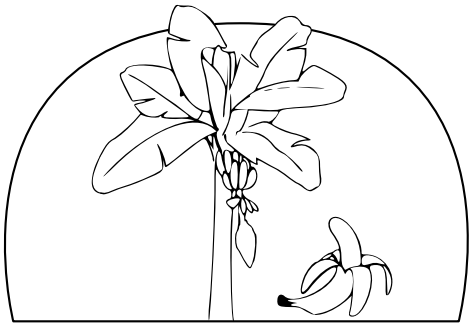
The city of Punta Alta is located on the Atlantic coastline of Argentina.

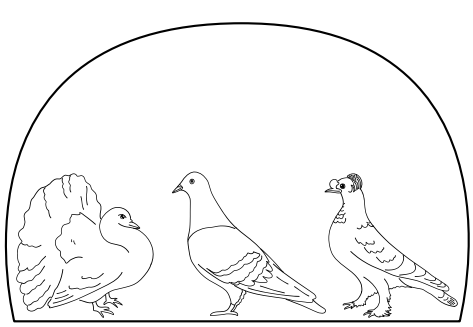
What clues from his visits did Darwin use to develop his theories of natural history and evolution?

Darwin found fossils of sea creatures on high mountains that showed shifting geology over time. He saw that plants and animals on different islands had variations that suited their needs for survival on the island, and that organisms with advantageous traits were more likely to survive and reproduce.

Genetic Variation







UNDERLINE THE CORRECT ANSWER TO EACH QUESTION:

Which reproductive strategy is most common among all the species living on Earth?		Asexual	Sexual
Which reproductive strategy produces individuals that are genetically identical?		Asexual	Sexual
Which reproductive strategy produces the most genetic variation?		Asexual	Sexual
Which of the populations above has the highest genetic diversity?	Banana	Mud Snail	Pigeon

Resources are Limited

Water, nutrients, and food are all finite resources. Consequently, not every individual will survive and reproduce. *But what if every member of a population did?* Use the information that follows to calculate the total mass of octopuses, puffballs, opossums, and elephants. Start with 100 individuals. Assume every individual survives to adulthood and reproduces once and only once. Two generations have been completed as examples.

Pacific Octopus - *Enteroctopus dofleini*
Average mass: 15 kg
Average number of offspring: 100,000

Generation 1: 100 octopuses
½ are female and ½ are male.
100/2 = 50 breeding pairs
50 × 100,000 = 5,000,000

Note that multiplying by 100,000 and dividing by 2 is the same as multiplying by 50,000

Generation 2: 5,000,000 octopuses
5,000,000/2 = 2,500,000
2,500,000 × 100,000 = 250,000,000,000 or 2.5×10^{11}

Generation 3: $250{,}000{,}000{,}000\times50{,}000 = 1.25 \times 10^{16}$

Generation 4: $1.25 \times 10^{16} \times 50{,}000 = 6.25 \times 10^{20}$

Generation 5: $6.25 \times 10^{20} \times 50{,}000 = 3.125 \times 10^{25}$

Total mass: $(3.125 \times 10^{25}) \times 15 \text{ kg} = 4.6875\times10^{26} \text{ kg}$

Western Giant Puffball - *Calvatia booniana*
Average mass: 3 kg
Average number of offspring: 1,000,000,000,000 or 1×10^{12}

Generation 1: 100 puffballs
Each puffball reproduces asexually to produce 1 trillion spores. 100 × 1,000,000,000,000 = 1×10^{14}

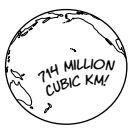
Generation 2: 1×10^{14} puffballs
1×10^{14} x 1×10^{12} = 1×10^{26}

Generation 3: $10^{26} \times 10^{12} = 10^{38}$

Generation 4: $10^{38} \times 10^{12} = 10^{50}$

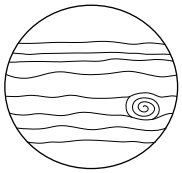
Generation 5: $10^{50} \times 10^{12} = 10^{62}$

Total mass: $10^{62} \times 3 \text{ kg} = 3 \times 10^{62} \text{ kg}$



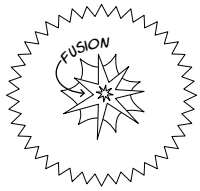
Mass of Pacific Ocean
6.8×10^{20} kg

Mass of Earth
5.97×10^{24} kg

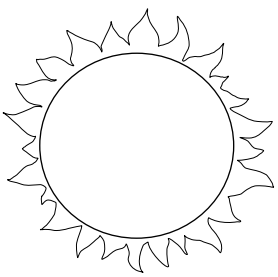


Mass of Jupiter
1.89×10^{27} kg

Star Formation Threshold



This much of anything will have strong enough gravity to create a new star!
1.6×10^{29} kg



Mass of the Sun
2×10^{30} kg

North American Opossum - *Didelphis virginiana*
Average mass: 4 kg
Average number of offspring: 16

Generation 1: 100 opossums
½ are female and ½ are male.
100/2 = 50 breeding pairs
50 × 16 = 800

For each 16 offspring, there will be 8 new mating pairs.

Generation 2: 800 opossums
800/2 = 400 pairs
400 × 16 = 6,400

Generation 3: 6,400 × 8 = 51,200

Generation 4: 51,200 × 8 = 409,600

Generation 5: 409,600 × 8 = 3,276,800

Total mass: 3,276,800 × 4 kg = 13,107,200 kg≈1.3×10^7 kg

Elephant - *Loxodonta africana*
Average mass = 5,000 kg
Average number of offspring: 1

Generation 1: 100 elephants
½ are female and ½ are male.
100/2 = 50 breeding pairs
50 × 1 = 50

Generation 2: 50 elephants
25 × 1 = 25

Generation 3: 12 breeding pairs give 12 offspring.

Generation 4: 6 breeding pairs give 6 offspring.

Generation 5: 3 breeding pairs give 3 offspring.

Total mass: 3 × 5,000 kg = 15,000 kg = 1.5×10^4 kg

Did any of the populations exceed the mass of the Earth? Yes: puffballs and octopus.

Did any of the hypothetical populations become large enough for the formation of a star? Yes: puffballs

Did any of the populations experience negative growth? The elephant population dropped.

What do you think?

In the wild, the survival rate for newly-hatched octopuses is less than 1%. What would happen if a certain species of octopus had a smaller birthrate but a higher survival rate?

It depends on how much higher and smaller the rates are! If the octopus only had 10 offspring but it stayed with them and took care of them till they were almost full grown, most of that generation would survive to reproduce. A population of "small birthrate but high-survival rate" octopuses might even grow faster than the population of octopuses where each female has 100,000 offspring.

Did the model of elephant population growth reflect what we observe in the real world? Why or why not? How could the model be adjusted to better reflect real-world conditions?

No. In the real world, elephants have more than one offspring because they have more than one pregnancy. The model would be more accurate if it used the average number of offspring an elephant had over a 25 year period, or during its lifetime.

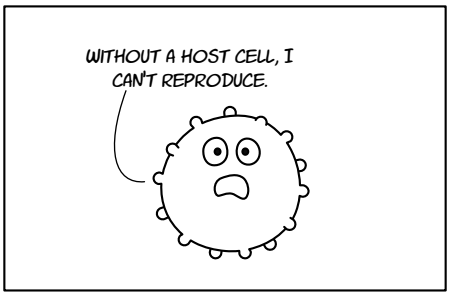
Survival of the fittest

FILL IN THE BLANKS USING THESE WORDS:

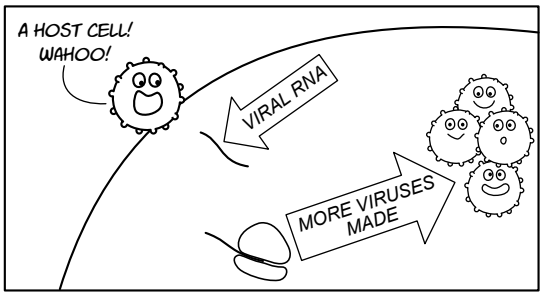
traits family mutations pressure limited survival

Not all members of a species or a ___family___ are the same. Some will have inherited different genes and ___traits___ than others, and ___mutations___ in DNA can cause further differences. If every individual reproduced, then most traits would be passed on. But because resources are ___limited___, the number of offspring that survive is also limited. Over time, the ___pressure___ of limited resources ensures that the traits passed on are those best suited for survival. This idea was first described by Charles Darwin and is called "___survival___ of the fittest." The word "fittest" in this phrase does not necessarily mean strongest or most athletic. Instead, "fit" refers to successful reproduction.

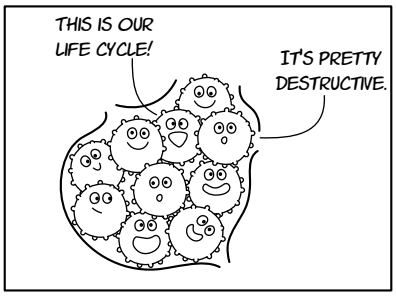
The Influenza Virus



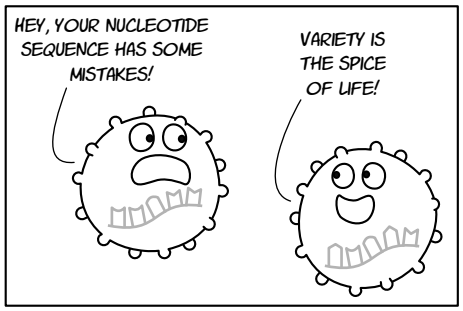
The influenza virus contains information for making more influenza viruses. But to reproduce, it needs a host cell.



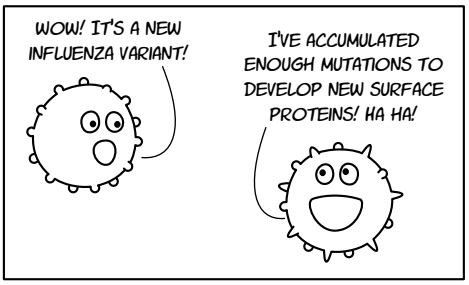
When it infects a cell, the viral RNA takes over the cell's tools for building proteins and makes more viruses.



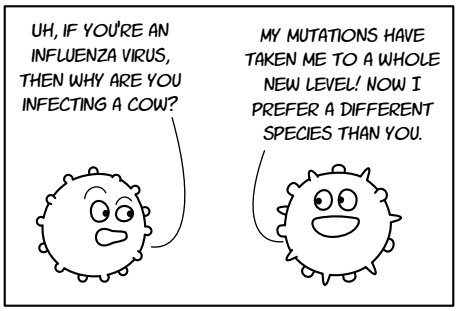
Eventually, the cell bursts. The virus particles go infect other cells.



The influenza virus has a high **MUTATION** rate. Small changes to its genetic material occur each time it infects a host.



Technically, any mutation can produce a new **VARIANT**. But most often, the term is used when talking about versions of the virus which appear or behave differently than previously described viruses.



Significantly different versions of a virus are called **STRAINS**. For example, Influenza A infects birds and humans. Influenza D only infects cattle and pigs.

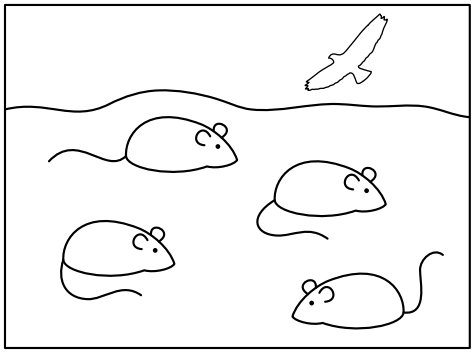
Two new variants of influenza are described: Variant X has mutated to become more transmissible and can survive on surfaces for 36 hours. Variant Y has mutated to become more fragile. It falls apart 5 minutes after leaving a host. Which variant will become more common, and why?

Variant X will become more common. It lasts longer and spreads more easily, so more people will catch Variant X and transmit it to others. Variant Y is much less likely to spread, and when it does spread, it will be less likely to continue to spread.

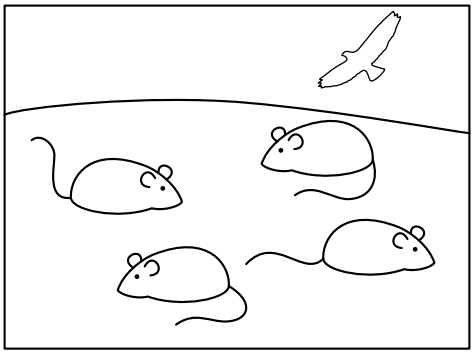
Selection

Selection happens when one item or trait is favored over another. For example, Sara buys a bag of trail mix and puts it in the kitchen pantry. Sara's brother Vance only eats the raisins from the trail mix, and then pretty soon the trail mix doesn't have any more raisins. They'll all have been "selected" out. This same process occurs in nature too.

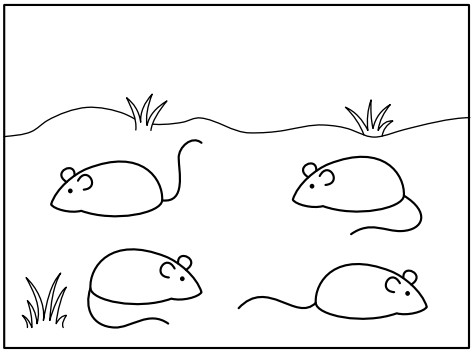
Consider a mixed population of mice where half are tan colored and half are black. Identical populations of mice arrive on three different islands. Color the islands according to their descriptions. Then match them with the most likely outcome.



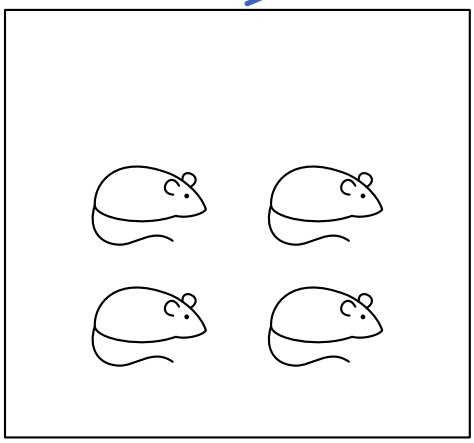
Volcanic island has black rock and hawks that hunt by sight.



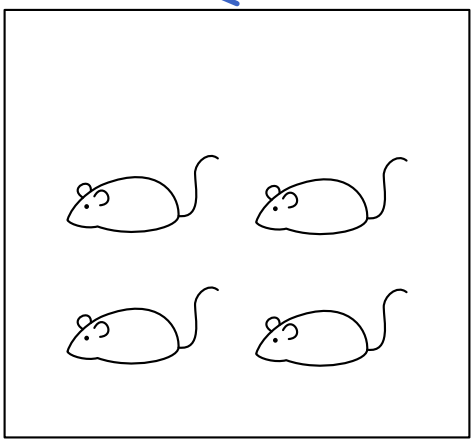
Sandstone island has tan rock and hawks that hunt by sight.



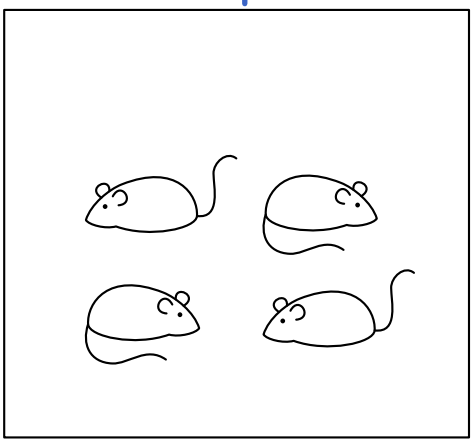
Green island has moss-covered rock and no predators.



The mouse population is all tan.

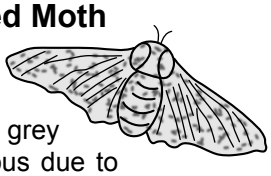


The mouse population is all black.



The mouse population is multicolored (both tan and black).

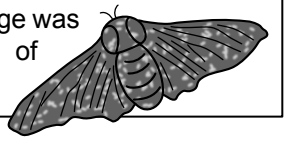
Case Study: The Peppered Moth



The peppered moth comes in both black and light varieties.

In the countryside, the light grey variety was much more numerous due to its superior camouflage. Its coloring matched that of the tree bark of many trees, allowing it to hide from predators.

In the late 1800s and early 1900s, naturalists noticed that the black peppered moth became more numerous than the lighter variety. The change was especially prominent in areas of London with industrial pollution.



Why was the black peppered moth more common in industrial areas?

The black peppered moth was more likely to survive because it blended in with the dark soot of the industrial areas of London. Predators were more likely to see the lighter moths, so fewer lighter moths survived and reproduced.

Adaptation

FILL IN THE BLANKS USING THESE WORDS:

alligators generations learned beaks climates confuse characteristic

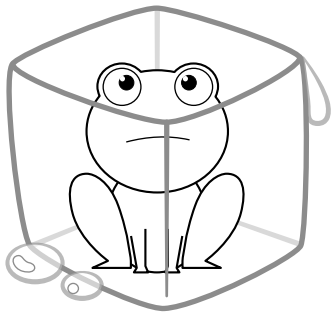
An adaptation is a characteristic that helps an organism survive in its habitat. It takes many generations for adaptations to develop. Birds have adapted different kinds of beaks that help them obtain their particular source of food. Alligators have eyes and nostrils placed on top of their heads, so they can stay mostly submerged. Spots and stripes can camouflage animals or confuse predators. In nearly all climates, plants and animals have adapted to survive and thrive. Learned behaviors are not considered adaptations.

Name a plant or animal that has the indicated adaptation:

Whiskers to help them feel their way through tight spots Rat	*Lives in large herds to protect against predators* Wildebeest	*Webbed feet for faster swimming* Duck
Fur that shifts color with the seasons Rabbit	*A look-a-like of a venomous or poisonous animal* King snake	*Acute eyesight to see prey at a distance* Peregrine falcon
Hibernation in cold seasons Groundhog	*Camouflage to blend in with surroundings* Chameleon	*Toxins excreted through their skin* Poison dart frog

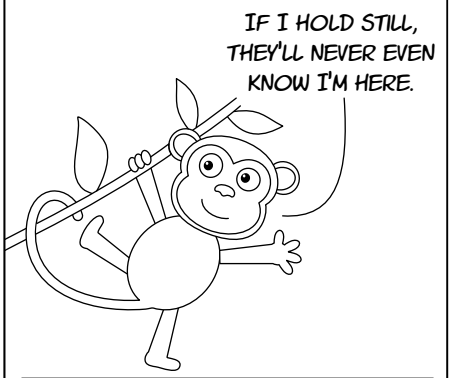
ARE THESE FACT OR FICTION? *Write your verdict below each statement.*

Some frogs freeze solid in the winter, then thaw out in the spring.



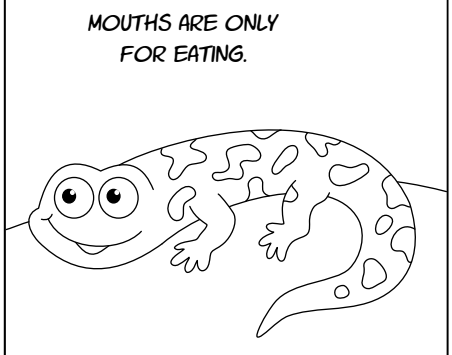
Fact - Wood frogs do exactly this!

The chameleon monkey can can change its skin to match its surroundings.



False. No such monkey exists.

Some salamanders have no lungs. They breathe through their skin!



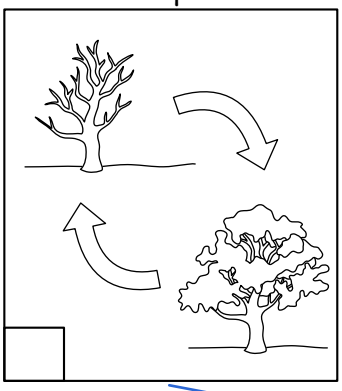
Fact - the arboreal salamander and the California slender salamander, don't have lungs or gills as adults.

Evolution

Evolution is change over time. More specifically, evolution is *descent with inherited modifications*. Mutations are always occurring, which introduces new variations into genetic material. The mutations that have advantages will be selected, and soon the genetic information of a population will be different than it was before. This change is evolution.

Sometimes the change is on a small-scale, such as changes in how often an allele appears in a population. Other times, the change is on a large-scale, such as when different species descend from a common ancestor.

Match each picture with the correct description. Check the box if it is an example of evolution.



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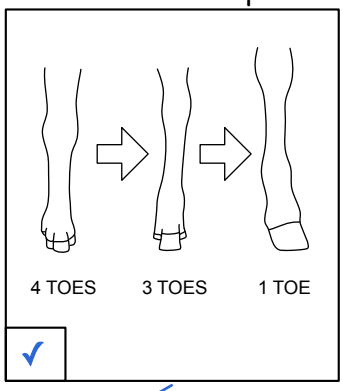
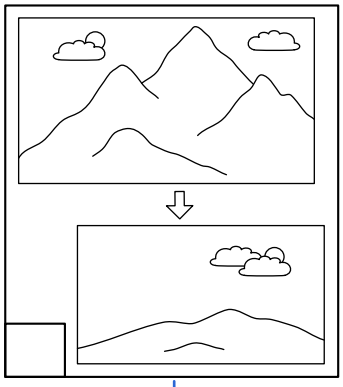


✓



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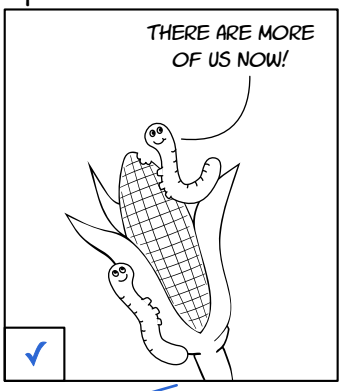


✓

Prehistoric horses were grazing animals that walked on four toes.

Over millions of years, the fossil record shows a change in the foot structure of the horse, leading to an animal that walks on one toe.

Farmers grew corn with Bt, a pesticide that killed more than 99.9% of corn borer insects.

Years later, the farmers discover that Bt is not killing as many insects.

Genetic testing shows that many insects have a gene that makes them resistant to Bt.

A mountain range that was once very rugged becomes eroded over time and eventually becomes smaller and covered in trees.

Geological evidence also shows that several ancient landslides changed the shape of the mountain range.

A large oak tree experiences many changes each year.

It flowers in the spring and produces acorns and lots of leaves. Then in the fall and winter, all of the leaves and acorns fall to the ground.

The next spring, the cycle begins again.

Can a single animal evolve? Why or why not?

No. Not according to the biological definition of "evolve." Evolution can only happen through descent with modification, which requires multiple generations.

Can a population of animals evolve? Why or why not?

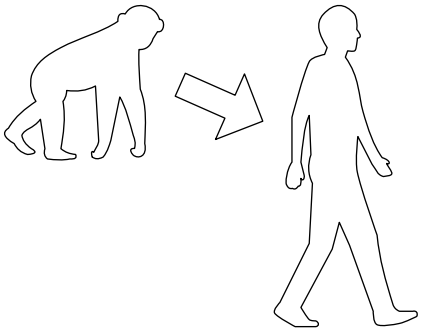
Yes, but only over time across generations. Genes for new traits can arise through mutations or the proportions of certain genes can change over time either through natural selection or through random processes. This is evolution.

Misconceptions about evolution

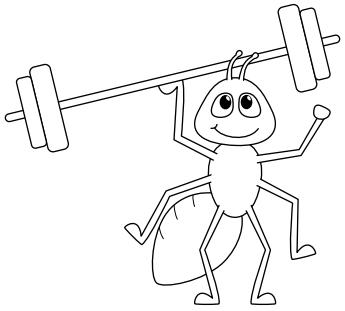
Here are three common misconceptions about evolution. Can you spot the errors in each idea or think of a counter example? Correct each idea by writing a better explanation in the boxes below.

THE MISCONCEPTIONS

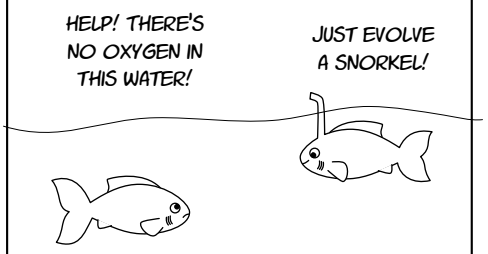
Humans evolved from chimpanzees.



Evolution always results in stronger and better organisms.



Humans can't permanently damage an ecosystem because species will evolve the traits they need to survive.



YOUR CORRECTIONS

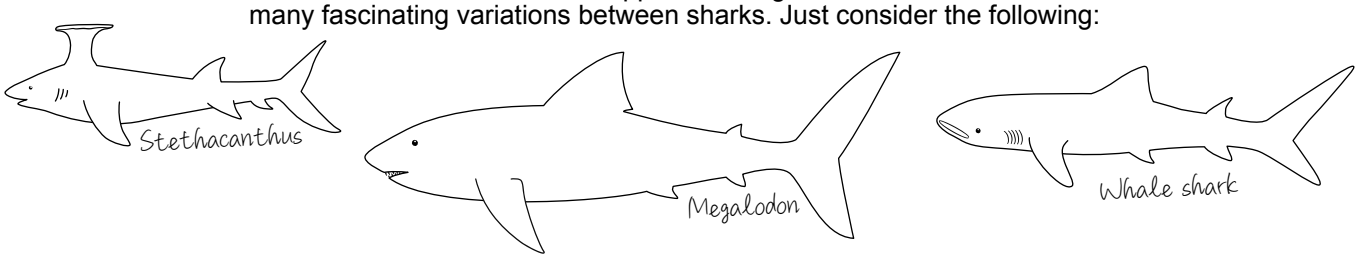
Chimpanzees did not evolve into humans. Humans and chimps are related because they both evolved from a common ancestor after diverging 12.1 million years ago.

Natural selection results in improved ability to survive and reproduce in a given environment. Evolution selects for "good enough to reproduce" but this is not always the stronger or "better" organism!

Evolution takes generations and can only take place if there is sufficient diversity and numbers of individuals in a breeding population. If an ecosystem is extensively damaged, it can cause species to go extinct.

ONCE A SHARK, ALWAYS A SHARK?

The first spiny sharks evolved during the Silurian Period, nearly 450 million years ago! Their cartilaginous skeleton and streamlined shape are still observed in modern shark species. But does that mean sharks have stopped evolving? Not at all! There have been and continue to be many fascinating variations between sharks. Just consider the following:



Stethacanthus, a Carboniferous shark with an anvil-like fin

Megalodon, a Cenozoic giant more than 65 feet long

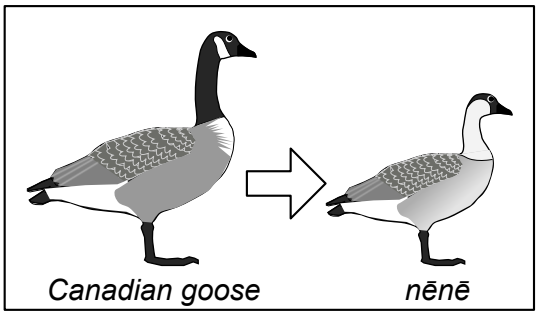
Rhincodon or whale sharks, a modern filter-feeding shark

Mitsukurina or goblin shark, a modern deep-sea shark

Sphyrna or hammerhead shark, a modern shark with an elongated head structure called a cephalophoil

Genetic Drift

About 500,000 years ago, a group of **Canadian geese** (*Branta canadensis*) were blown off course and landed on the the islands of Hawaii.



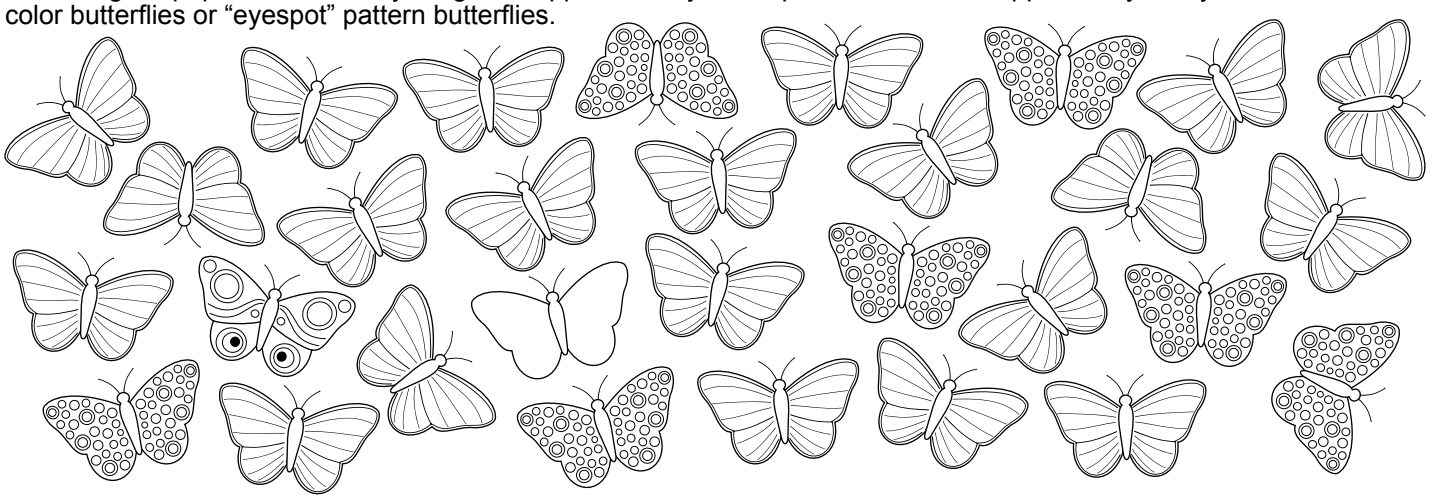
The environment of Hawai'i was different than North America. On Hawaii, the geese enjoyed a more stable temperature, so they didn't have to migrate. They also had fewer predators, making flight less of a priority.

Over time, the coloring changed, and some of the geese lost the ability to fly. Today, the only surviving species of goose on Hawaii is called the **nēnē** (*Branta sandvicensis*). It's smaller than its Canadian goose cousin, and it doesn't migrate.

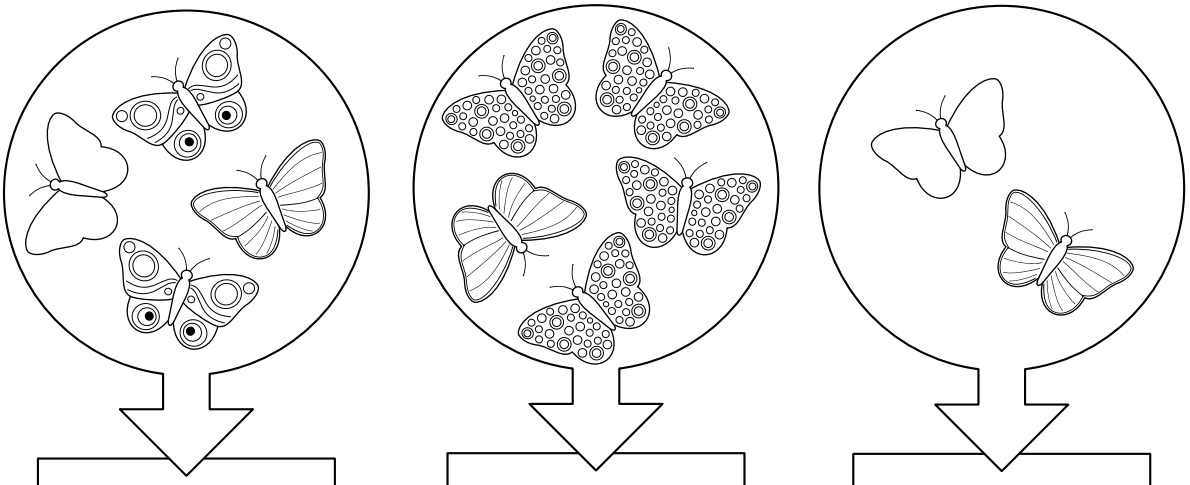
When humans introduced new species to the Hawaiian islands, the nēnē nearly went extinct because they were not adapted to predators. In the 1700s, there were estimated to be more than 25,000 nēnē living in the Hawaiian islands. In 1952, there were only 30! Fortunately, conservation efforts brought the nēnē back form the brink of extinction. Today, there are approximately 3,000 nēnē living in the islands of Hawaii.

The Founder Effect

In the original population, butterfly wings are approximately 75% spotted and 25% stripped. Very rarely, there are solid color butterflies or "eyespot" pattern butterflies.



What happens when a small group of organisms starts or "founds" a large population? Consider three small groups of butterflies from the main population. Each founds a new population on an isolated island. Assuming the proportions of traits remain the same as the populations grow, what percentage of each type would you expect to see 15 years later?



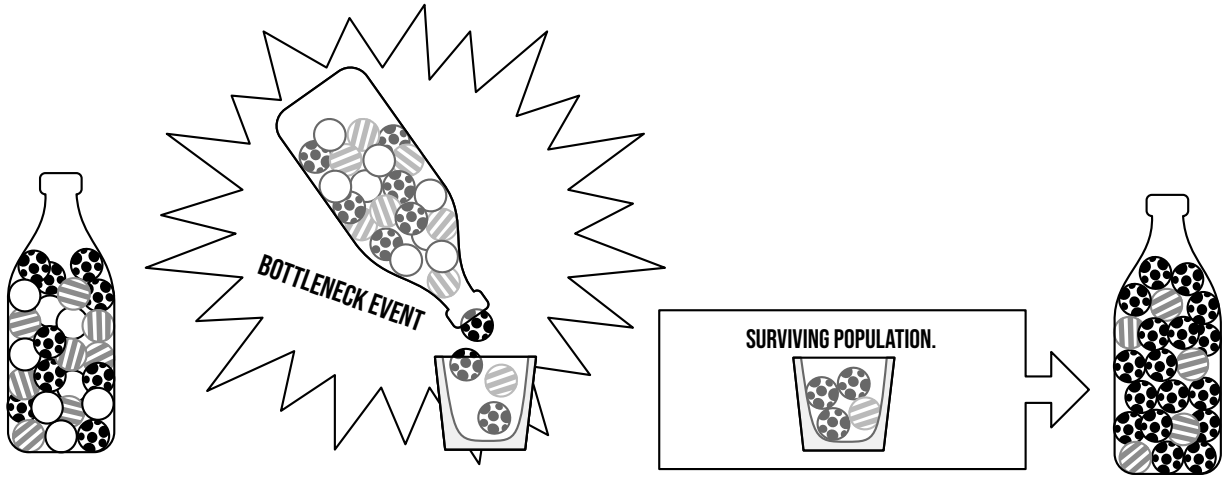
0	% spotted
25	% striped
25	% solid
50	% eyespot

80	% spotted
20	% striped
0	% solid
0	% eyespot

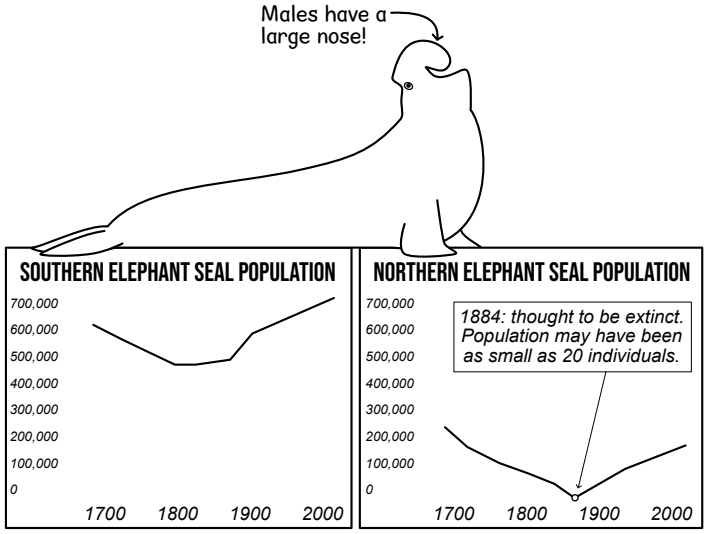
0	% spotted
50	% striped
50	% solid
0	% eyespot

Population bottleneck

A population bottleneck occurs when a substantial portion of a the population is reduced. Famine and disease are common causes of a population bottleneck. When a small group is geographically separated from the main population (the founder effect) this is sometimes considered to be is a type of bottleneck. In the case of the founder effect, other parts of the population exist that did not experience the loss of genetic diversity.



1. The original population of spheres is evenly mixed with solid, dotted, and striped individuals.
2. A bottleneck event drastically reduces the number of individuals. There are no solid spheres in the surviving population.
3. The population rebounds, but the distribution of traits is very different than before.



Why do northern elephant seals have far less genetic diversity than southern elephant seals?

The northern elephant seals dropped in population to as few as 20 individuals. The only genes available in the population came from those 20 elephant seals.

*There are currently estimated to be 200,000 northern elephant seals and nearly 700,000 southern elephant seals. Historical data is missing. The graphs are a rough guess.

The Hawaiian Islands

More than 3,000 of the species living in the Hawaiian islands are endemic, meaning they are found nowhere else in the world.

The island of Vancouver in British Columbia is slightly larger than the the combined area of the Hawaiian islands. But it has less than 20 endemic species.

Why are there more endemic species in Hawai'i?

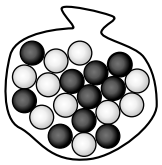
Hawaii is very isolated. There are more than 2,000 miles of ocean surrounding Hawaii in every direction! Without the help of human transportation, it is very difficult for species to get to, or leave the islands. Evolution in an isolated environment is more likely to create endemic species. Vancouver island is only 25 miles from British Columbia.

Drifting Marbles

Read through the instructions for the simulation below. But before trying it out, go to the next page and make some predictions!

This activity simulates genetic drift by considering a population of 20 marbles. To keep things simple, the population is capped at 20, and just a single trait (color) is measured. For the instructions, we chose black and white marbles, but you could use any object. You will want 40 marbles (or peas, beans, pieces of candy, etc.) with half of them being marked or colored so that they can be easily distinguished. Each generation of marbles will pass on their colors to the next generation through random selection as follows.

STEP 1 Place 10 white and 10 black marbles in a bag.



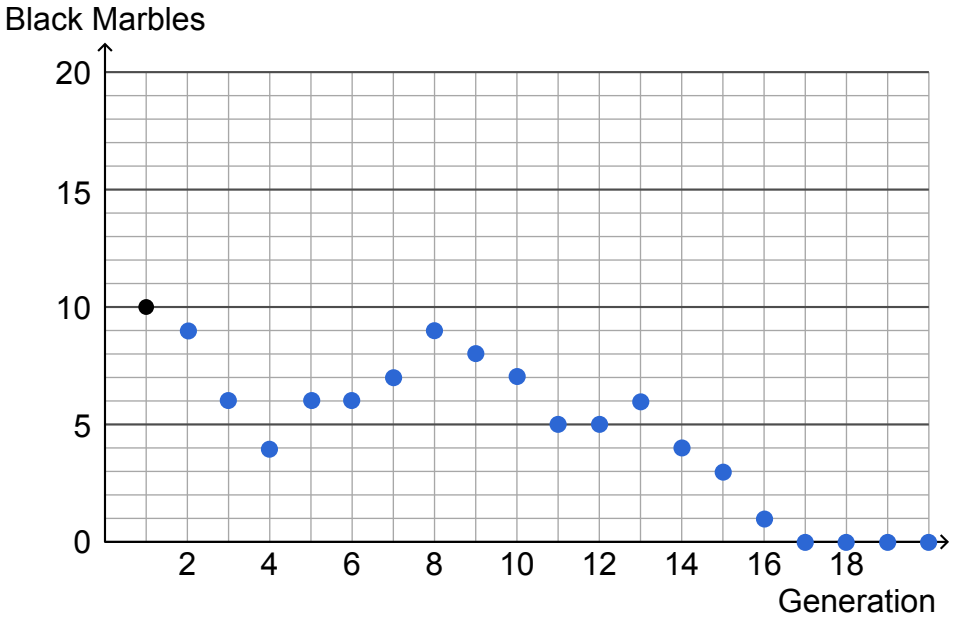
STEP 2 Draw one marble at random and record its color. ○ → W

STEP 3 Return the marble to the bag, and repeat STEP 2 until you have recorded 20 colors.

WWWBWWBBBBWBBWBBBBWW

STEP 4 Gather marbles to match the 20 colors you recorded to make up the next generation of marbles.

STEP 5 Plot the number of black marbles for this generation. Then go back to STEP 1, and repeat the process for another generation.



What do you predict will happen with the marble population? Will it stay half white marbles and half black marbles or will the proportions change over time?
The portions will likely change up and down over time. Eventually, it might become all black or all white. After that, it would stay unchanged.

Place a checkmark next to each outcome that will always be true for this simulation:

☐ There will always be 10 black and 10 white marbles.

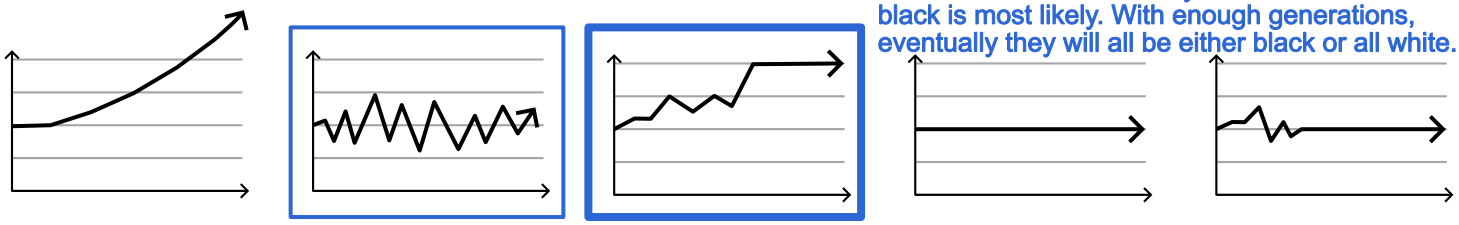
☑ After enough generations, one of the colors will disappear entirely.

☐ There will always be some black marbles and some white marbles, but the number will vary.

☑ The number of each color will eventually become stable.

Below are 5 graphs. Which one do you think is the most likely to occur in this simulation of the number of black marbles in each generation?

The answer that eventually levels out with all black is most likely. With enough generations, eventually they will all be either black or all white.



Now go back and carry out the simulation for 20 generations. Was your prediction correct?

Yes, my prediction was essentially correct. After 17 generations, only the white marbles were left. It was a random process, but the limited size of the population caused one color to "die out" eventually.

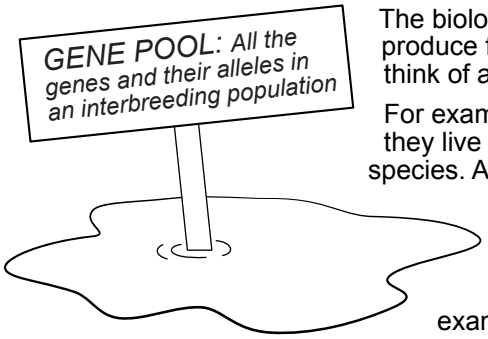
Consider how the situation would change if we didn't cap the marble population at 20. Suppose each new generation added an additional marble. Do you think that one of the colors would be eliminated from the population?

Maybe. Sometimes in the simulation, one color will be eliminated, but growing population allows both versions to stay. (We ran the simulation many times for thousands of generations and saw both scenarios occur.)

In what type of population in the real world might we see the loss of an allele through genetic drift? Give an example, and explain why genetic drift might occur.

Animals might wash up on an isolated island. If the island is small, then the population will be limited, and we would see genetic diversity disappear over the generations just through random chance in the same way we saw the black marble die out in this simulation.

What is a species?

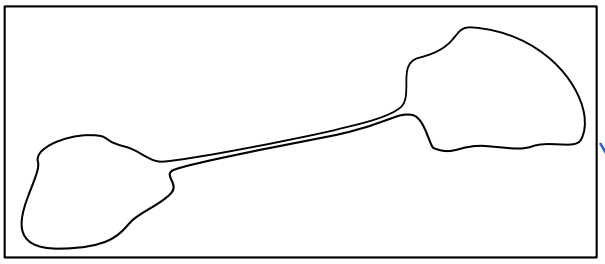


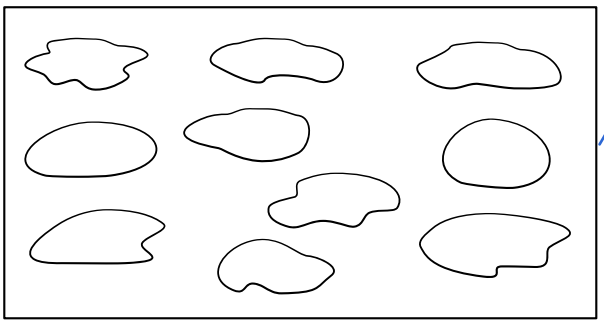
The biological concept of a species is often defined as follows: living organisms that can produce fertile offspring belong to the same species. But in practice, it's more useful to think of a species as a **gene pool** where genetic information is exchanged.

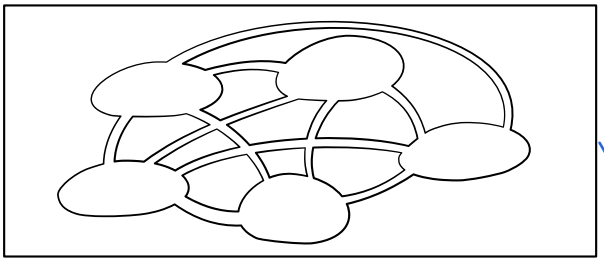
For example, lions and tigers can interbreed and produce fertile offspring, but in the wild they live in separate populations. There are two separate gene pools, one for each species. As individuals of a species breed and produce offspring, the genetic information in the gene pool changes. Mutations may arise or disappear, and the frequency of certain traits will increase or decrease.

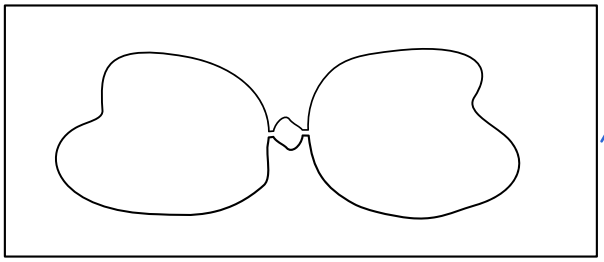
Life doesn't exactly fit into the categories people have made to help them understand the world. No matter how one defines a species, there are multiple examples where scientists have lively debates about whether a group of individuals are participating in the same gene pool or not.

Match the description of each species or group of animals with the corresponding diagram representing the gene flow within the gene pools.









Orcas are all currently classified as being part of the same species, but they live in ten distinct breeding populations. The different populations have different diets and hunting behaviors. Their social behaviors and communication techniques are different enough that they never interbreed, even when they live in the same geographic area.

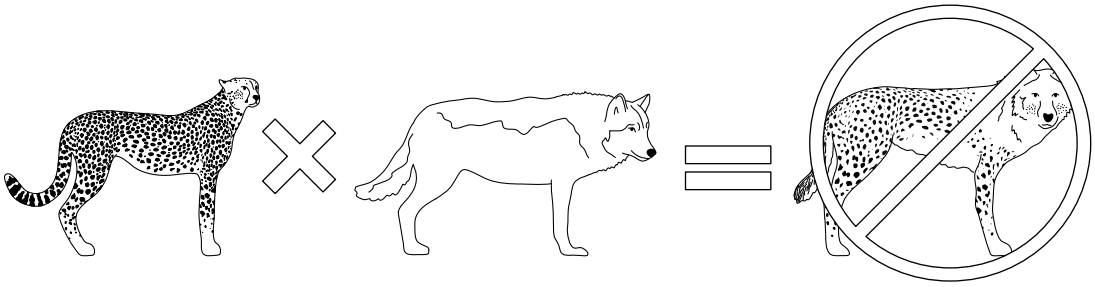
Polar bears and grizzly bears are classified as two different species: *Ursus maritimus* and *Ursus arctos horribilis.* While they live in different habitats and have different behaviors and diets, they occasionally interbreed when they come in contact with each other, producing a hybrid called a "grolar bear," "grizzlar," or "nanulak." Genetic analysis shows that hybridization has also occurred in the past.

The carrion crow, *Corvus corone,* and the hooded crow, *Corvus cornix,* are classified as separate species but hybridize freely where their geographical ranges overlap.

Species in the Asteraceae, or daisy, family hybridize easily. Members of the *Helianthus* genus (sunflowers) are especially prone to hybridizing. If five wild sunflower species live in the same area, there will likely be hybrids between all of them!

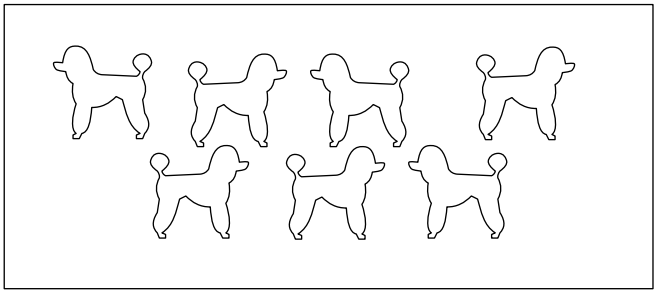
If DNA from a prehistoric dragonfly was recovered and that dragonfly was cloned, would it be the same species as a modern dragonfly? Why or why not?

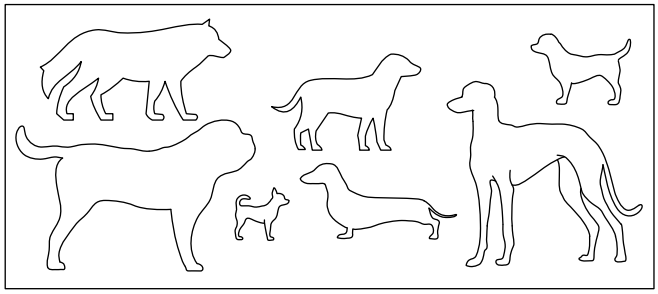
The appearance of dragonflies has remained similar over millions of years, but even so, it is unlikely that the genes will be compatible. More junk DNA will have been added to modern dragonflies and other mutations and changes would have occurred. Most likely, the modern genome would not be similar enough for ancient and modern dragonflies to breed.



Explain why a cheetah and a wolf belong to gene pools that will never naturally hybridize.

Cheetahs and wolves do not live in overlapping regions. However, even if they did, they wouldn't be able to breed. They have different numbers of chromosomes, and their most recent common ancestor lived millions of years ago.





Consider two populations of dogs, each with 1,000 individuals. The first contains pure-bred miniature poodles, and the second contains dogs from animal shelters, most of mixed or unknown breeding. Which population of dogs will have more diversity in their gene pool and why?

Which population would be more likely to survive if placed in a new location such as an island?

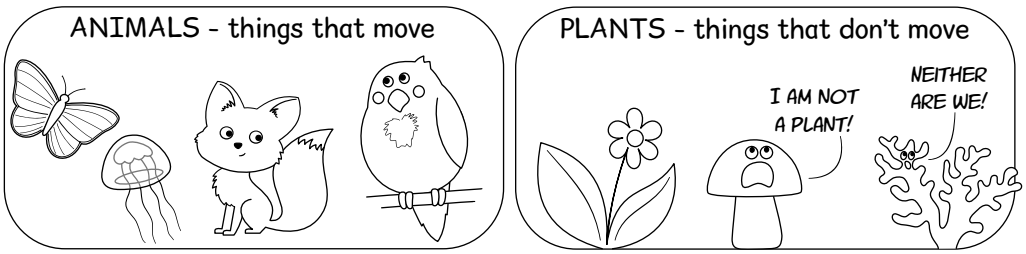
The animal shelter will have a wide variety of genes among the mixed breeds, while the poodles will share many genes, especially genes related to physical characteristics.

If they are transferred to an island to form a new population, the dogs from the animal shelter would have a better chance of surviving because their population would have more genetic diversity.

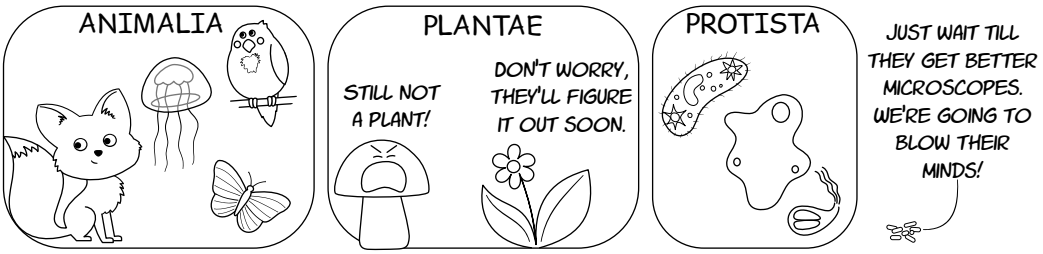
Taxonomy

Grouping living organisms according to shared attributes is called *taxonomy*. This field of study is useful in the study of biodiversity and conservation biology. There have been several different classification systems in the past. Systems change as new information is gathered.

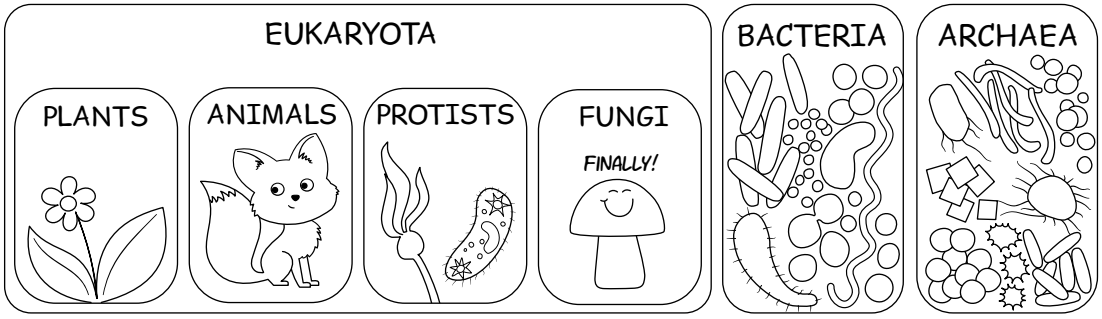
Two Kingdoms
300 BCE - Aristotle



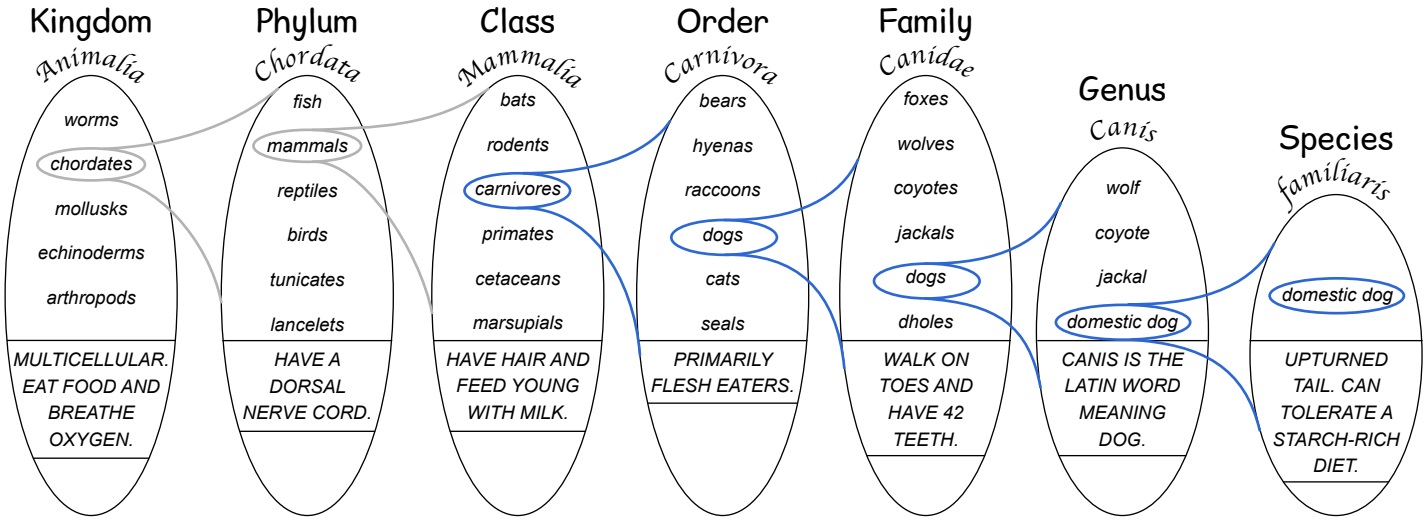
Three Kingdoms
Late 1800s - John Hogg



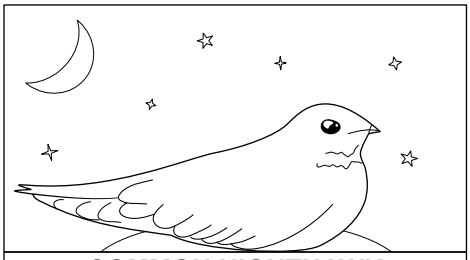
Three Domains
Six Kingdoms
1977 - Carl Woese



Within each domain there are smaller categories: phylum, class, order, family, genus, and species. Notice how much more similar the animals become in each category in the diagram below. Can you circle the correct animal type from each category to show the classification of the domestic dog? The first two have been filled in as examples.

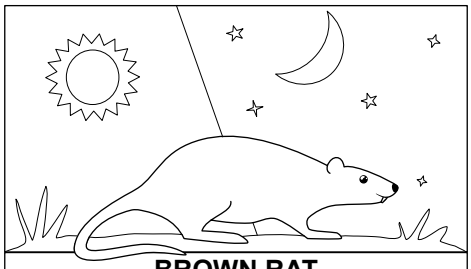


About Shared Traits



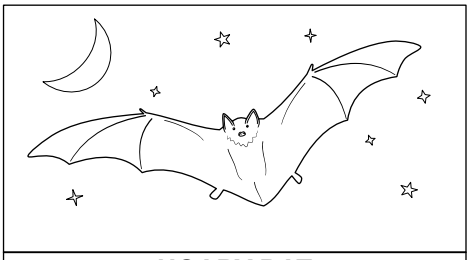
COMMON NIGHTHAWK
Chordeiles minor

MOBILITY: Flying, walking, hopping
BEHAVIOR: Crepuscular/Nocturnal
DIET: Insectivore
ANATOMY: Bones are hollow and porous. Lungs have air sacs.
REPRODUCTION: Lays eggs



BROWN RAT
Rattus norvegicus

MOBILITY: Walking, running, jumping
BEHAVIOR: Often nocturnal
DIET: Omnivore
ANATOMY: Bones are not hollow. Lungs do not have air sacs.
REPRODUCTION: Live birth



HOARY BAT
Aeorestes cinereus

MOBILITY: Flying, walking
BEHAVIOR: Crepuscular/Nocturnal
DIET: Insectivore
ANATOMY: Bones are not hollow. Lungs do not have air sacs.
REPRODUCTION: Live birth

Compare the nighthawk and rat. Which of these animals is more closely related to a bat? Support your opinion by including similar and dissimilar traits.

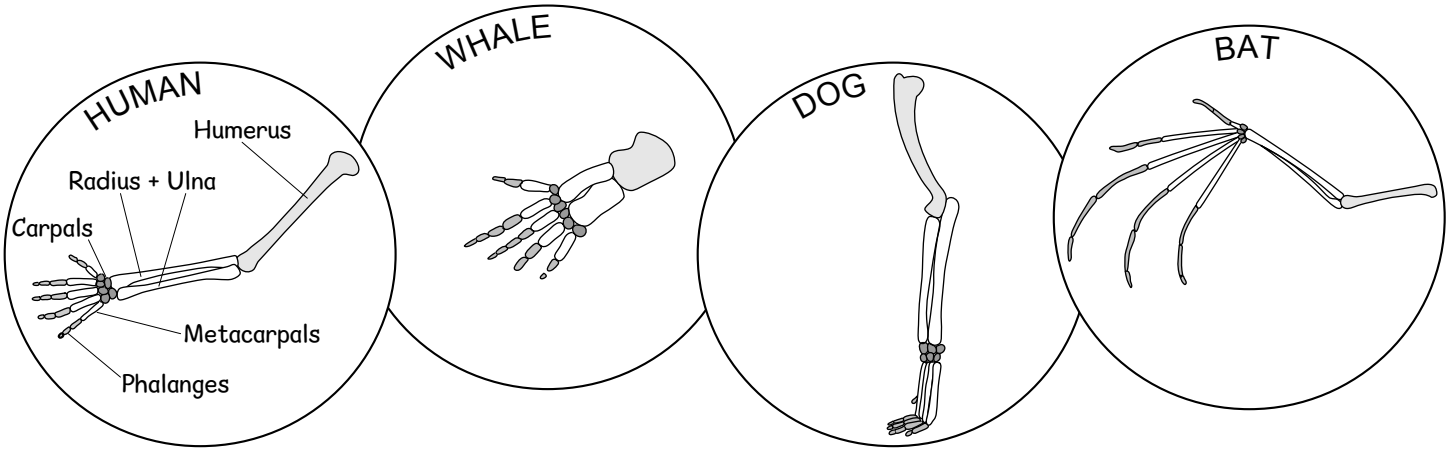
The nighthawk and bat both fly and have similar diets. However, the brown rat and bat have more in common with their anatomy and reproduction. Bats are more closely related to rats than birds because bats and rats are both mammals. While the wings of a bird and bat both provide the ability to fly, their structures are quite different.

Homologous Traits

FILL IN THE BLANKS USING THESE WORDS:

similar homologous bone common

A homologous trait is one that is inherited from a common ancestor. The bones in the limbs of tetrapods are one example of homologous traits. Dogs, whales, bats, and humans all have front limbs that look and function differently from each other. But the bone structures of those limbs are remarkably similar. Each limb has a humerus, radius and ulna, carpals, metacarpals, and phalanges.



Convergent Traits

FILL IN THE BLANKS USING THESE WORDS:

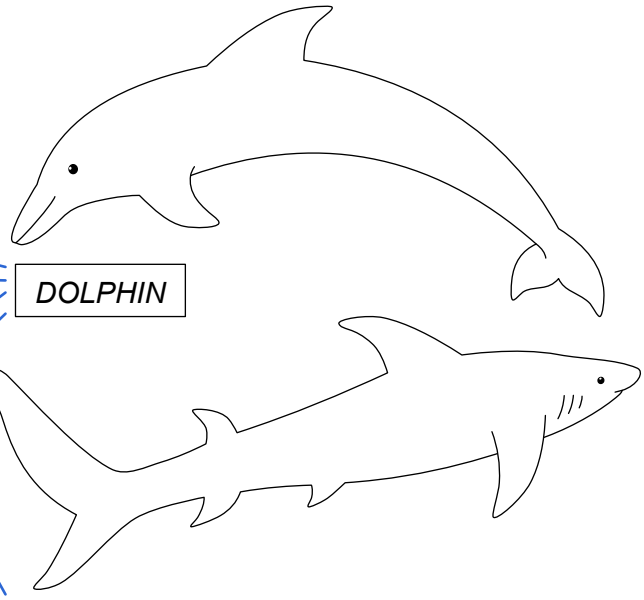
environment diets convergent closely streamlined

Sharks and dolphins look a lot alike. They both have streamlined bodies with two fins on their sides and a dorsal fin on top of their body. They also have similar diets. But these similarities do not mean that sharks and dolphins are closely related. They each have a streamlined body shape, dorsal fin, and flippers because they live in the same environment and these traits help them to swim faster to catch prey. Their shared traits are an example of convergent evolution.

SHARK vs DOLPHIN

Draw lines to match each trait to the correct animal

- *Skeleton made of cartilage*
- *Breathes air through blowhole*
- *Skeleton made of bone*
- *Uses gills to get oxygen from water*
- *Do not nurse young with milk*
- *Has hair*
- *Nurses young with milk*
- *Does not have hair*

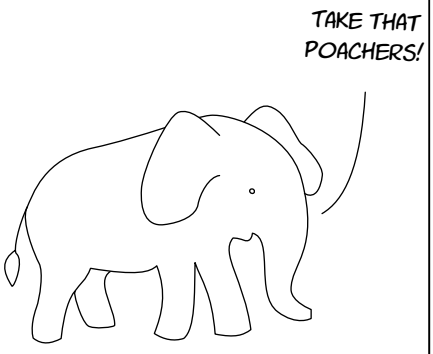


ARE THESE FACT OR FICTION? *Write your verdict below each statement.*

Bats and birds share a common ancestor.

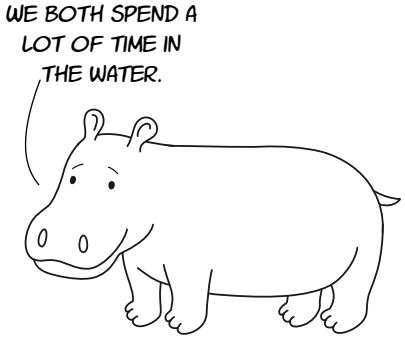
True. All vertebrates share a common ancestor.

Today's elephants have evolved to be less likely to have tusks.



True. By poaching elephants with tusks, humans have artificially selected for a lack of tusks by making those genes more likely to be passed on.

Hippos are the ancestors of whales.



False. Hippos are the most closely related land mammals to whales, but not their ancestor. Both hippos and whales descended from a common ancestor that is now extinct.

The Fossil Record

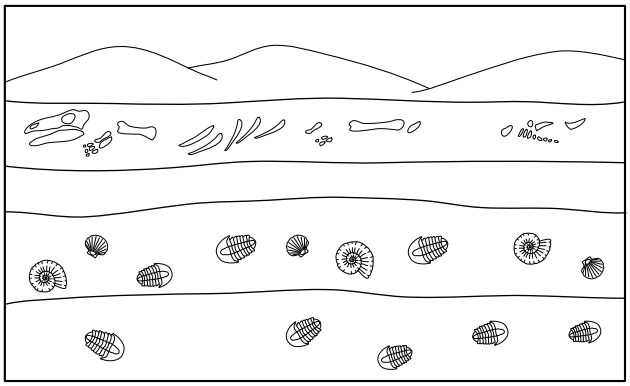
FILL IN THE BLANKS USING THESE WORDS:

pressure survive fossils complete circumstances geological

Very few organisms leave behind fossils. Fossils can only form when an organism dies at the right time, in the right place, and under the right circumstances. Over a long period of time, intense heat and pressure are needed to encase the organism within a sedimentary rock that will eventually become the fossil. Usually, only the hard parts of the body like bones and teeth can survive this process to become a fossil. Even when a fossil is made, it may not survive geological changes over time as rocks break or melt. Fortunately, the fossil record is sufficiently complete for us to learn about how life evolved throughout history.

What can be inferred about the ages of the fossils in this picture? Why do you think one layer doesn't contain any fossils?

The oldest fossils (the trilobites on bottom) are on the lowest layer. We see the dinosaurs came later as they are in higher layers. The layer without fossils may indicate that earlier organisms died out.



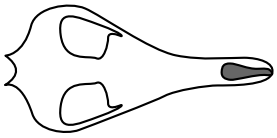
What is the best explanation for a fossil being found in an older layer of rock but not any newer layers? Draw a picture of an example.

Likely, the organism died out so there was no chance for new fossils. It's also possible the new layer is not a type of rock that forms fossils.

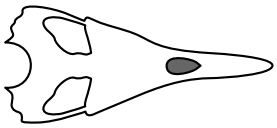
Draw lines to match the name of each fossil type with its corresponding description:

MOLD or CAST	*TRACE FOSSIL*	*ACTUAL SPECIMEN*	*PERMINERALIZED*
Something left behind by the organism  footprints	The impression of the organism  seashell mold	Tissue that has been replaced with minerals  Bone, claw, petrified wood	The actual animal or plant is preserved.  insect in amber

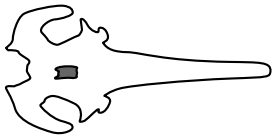
BONY NOSTRILS MIGRATE TO TOP OF HEAD



Artiocetus - *47 million years*



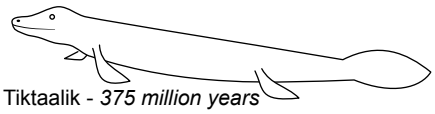
Dorudon - *36 million years*



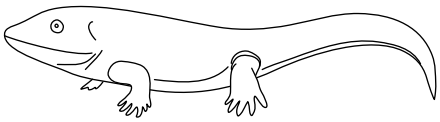
Amazon River Dolphin - *living*

LEGS EVOLVE TO ASSIST MOVING ON LAND

Panderichthys - *380 million years*

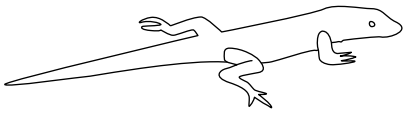


Tiktaalik - *375 million years*

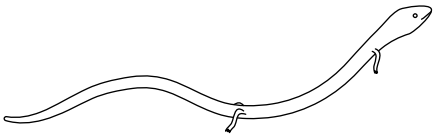


Pederpes - *348 million years*

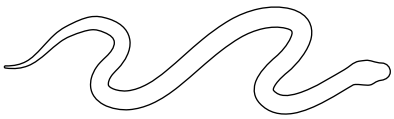
LEGS DISAPPEAR AND BODY BECOMES LONGER



Megachirella wachtleri - 240 million years



Tetrapodophis amplectus - 120 million years



Snake - *living*

Transition Fossils

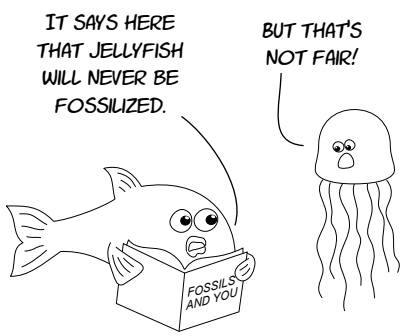
FILL IN THE BLANKS USING THESE WORDS:

snakes transitional tetrapods whales discoveries document

The fossil record has gaps where organisms and characteristics have arisen with little fossil evidence to show how the new attributes came about. Fossils that fill in a perceived gap are called transitional fossils. Darwin didn't expect to be able to fill in these holes, but many surprising discoveries have filled in the "missing links" in the fossil record. Snakes evolved from lizards with legs. Four-legged creatures (tetrapods) evolved from fish and emerged from the water to live on the land. Whales evolved from land mammals as the nostrils gradually moved to the back of the skull, the front arms were replaced with flippers, and the hind legs diminished as the tail widened. We now have fossils to document each of these changes.

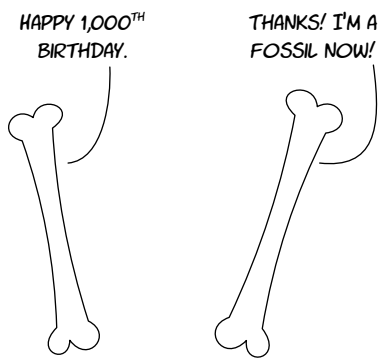
ARE THESE FACT OR FICTION? *Write your verdict below each statement.*

Soft tissue animals cannot form fossils.



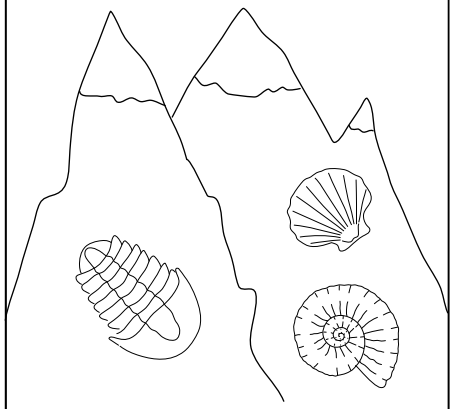
False. They can leave behind imprint fossils.

Bones can become fossils after being buried for 1,000 years.



False. Fossils are at least 10,000 years old by definition.

Sea creature fossils have been found on Mt. Everest.

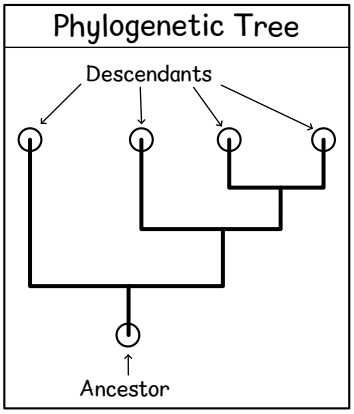


Fact

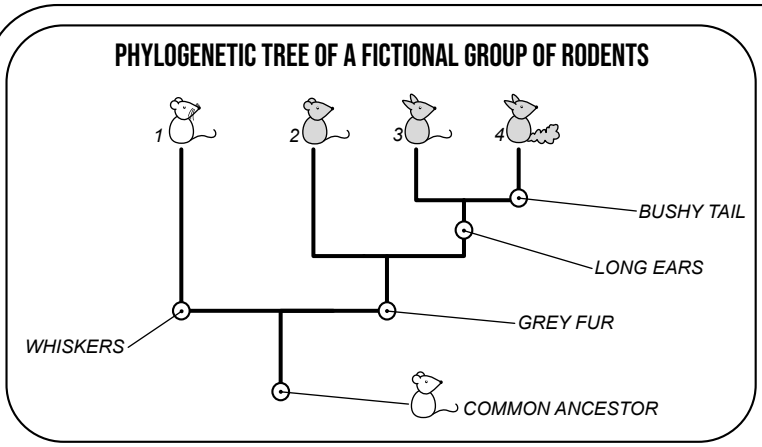
Phylogeny

FILL IN THE BLANKS USING THESE WORDS:

higher phylogeny common recent ancestor descendent speciation



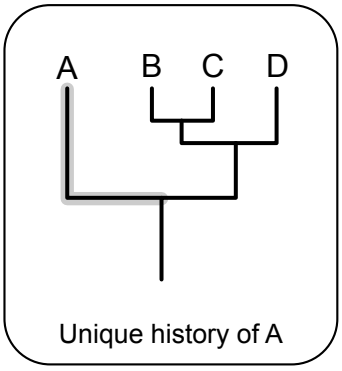
A phylogenetic tree or a ___phylogeny___ is a diagram that depicts the lines of evolutionary descent of different species, organisms, or genes from a ___common___ ancestor. The bottom of a phylogenetic tree represents the past and the ___higher___ branches represent more ___recent___ times. As we travel from the bottom to the top of the tree we are tracing the history from ___ancestor___ to ___descendent___. Each fork or branch represents the splitting of a lineage or ___speciation___.



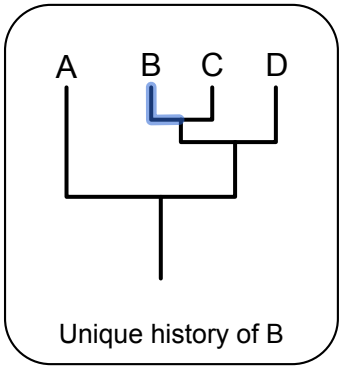
Some parts of a phylogeny will be unique while other parts will be shared. Notice the following connections:

- Rodents 3 and 4 have long ears because they both share the long-eared common ancestor.
- Rodent 2 does not have long ears because it is not connected to the long-ear ancestor.
- Rodent 1 is not grey because it is not connected to the grey fur ancestor.
- All the rodents after the "grey fur" trait have grey fur.

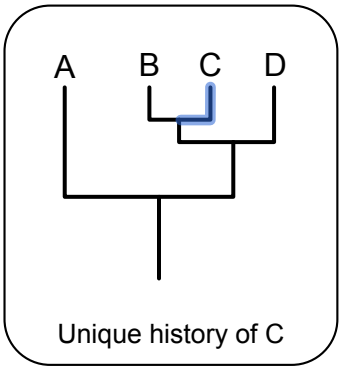
Highlight the unique or shared portions of the diagrams below. The first is completed as an example.



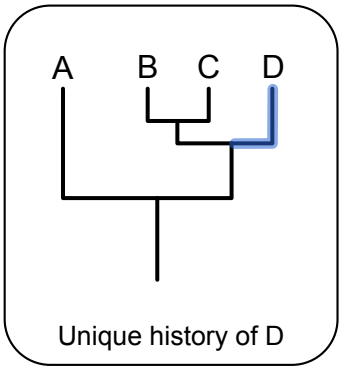
Unique history of A



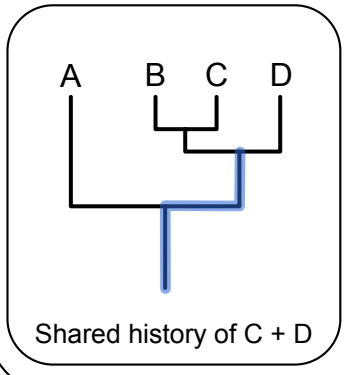
Unique history of B



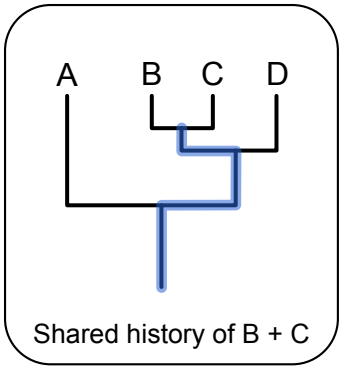
Unique history of C



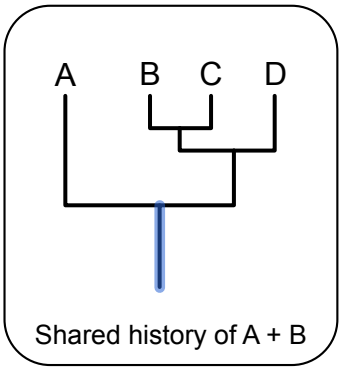
Unique history of D



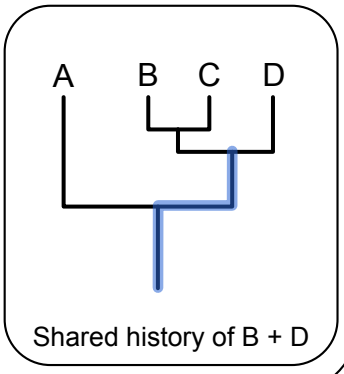
Shared history of C + D



Shared history of B + C

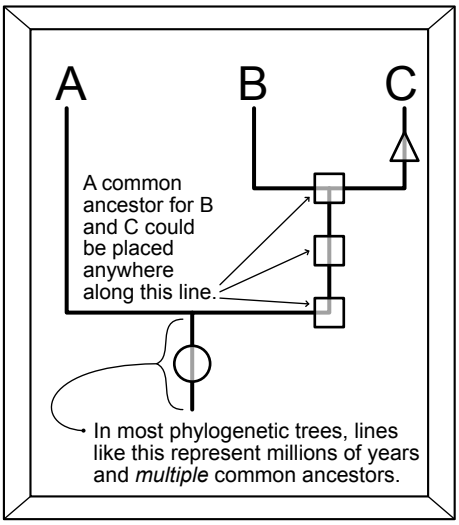


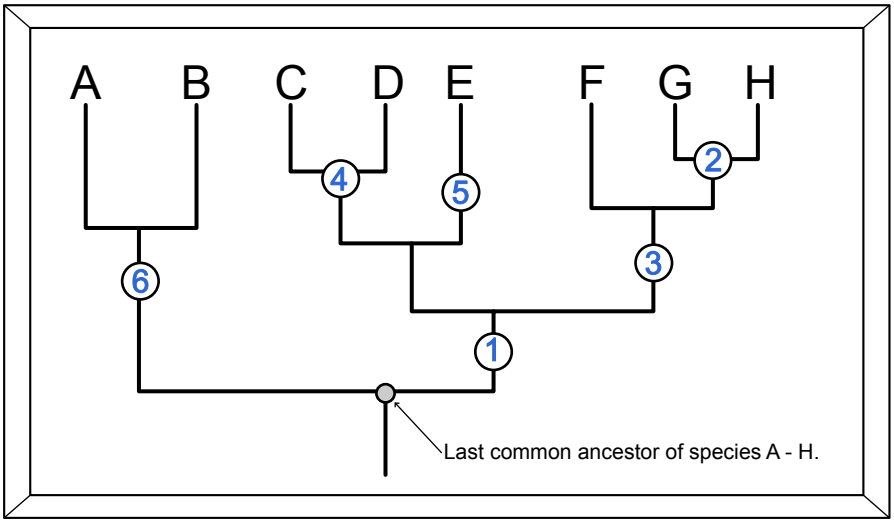
Shared history of A + B



Shared history of B + D

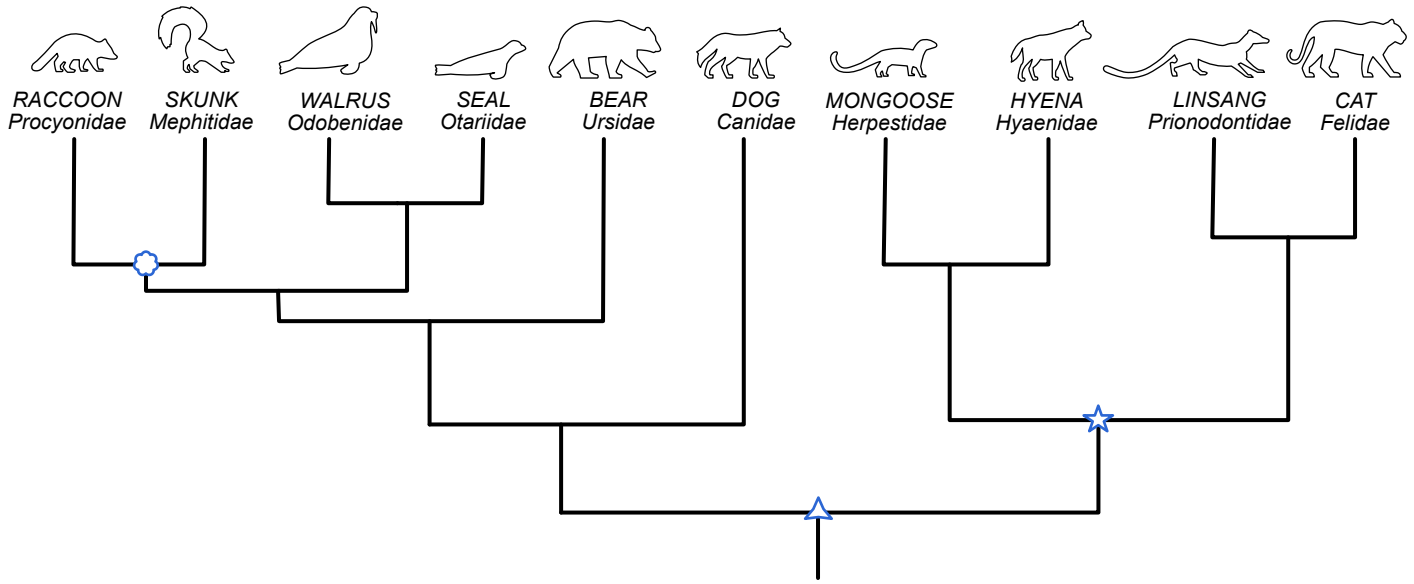
Each species on earth has ancestors that are unique to them and ancestors that they share with other species. Study the example of unique and common ancestors on the small phylogenetic tree for species A, B, and C. Then use the key to mark the unique and common ancestors in the larger phylogenetic tree.





△ Unique ancestor of C
□ Common ancestor of B and C
◯ Common ancestor of A, B, and C

① Common ancestor of C - H
② Common ancestor of G and H
③ Common ancestor of F, G, and H
④ Common ancestor of C and D
⑤ Unique ancestor of E
⑥ Common ancestor of A and B



According to the phylogenetic chart above, is the hyena more closely related to cats or dogs?

Hyenas are more closely related to cats than dogs because hyenas and cats have a more recent common ancestor (marked ☆) than hyenas and dogs (marked △).

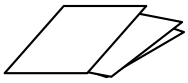
Are skunks more closely related to raccoons or mongooses? How can you tell?

Skunks are more closely related to raccoons than mongooses because skunks and mongooses have a more recent common ancestor (marked ⬡) than skunks and mongooses ?(marked △).

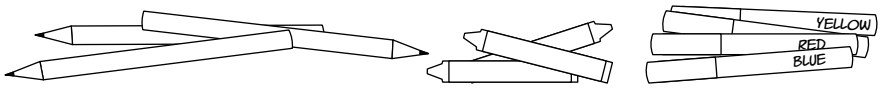
Hands-on Science Project

BUILD YOUR OWN PHYLOGENY

MATERIALS:



paper

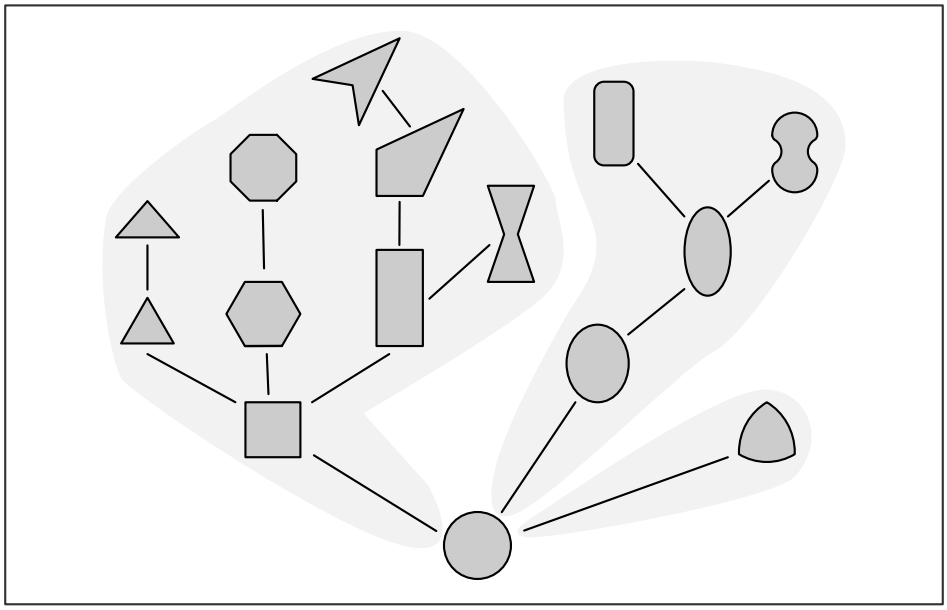


crayons, colored pencils, or markers

Invent your own phylogeny by considering an organism (it can be real or invented) and the different environmental conditions it could face. Draw out different descendants and evolutionary branches that could result. Your conditions could be realistic and based on actual fossils or living organisms, or you could invent something fanciful like Math Dad did with the example phylogeny for shapes below.

Once you have your idea figured out, draw the complete phylogenetic tree and explain why each branch formed.

Math Dad's Example



2D shapes live in a flat plane and experience gravity. Circles are great for rolling and moving around, but they are not very good at stopping or standing still. In steep regions, rolling is a disadvantage and flat sides are a desirable trait.

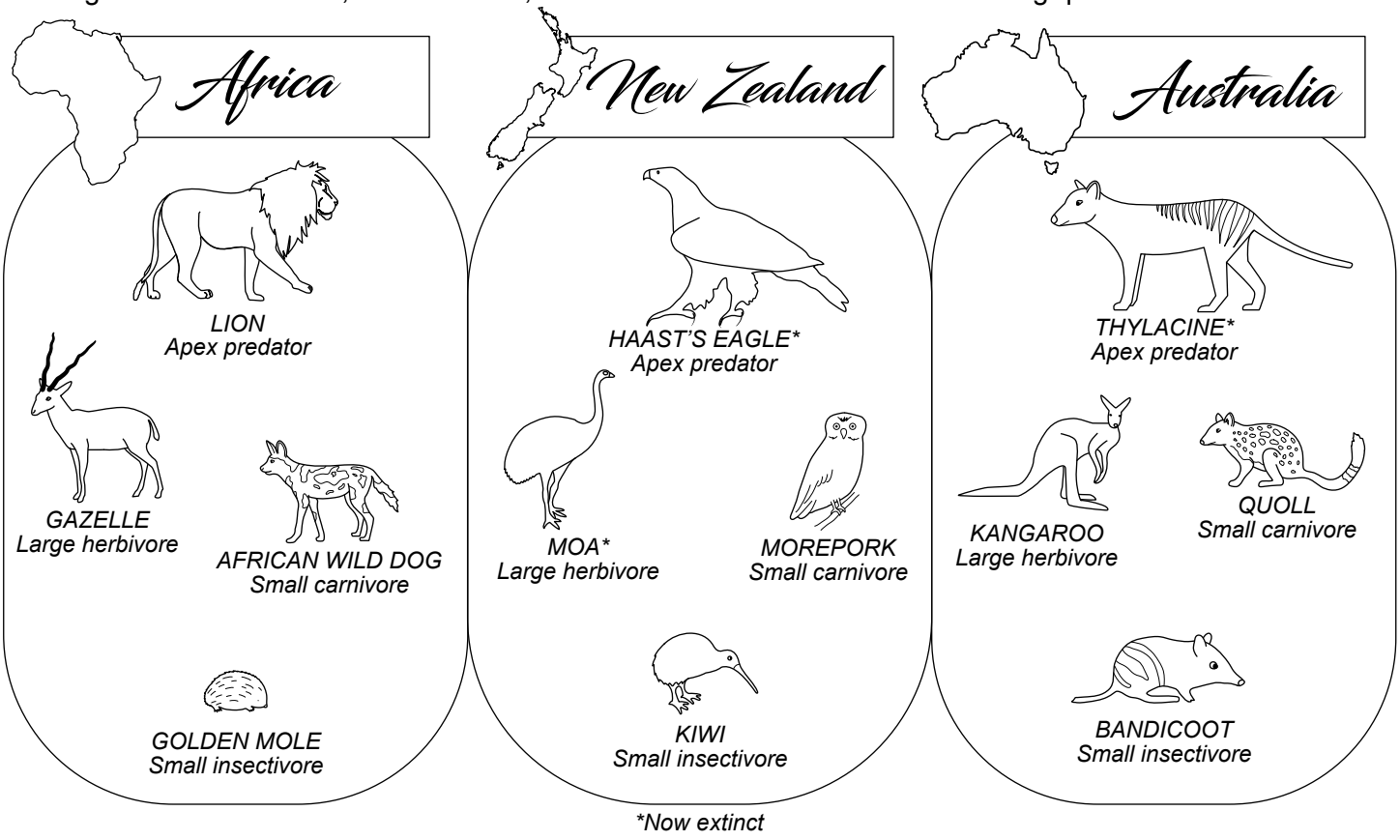
In the left branch, we see descendants of the circle that lived in steeper regions where flat edges provided an advantage. Over time, the shapes evolved flat edges which led to the square. Triangles and rectangles had an advantage when minimal motion was desirable because they were unlikely to roll unintentionally, so they could live in extra steep regions. A hexagon and octagon were able to roll much more easily while still having straight edges for resting, so they were able to live in moderately-steep regions. But they could also compete in flatter regions with other more mobile or rounder shapes.

In the middle branch, the terrain was gently sloped with narrow pathways. Roundness was a useful trait but the shapes got longer over time because added length helped them avoid rolling too far. A thinner middle also made the shapes more flexible so they could navigate the narrow pathways.

In the right branch, we see a shape called a Reuleaux triangle that has a constant diameter like a circle. The Reuleaux triangles are able to climb in canyons of constant width just like circles. But they have an advantage over circles in that they have a smaller area, so they don't have to find as much food as a circle to survive.

Australia vs New Zealand

In ecosystems around the world, we find organisms adopting the same roles. There are producers (plants), animals that eat plants (herbivores), animals that eat insects (insectivores), and predators (carnivores). At the top of the food chain is a predator that has no natural predators (an apex predator). Consider these ecological niches in Africa, New Zealand, and Australia. Then answer the following questions:



*Now extinct

Before humans arrived, bats and seals were the only mammals living in New Zealand. Why didn't New Zealand have other mammal species such as canines, felines, ungulates, or rodents?

New Zealand broke away from the Southern supercontinent Gondwana 80 million years ago. Dinosaurs still roamed the Earth, and few mammals were around at that point. As an isolated island, only flying or swimming mammals were able to get to New Zealand.

Why do you think birds were the dominant animal in New Zealand, while marsupial mammals dominated Australia?

Both Australia and New Zealand are examples of the founder effect. Placental mammals were not living in either location. Marsupials evolved to occupy the main ecological niches (apex predators, large grazers, small foragers, etc) in Australia while birds did the same in New Zealand.

Timeline of Life on Earth

Extinctions occur periodically as a normal part of Earth's natural history. Two billion years ago, cyanobacteria evolved photosynthesis and the ability to produce oxygen. Earth's atmosphere changed from one with virtually no oxygen to one with abundant oxygen, which was toxic to many forms of cellular life. This is called the Great Oxidation Event or the Oxygen Catastrophe. It is not known how many species went extinct because all life on Earth at this point was single celled, and the fossil record is sparse.

In normal conditions, we expect about 10% of species to be lost every million years while new species are arising.

A mass extinction occurs when 75% of the species die in a relatively short period of time. The fossil record shows evidence of five major mass extinction events in Earth's history.

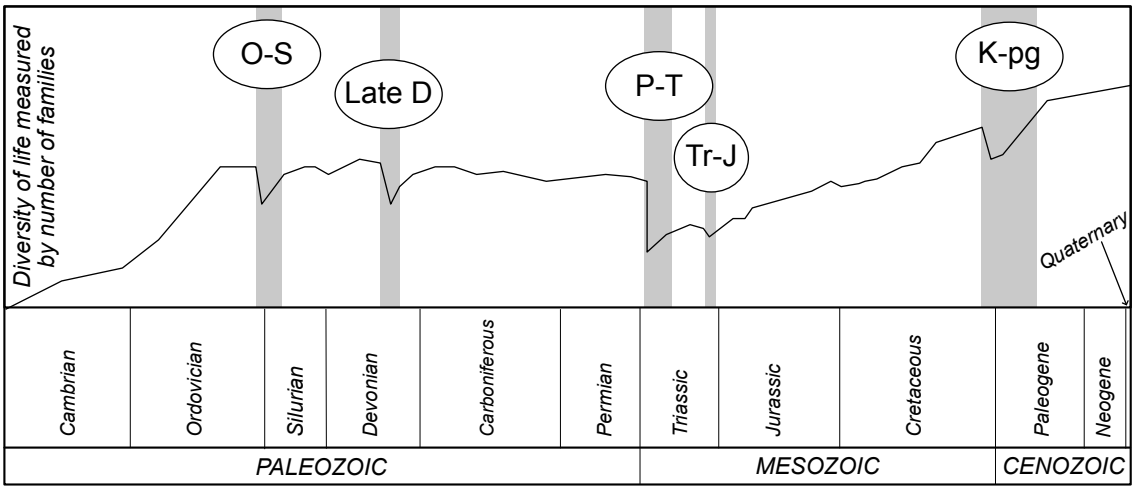


Image adapted from End-Paleozoic Mass Extinction *by Yukio Isozaki in the Journal of Astrobiology. Feb 28, 2019*

Match each extinction event with the cause

Ordovician-Silurian (**O-S**) extinction - 450 MYA

85% of marine species

After this event, many trilobites, echinoderms, crinoids, bivalves, and brachiopods disappeared from the fossil record.

Late Devonian (**Late D**) extinction - 375 MYA

75% of marine species

Placoderms (armored fish) went extinct as well as many species of coral, trilobites, and brachiopods.

Permian-Triassic (**P-T**) extinction - 250 MYA

96% marine life; 70% terrestrial life

Also known as the Great Dying. Trilobites became entirely extinct. This may be the only mass extinction to significantly affect insect diversity.

Triassic-Jurassic (**Tr-J**) extinction - 200 MYA

70% of marine/terrestrial life

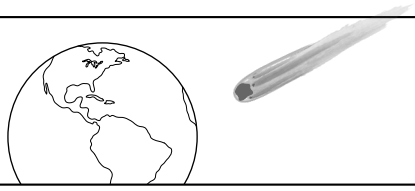
Large amphibians and crocodiles disappeared, making room for dinosaurs to diversify and fill other ecological niches.

Cretaceous-Paleogene (**K-Pg**) extinction - 65 MYA

75-80% of marine/terrestrial life

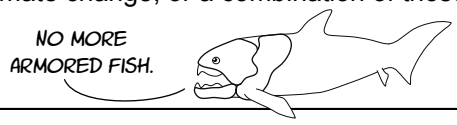
Large dinosaurs and pterosaurs became extinct. No tetrapods weighing more than 25 kg (55 lbs) survived.

A massive asteroid collided with Earth.

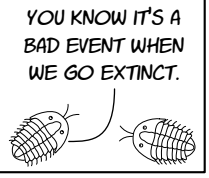


The exact cause is unknown. It could have been a gamma-ray burst from a nearby supernova, glaciation, or volcanic eruptions.

This extinction may have been caused by volcanic eruptions, plants colonizing land, an asteroid impact, climate change, or a combination of those factors.



Enormous volcanic eruptions in modern-day Siberia, the release of methane into the atmosphere, and climate change all contributed to this extinction.



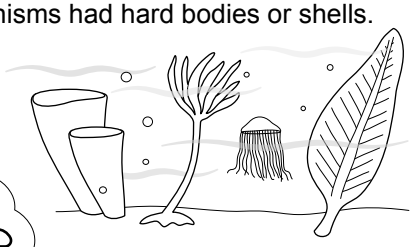
Volcanic eruptions caused climate change. An asteroid impact could have also played a role.

Color the timeline to match each corresponding age or era.

4.6 Billion Years Ago

Precambrian
4.6 billion to 542 Million Years Ago (MYA)

The Precambrian era is the name for the first 4 billion years of Earth's existence. The fossil record is less complete because most life was in the ocean, and few organisms had hard bodies or shells.



Cambrian Explosion

542 MYA

Paleozoic Era
542 Million to 250 Million Years Ago

The Cambrian explosion started a period of incredible growth where the first land animals and vertebrates arose. The Paleozoic Era ended with the Earth's largest mass extinction event.

250 MYA

NOW

65 MYA

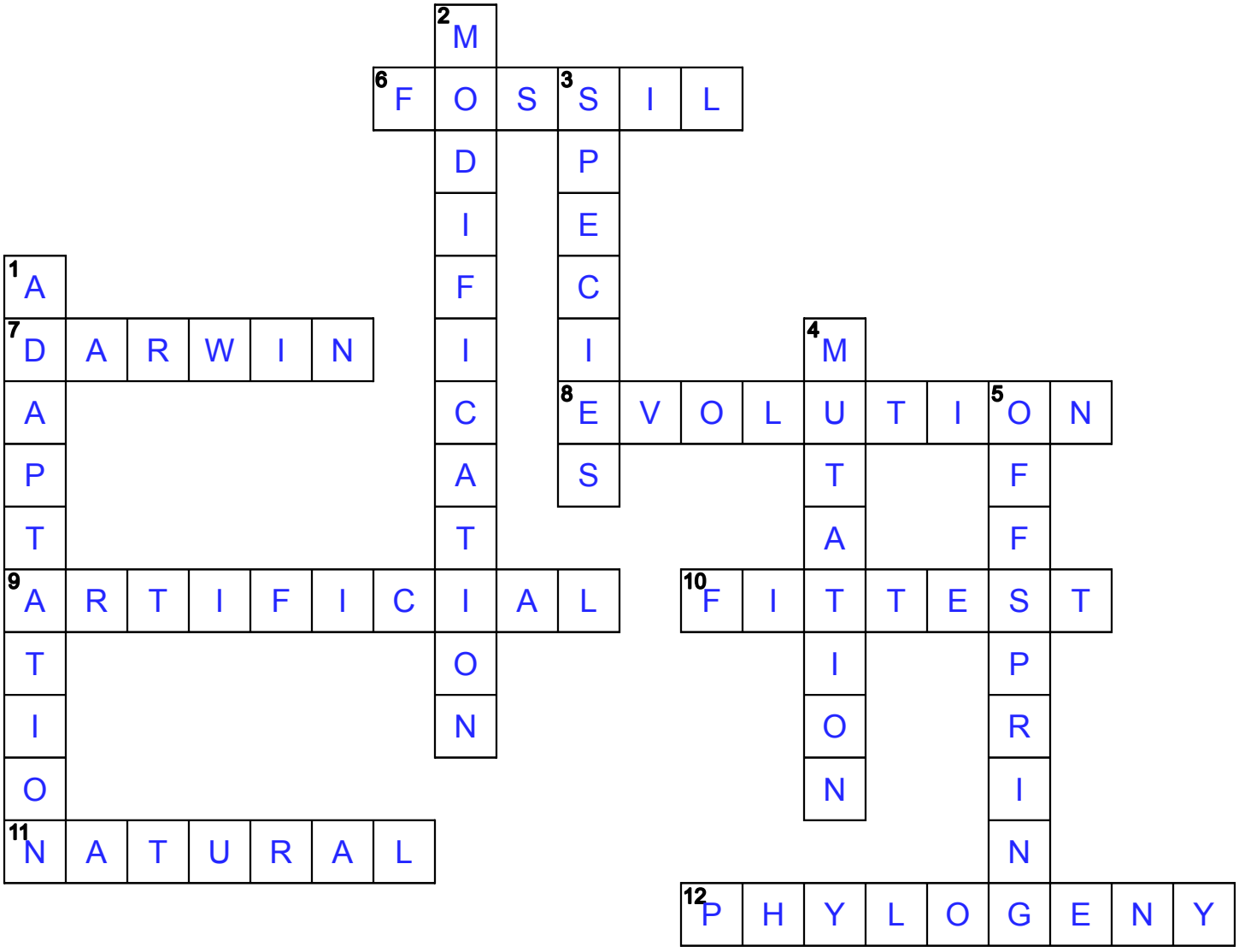
Cenozoic Era
65 Million Years Ago to the present

Our current era is the Cenozoic. This era is characterized by alternating ice ages and warmer periods. The first humans appeared 2 million years ago.

Mesozoic Era
250 Million to 65 Million Years Ago

The Mesozoic Era saw the rise of the dinosaurs and the first mammals. Flowering plants developed for the first time during the Cretaceous Period. The Mesozoic Era ended when a giant meteorite crashed into the Gulf of Mexico, causing nearly 80% of all species to go extinct.

Evolution Crossword Puzzle



VERTICAL Words

1. Characteristics of organisms that enhance survival and reproduction chances
2. Darwin described evolution as “Descent with _____”
3. A taxonomic group whose members can interbreed
4. A change in the structure of a gene
5. The immediate descendants of an organism

HORIZONTAL Words

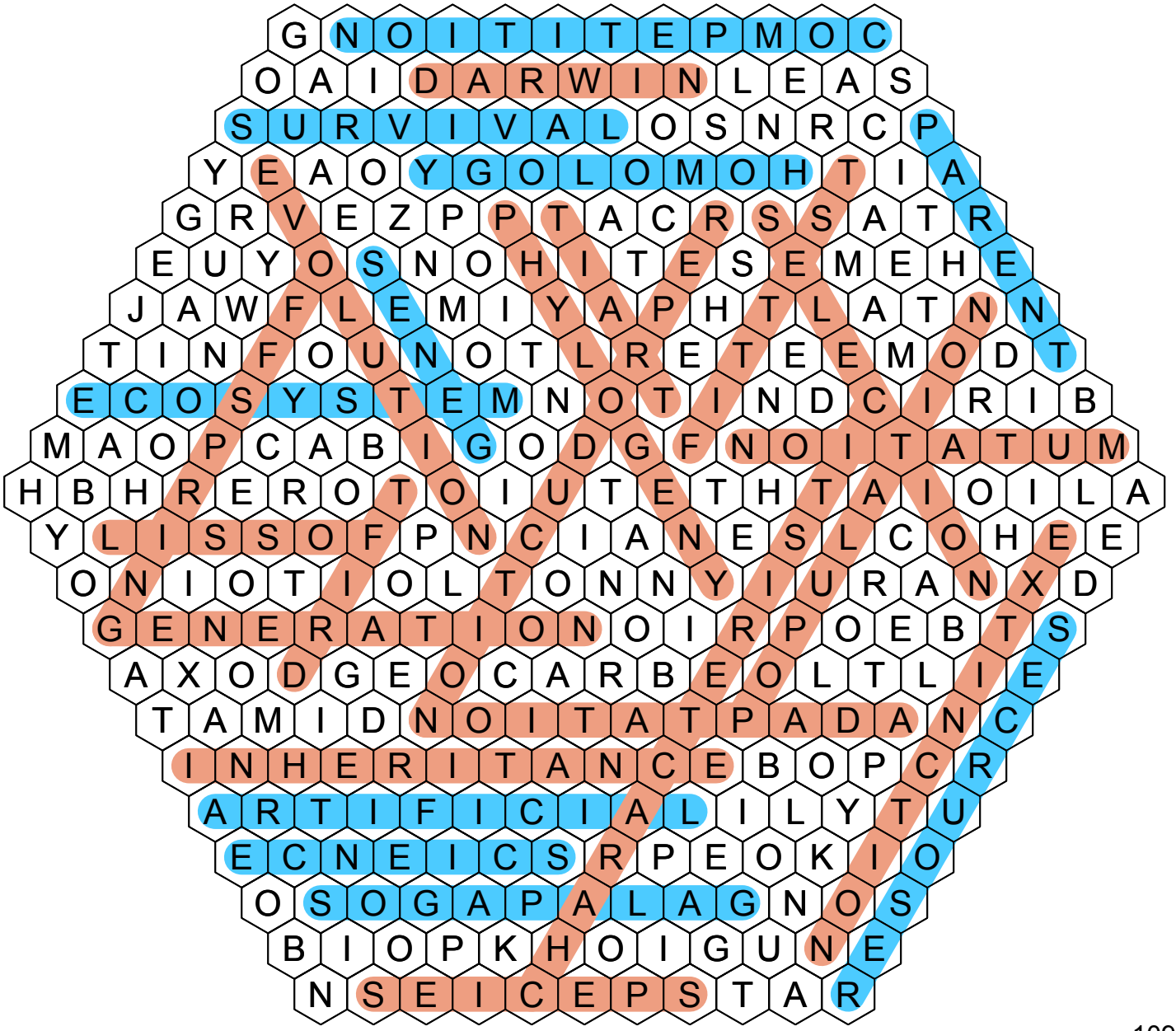
6. The preserved remains of an ancient organism
7. The author of *On the Origin of Species*
8. The process of changing over time
9. Selective breeding for traits is _____ selection.
10. Survival of the _____
11. The process through which populations adapt and change is _____ selection
12. Mapping the evolutionary development and diversification of species

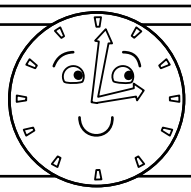
Evolution Word Search

There are a lot of new words to learn when studying biology. Repetition is the best way to learn them, and word games can be part of that! Find each of the hidden words in the word-search. The words can run in any direction: horizontal or diagonal. The letters might go left to right or right to left!

ADAPTATION	REPRODUCTION	TRAIT
FITTEST	INHERITANCE	DARWIN
SPECIES	EVOLUTION	GENERATION
EXTINCTION	SELECTION	FOSSIL
OFFSPRING	POPULATION	MUTATION
CHARACTERISTIC	DRIFT	PHYLOGENY

Bonus words in blue -





Quiz Time!

ANSWER THE QUESTIONS TO SEE WHAT YOU LEARNED ABOUT EVOLUTION!

1 Any variation that can help an organism survive in its environment is called a(n)

A. adaptation
B. characteristic
C. competition
D. natural selection

2 Which of the following is NOT a component of the Theory of Evolution by Natural Selection?

A. variation among individuals
B. inheritance of acquired characteristics
C. competition for limited resources
D. survival and reproduction

Acquired traits are not passed on.

3 The dog breeds we have today developed by

A. Sexual selection
B. Disruptive selection
C. Artificial selection (selective breeding)
D. Natural selection

4 What is the correct definition of evolution?

A. Changes in a population of organisms over a period of time
B. Changes in individual organisms during their lifetime
C. Organisms coming into existence at a defined moment in time and not changing
D. One organism transforming into another organism

5 Which of the following provide evidence for the evolution of species? Choose all that apply.

A. The fossil record
B. Biogeography (locations of organisms on the globe)
C. DNA
D. Comparative anatomy (between species)

6 In evolutionary biology, what does fitness mean?

A. The ratio of body fat to muscle weight
B. The ability of that individual to survive to reproductive age
C. The likelihood that that individual will have 2 or more offspring
D. The likelihood that an individual will contribute its genes to the next generation

7 Which of the following is the best example of natural selection?

A. A population of jackrabbits undergoes a seasonal coat color change from brown to white as soon as snow covers their habitat.
B. Field mice born during a year with excess wheat will gain muscle mass and thus have offspring that have an increased muscle mass.
C. Bass that are born with darker scales are better able to survive in the shadows among the river rocks.

8 Traits that perform a similar function but arise from different ancestral traits (such as bat and bird wings) are called

A. Anomalous
B. Homologous
C. Divergent
D. Convergent

9 The term species is defined as

A. A grouping of morphologically similar organisms
B. A grouping of organisms that do not interbreed
C. A group of populations that can interbreed to produce viable offspring
D. A group of populations that live in the same area

10 How many mass extinctions has the Earth experienced in the past?

A. 2
B. 5
C. 8
D. 9

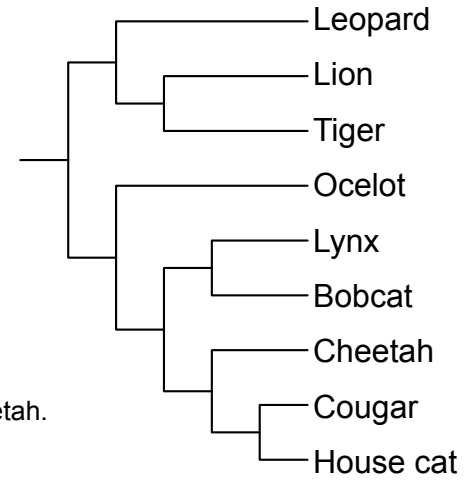
11 According to the fossil record, how long ago did life appear on earth?

A. 3.5 million years
B. 35 million years ago
C. 350 million years ago
D. 3.5 billion years ago

12 Number each period below using the numbers 1-4 to put them in chronological order.

- 3 Mesozoic
- 1 Precambrian
- 2 Paleozoic
- 4 Cenozoic

Use the feline phylogeny to the right to answer the next four questions.



13 Of the options below, which species is most closely related to a lynx?

A. Ocelot
B. Cheetah
C. Tiger
D. Leopard

Look for the most recent common ancestor!

14 Of the options below, which species is most closely related to a Ocelot?

A. House cat
B. Leopard
C. Lion

15 An ancestor of both a cougar and a lynx must also be an ancestor of a cheetah.

A. True
B. False

16 Ocelots and Lions have no common ancestors.

A. True
B. False

Below are the mechanisms by which evolution takes place. Match the mechanism on the left with the corresponding example on the right.

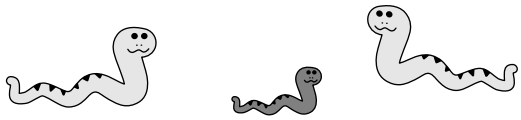
Genetic Drift
A change in the frequency of a genotype due to chance

Mutation
A change in the structure of a gene

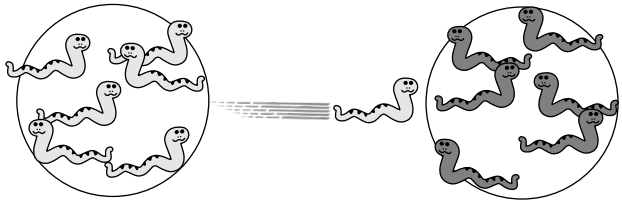
Migration
Movement from one region to another

Natural Selection
The survival of a species that is better adapted to an environment

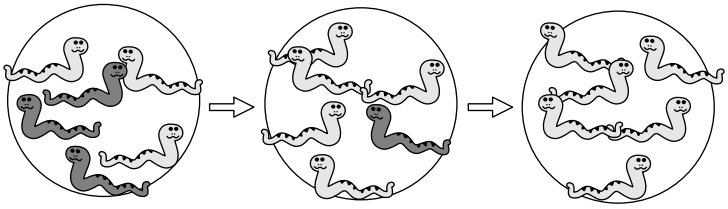
Parents with genes for light coloring could have an offspring with dark coloring.



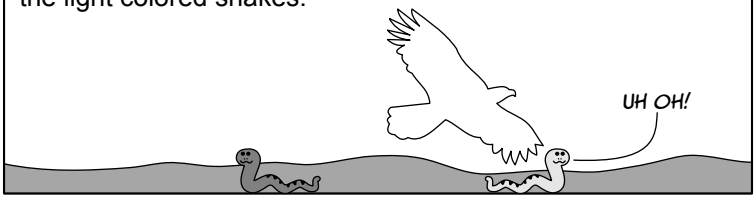
A snake with light coloring might move to a region inhabited by dark colored snakes.



Through random chance, the dark coloring gene might disappear from the population.



The environment might make it easier for predators to spot the light colored snakes.



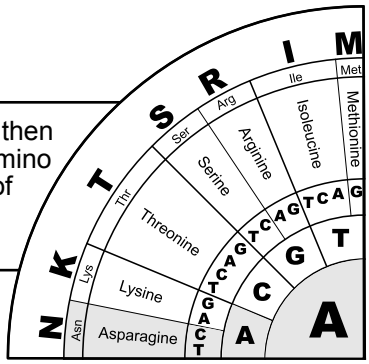
APPENDIX

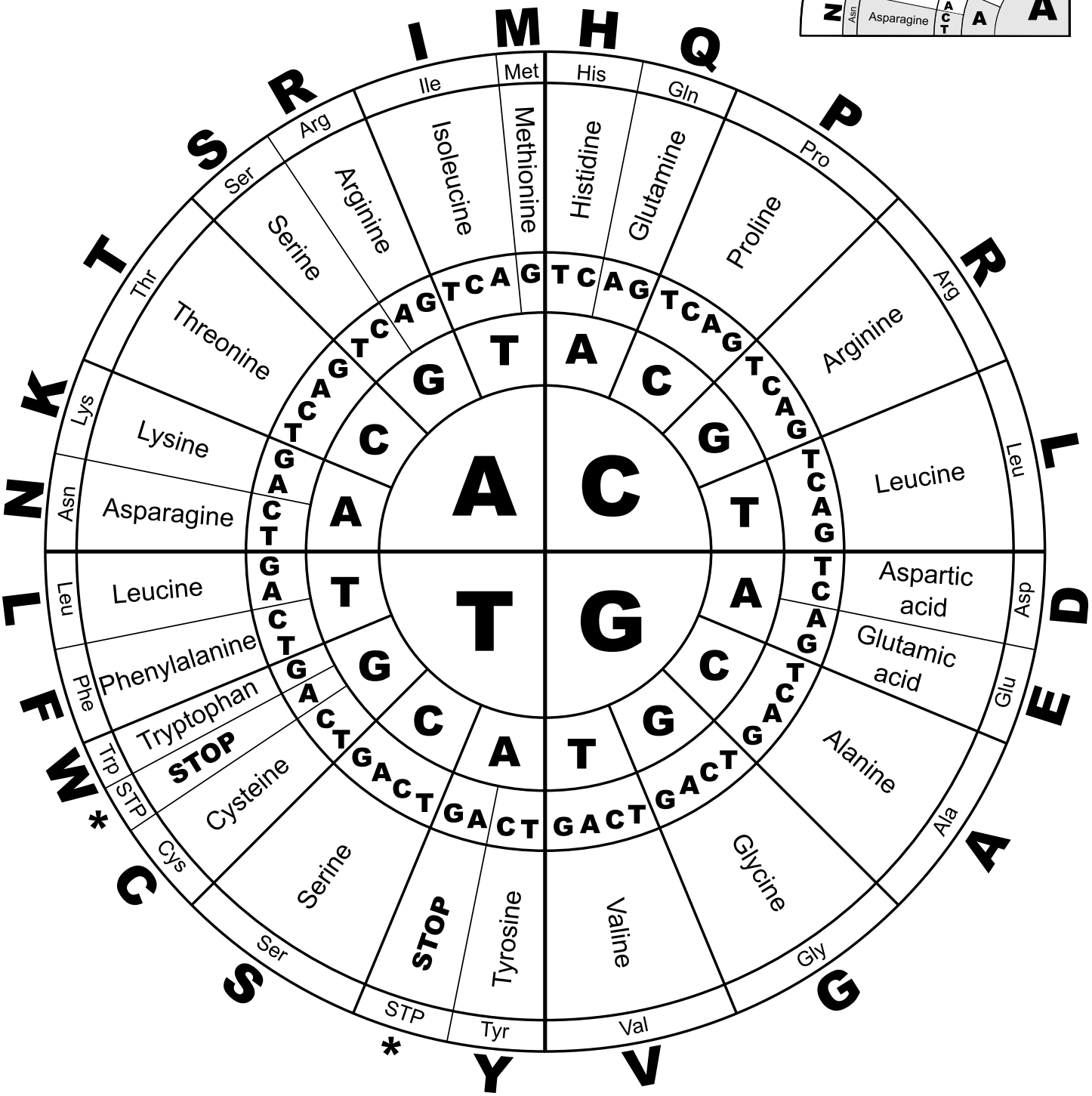
THE CODON WHEEL

A tool for deciphering the genetic code!

How to use: Start in the center and follow the letters outward!

For example, if the codon you are deciphering reads “AAT,” select A in the inner circle, then A again in the second ring, and T in the third ring. This shows that AAT codes for the amino acid **asparagine**, which has a 3-letter abbreviation of **Asn** and a 1-letter abbreviation of **N**. Be aware that multiple codons can code for the same amino acid! Notice that the codon AAC also codes for asparagine.





The Math of Punnett Squares

The number of allele combinations quickly rises when the number of traits rise. For a genotype, the order of the alleles doesn't matter. For example, **Aa** is the same as **aA**. To keep things simple, we usually put the capital letter first. For example, when there is just one trait with alleles **A** and **a,** then there will be 3 possible genotypes (**AA**, **Aa**, and **aa**) but only 2 possible phenotypes: the dominant phenotype **A** (from **AA** or **Aa**) and the recessive phenotype **a** (from **aa**).

With 2 traits we must count the possible combinations for alleles **A** and **a** together with **B** and **b**.

Complete the table below by identifying how many distinct combinations arise for a given number of traits? You will probably want to write out the possibilities on a piece of scratch paper.

Number of traits	Number of distinct phenotypes	Number of distinct genotypes	Number of cells in a Punnett Square
1	2	3	4
2	4	9	16
3	8	27	64
4	16	81	256
5	32	243	1024
n	2^n	3^n	4^n

Now you have a formula that will let you find the number of distinct phenotypes or genotypes for any number of traits. Suppose we considered 25 specific traits that a person could have determined by their genotypes. For each of the possible phenotypes of the 25 traits, do you think there is someone in the world that exhibits that phenotype? Explain.

The total number of possible phenotypes is 2^{25} = 33,554,432. There are 200 times as many people on Earth as that number, so it's very possible that each of the different phenotype combinations could exist for those 25 traits.

For each of the possible genotypes of the 25 traits, do you think there is someone in the world that has that genotype? Explain.

The total number of possible genotypes is 3^{25} = 847,288,609,443. This is way bigger than the population of the Earth, so most of the genotype combinations will not occur.

Identical twins share the same alleles. Do you think it is possible for non-twins to have the same alleles? Explain.

Not unless you limit the scope of the question. Siblings are most likely to share many alleles, but there are so many different genotypes possible that two non-twins would only have the same alleles if you limit the inquiry to a small number of genes. For example, if you look at just 4 traits, there are only 81 possible genotypes, so many pairs of people would match genotypes on those 4 traits.

Calculating Probabilities

For a single trait, we can find the probability of passing a specific phenotype or genotype along by filling in a simple Punnett square.

For example, in the cross **Aa×Aa**, there are 4 equally likely outcomes: **AA**, **Aa**, **aA**, and **aa.** That means:

- ¼ of the time we get the homozygous dominant genotype **AA**.
- ½ of the time we get the heterozygous genotype **Aa**.
- ¼ of the time we get the homozygous recessive genotype **aa**.

In the cross **Aa×Aa,** the probability (P) of each ***genotype*** is:

P(genotype **AA**) = ¼

P(genotype **Aa**) = ½

P(genotype **aa**) = ¼

In the cross **Aa×Aa,** the probability of each ***phenotype*** is:

P(phenotype **A**) = ¾

P(phenotype **a**) = ¼.

Punnett square for the cross **Aa×Aa**

	A	**a**
A	**AA**	**Aa**
a	**aA**	**aa**

To calculate the probabilities for multiple traits, we find the probabilities of the outcomes for each individual trait and then multiply the probabilities.

For example: Find the probability of getting the genotype **AaBB** in the cross **AABb×AaBB.**

1. First find the probability of the genotype Aa from the cross AA×Aa.
   P(genotype Aa) = ½
2. Find the probability of the genotype BB from the cross Bb×BB. P(genotype BB) = ½.
   P(genotype BB) = ½
3. Multiply the probabilities.
   P(genotype AaBB) = P(genotypeAa) × P(genotypeBB) = ½ × ½ = ¼

Challenge 1. Find the probability of getting the genotype **AaBb** in the cross **AABb×aaBB.**

The chance of getting **Aa** is 4/4=1, and the chance of getting **Bb** is 1/2, so the chance of getting **AaBb** from this cross is 1×1/2=1/2.

Challenge 2. Find the probability of getting the recessive phenotype **ab** in the cross **Aabb×aaBb.**

The chance of getting phenotype **a** is 1/2, and the chance of getting phenotype **b** is 1/2, so the chance of getting both **a** and **b** is 1/2×1/2 =1/4.

Challenge 3. Find the probability of getting the phenotype **AbC** in the cross **AabbCC×AaBbcc.**

The chance of getting phenotype **A** is 3/4, phenotype **b** is ½, and phenotype **C** is 1, so the chance of getting phenotype **AbC** is 3/4×1/2×1 =3/8.

Challenge 4. Find the probability of getting the genotype **AaBbcc** in the cross **aaBbCc×AaBbcc.**

The chance of getting **Aa** is 1/2, **Bb** is 1/2, and **cc** is 1/2, so the chance of getting phenotype **AaBbcc** is 1/2×1/2×1/2 =1/8.

Tri-hybrid Cross!

Make up a critter and supply phenotypes and genotypes for three different traits that can be determined by alleles.

Critter Name: _____

Trait 1: _____ vs _____

Details:

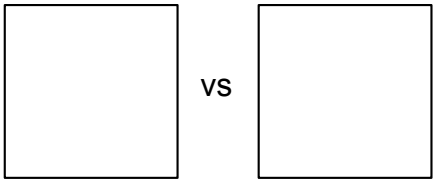
_____

_____

_____

_____

Phenotypes



Genotypes

_____ vs _____

Trait 2: _____ vs _____

Details:

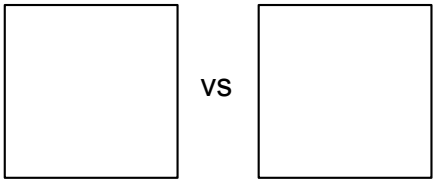
_____

_____

_____

_____

Phenotypes



Genotypes

_____ vs _____

Trait 3: _____ vs _____

Details:

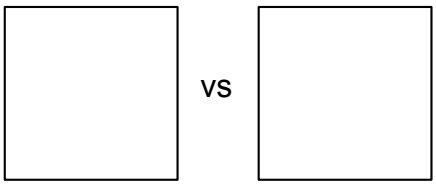
_____

_____

_____

_____

Phenotypes



Genotypes

_____ vs _____

What will the genotype and phenotype for your critter be if it is heterozygous for all three traits?

Genotype: _____ Phenotype:

Now cross two of your critters that are heterozygous for all three traits. Include both the genotype and phenotype in each cell of your Punnett square.

Tetrahybrid Cross!

Make up a critter and supply phenotypes and genotypes for four different traits that can be determined by alleles.

Critter Name: _____

Trait 1: _____ vs _____

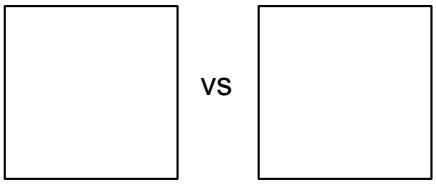
Details:

_____

_____

_____

Phenotypes



Genotypes

_____ vs _____

Trait 2: _____ vs _____

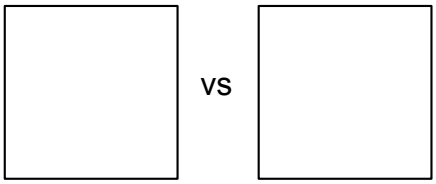
Details:

_____

_____

_____

Phenotypes



Genotypes

_____ vs _____

Trait 3: _____ vs _____

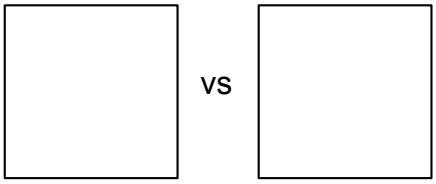
Details:

_____

_____

_____

Phenotypes



Genotypes

_____ vs _____

Trait 4: _____ vs _____

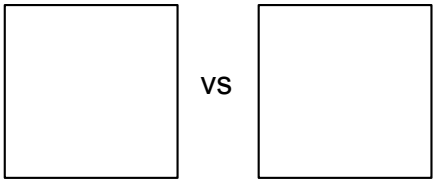
Details:

_____

_____

_____

Phenotypes

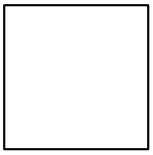


Genotypes

_____ vs _____

What will the genotype and phenotype for your critter be if it is heterozygous for all four traits?

Genotype: _____ Phenotype:



Now cross two of your critters that are heterozygous for all four traits.

Gummy Worm Karyotype Game

Instructions:

1. Prepare gummy worms according to instructions for the gummy worm karyotype activity.

2. Print off the Trait Key and Fruit Fly Phenotype Cards.

3. Cut out the 16 fruit fly phenotypes. Color them to match their description.

4. Take turns arranging karyotypes and matching the cards by playing one of the following versions of the Karyotype game!

**Note that although the Y and number 4 chromosome are collored in this template, there are no traits being tracked for these chromosomes in the karyotype game.*

It's a race!

All 16 phenotype cards are placed face up. One person arranges a karyotype from either gummy worms or paper chromosomes. The karyotype is revealed to the players, who then race to find the correct phenotype card. The first person to choose the correct card earns a point! Play to 10 points.

Reverse it

Shuffle the phenotype cards and draw one at random. The player then uses gummy worms or paper chromosomes to arrange a karyotype that would produce that phenotype.

For a more advanced version, don't look at the trait key while building the phenotype! Just use it after the karyotype is made to check and see if it's correct. If it is, the player earns a point! Play to 10 points.

Double Trouble

Shuffle the phenotype cards and draw one at random. Each player should have a piece of paper and pencil and will draw a karyotype to match the phenotype card, making sure that their answer is not visible to the other player.

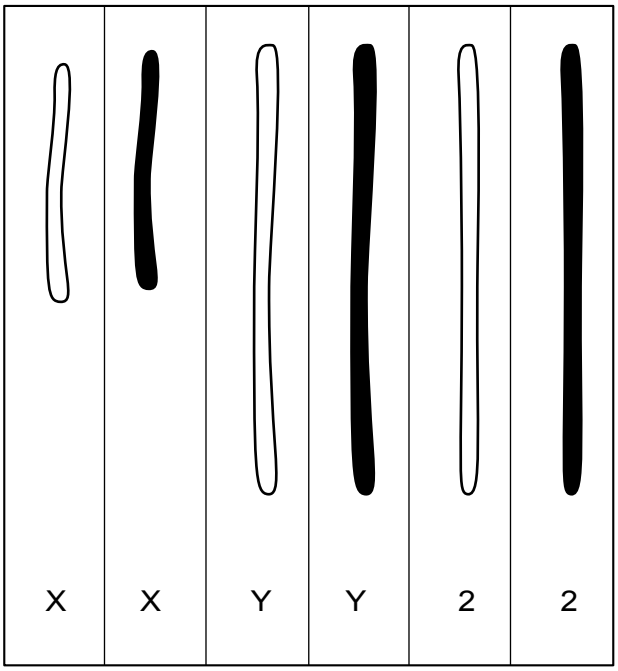
The karyotypes are revealed. If they match, neither player gets a point. If the karyotypes are different but both produce the same phenotype, each player receives 2 points. If either player creates a karyotype that does not match the card, both players lose 1 point. Play until 10 points.

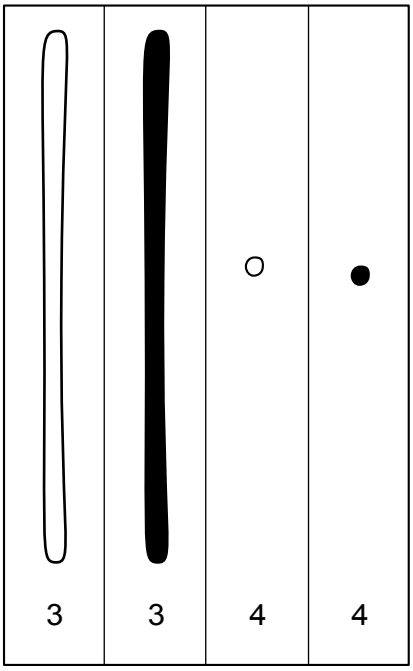
Trait Key

XX chromosomes = female
XY chromosome pair = male
Dominant trait in X = red eyes
Recessive trait in X = white eyes
Dominant trait in 2 = functional wings
Recessive trait in 2 = miniature wings (flightless)
Dominant trait in 3 = yellow body color
Recessive trait in 3 = ebony or black body color

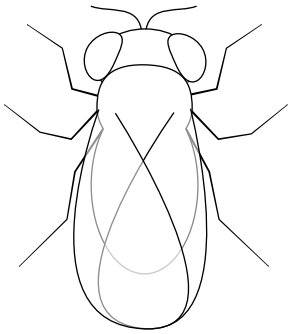
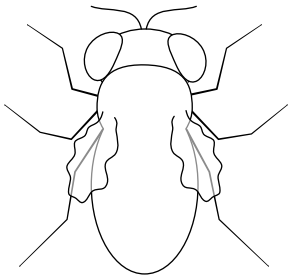
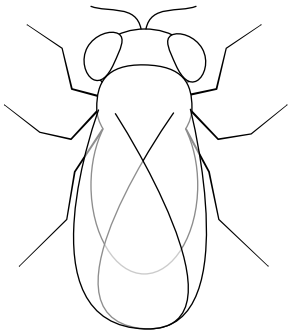
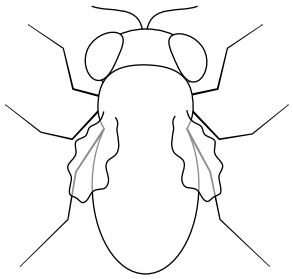
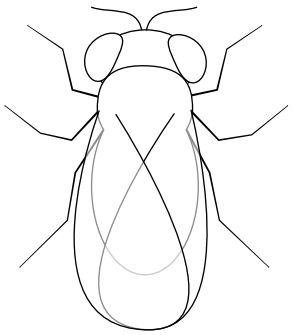
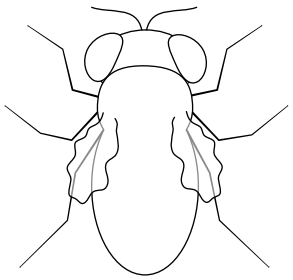
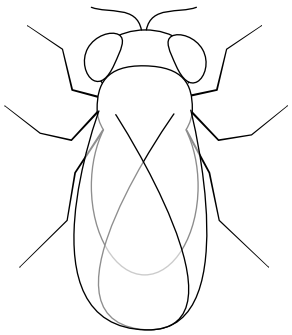
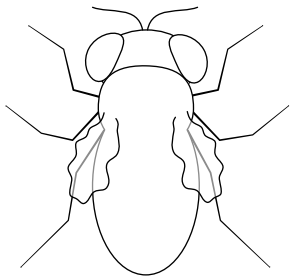
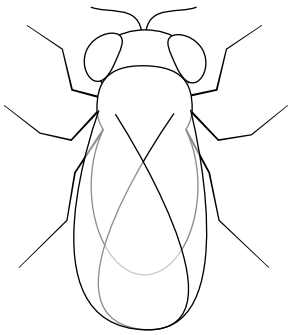
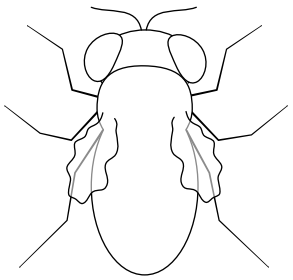
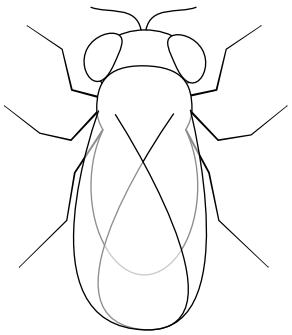
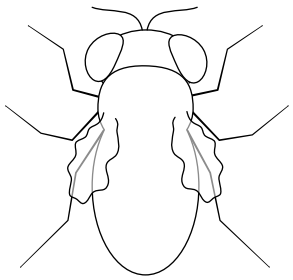
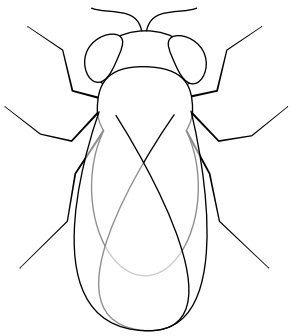
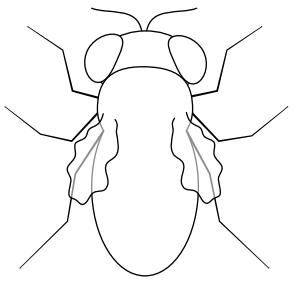
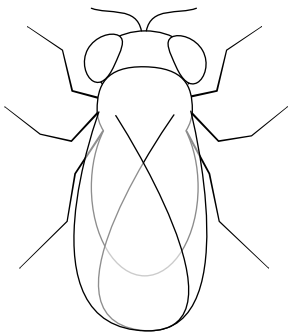
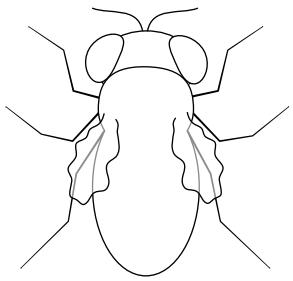
Chromosome Templates

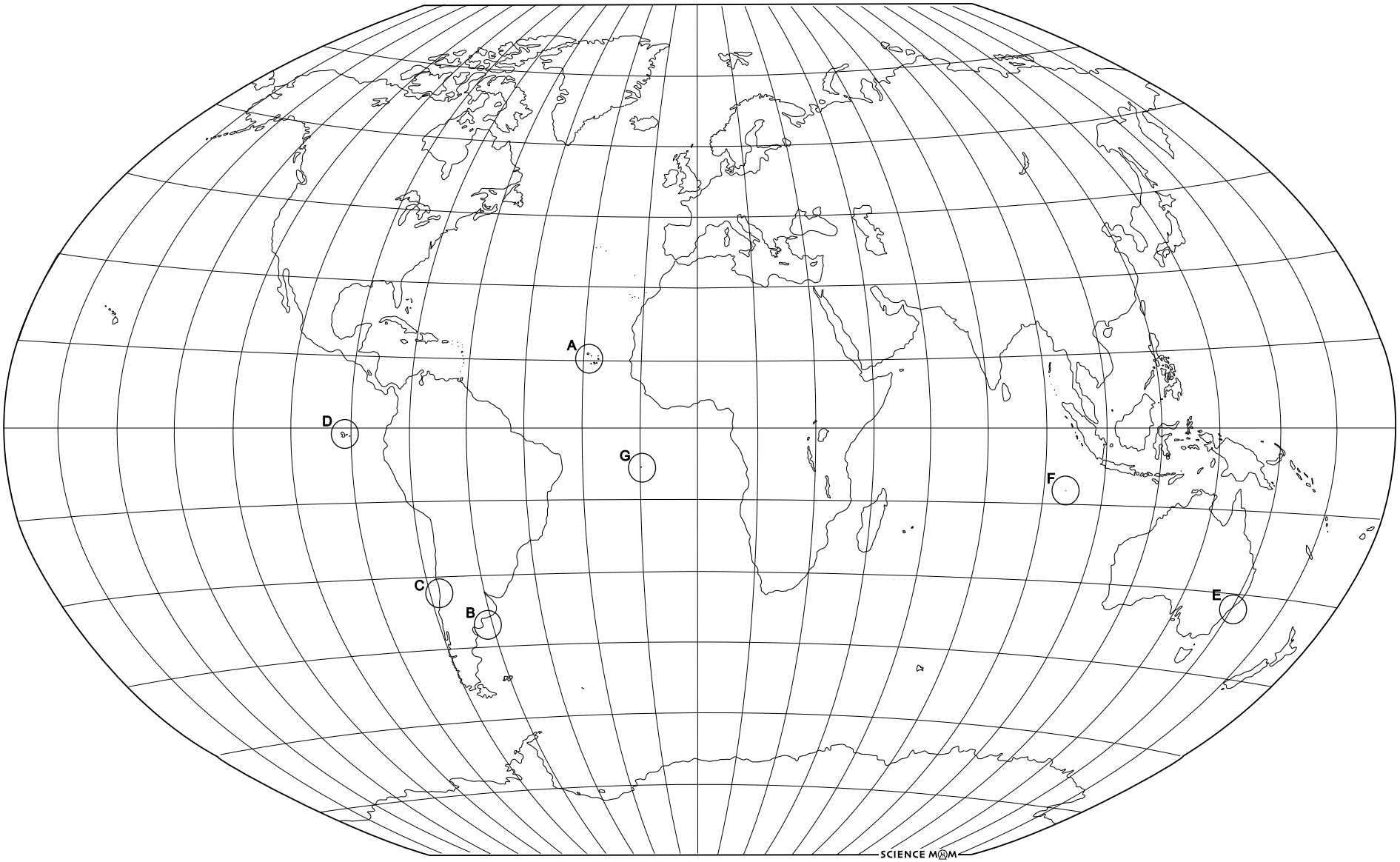
Can be used in place of gummy worms for either gummy worm karyotypes or meiosis. Print this page twice, so there are 4 copies of each chromosome.





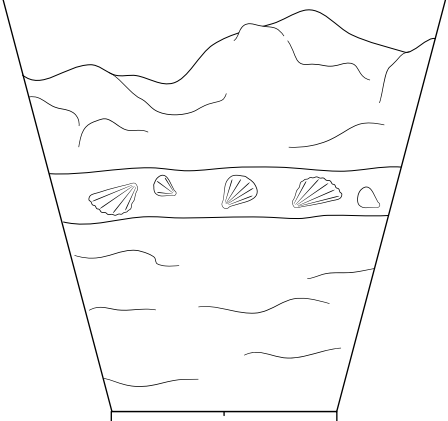
Fruit Fly Phenotype Cards

 ♂ Yellow, winged, red-eyed male	 ♂ Yellow, flightless, red-eyed male	 ♂ Yellow, winged, white-eyed male	 ♂ Yellow, flightless, white-eyed male
 ♀ Yellow, winged, red-eyed female	 ♀ Yellow, flightless, red-eyed female	 ♀ Yellow, winged, white-eyed	 ♀ Yellow, flightless, white-eyed female
 ♂ Ebony, winged, red-eyed male	 ♂ Ebony, flightless, red-eyed male	 ♂ Ebony, winged, white-eyed male	 ♂ Ebony, flightless, white-eyed male
 ♀ Ebony, winged, red-eyed female	 ♀ Ebony, flightless, red-eyed female	 ♀ Ebony, winged, white-eyed	 ♀ Ebony, flightless, white-eyed female



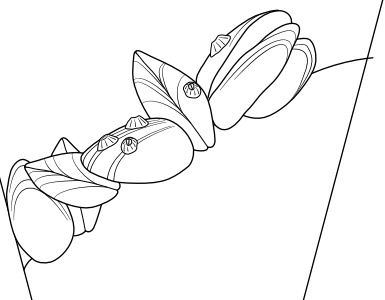
Journey of the H.M.S. Beagle

CAPE VERDE ISLANDS

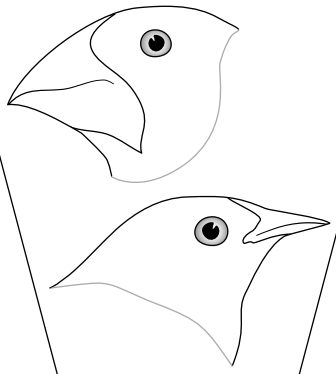


PUNTA ALTA, ARGENTINA

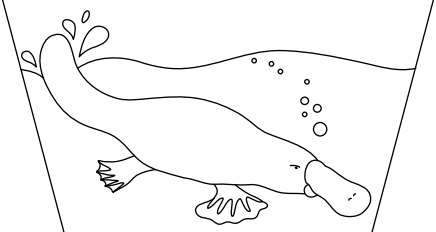
CONCEPCIÓN, CHILE



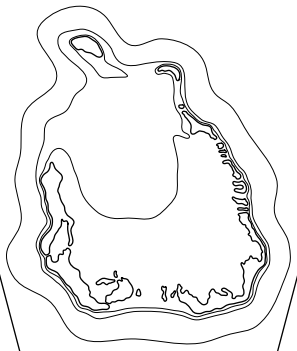
GALAPÁGOS ISLANDS



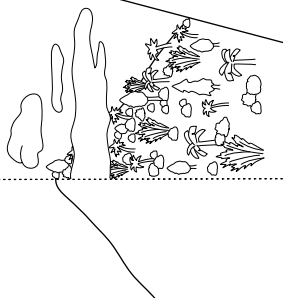
WALLERAWANG, AUSTRALIA



KEELING-COCOS ISLANDS



ASCENSION ISLAND



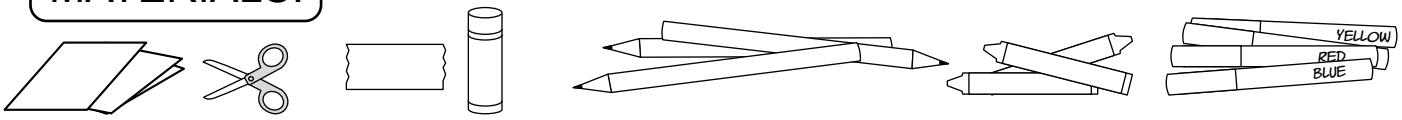
AFTER

BEFORE

Hands-on Science Project

BUILD A TIMELINE OF LIFE ON EARTH

MATERIALS:



paper scissors glue or tape crayons, colored pencils, or markers

Print each of the 10 pages that follow. Print single-sided. Then choose a color for each of the circles below. Color the corresponding portion of the timeline to match. (Note that the Pangea circle overlaps two periods of time, the Carboniferous and Permian). Then cut along the dotted lines to create the narrow strips of paper for your timeline. Tape the strips together so that they form a continuous timeline of life on Earth!

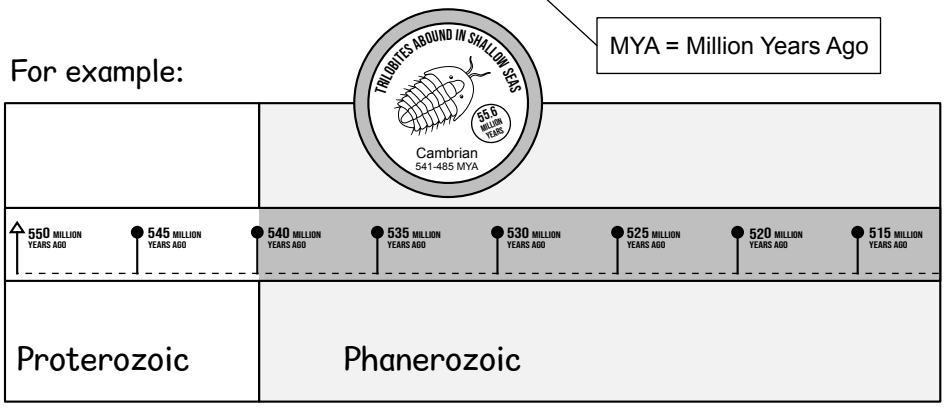
**Note: The entire timeline will be approximately 80 ft (25 m) long. Each inch represents 5 million years of time! If you do not have room to lay out the entire timeline, you can put together 10 foot segments and line them up on a wall or floor.*

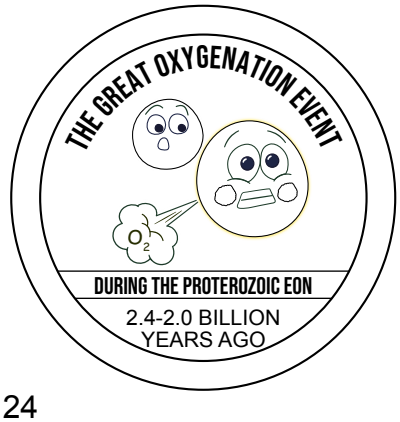
As an optional extension, cut strips of colored paper to represent the four eons of Earth's history, and use these as a colorful backing to the timeline.

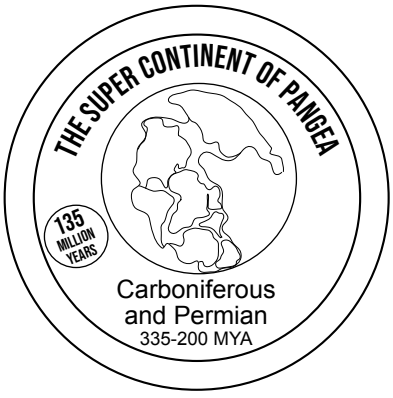
EON	TIME	NOTABLE EVENT(S)
Hadean	4.6 - 4 billion years ago	Earth formed and the surface cooled.
Archaean	4 - 2.5 billion years ago	First bacteria evolved. Atmosphere lacked oxygen.
Proterozoic	2.5 billion - 541 MYA	Oxygen entered the atmosphere.
Phanerozoic	541 MYA - present	This era includes everything from the Cambrian explosion onward.

MYA = Million Years Ago

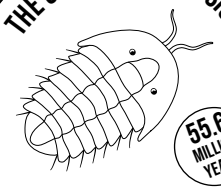
For example:







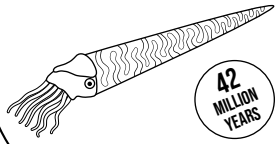
THE CAMBRIAN EXPLOSION



55.6 MILLION YEARS

Cambrian
541-484.5 MYA

THE ORDOVICIAN RADIATION

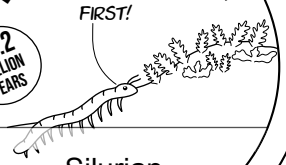


42 MILLION YEARS

Ordovician
484.5-443.4 MYA

LIFE BECOMES TERRESTRIAL

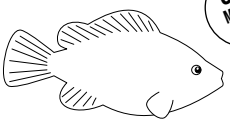
FIRST!



24.2 MILLION YEARS

Silurian
443.4-419.2 MYA

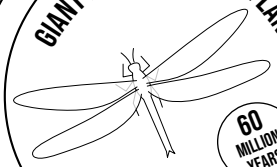
THE AGE OF FISHES



60.3 MILLION YEARS

Devonian
419.2-358.9 MYA

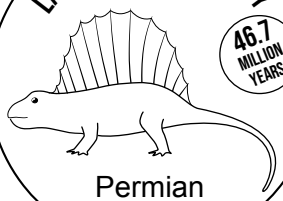
GIANT INSECTS RULE THE LAND



60 MILLION YEARS

Carboniferous
358.9-298.9 MYA

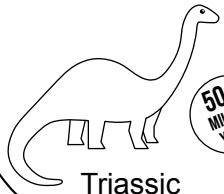
LAND REPTILES DIVERSIFY



46.7 MILLION YEARS

Permian
298.9-252.2 MYA

THE FIRST DINOSAURS



50.9 MILLION YEARS

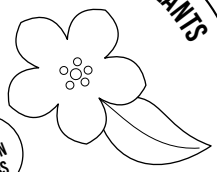
Triassic
252.2-201.3 MYA

THE FIRST MAMMALS

56.3 MILLION YEARS

Jurassic
201.3-145 MYA

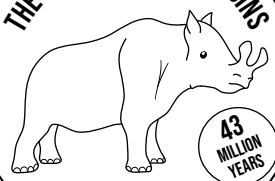
THE FIRST FLOWERING PLANTS



79 MILLION YEARS

Cretaceous
145-66 MYA

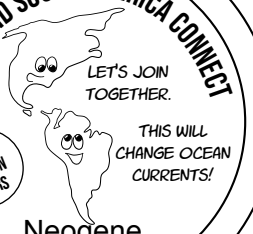
THE AGE OF MAMMALS BEGINS



43 MILLION YEARS

Paleogene
66-23 MYA

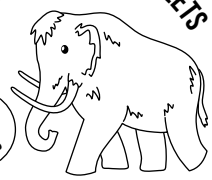
NORTH AND SOUTH AMERICA CONNECT



20.4 MILLION YEARS

Neogene
23-2.58 MYA

GLACIATION AND ICE SHEETS



2.5+ MILLION YEARS

Quaternary
2.58 MYA - PRESENT


450 MILLION YEARS AGO
445 MILLION YEARS AGO
440 MILLION YEARS AGO
435 MILLION YEARS AGO
430 MILLION YEARS AGO
425 MILLION YEARS AGO
420 MILLION YEARS AGO
415 MILLION YEARS AGO
410 MILLION YEARS AGO
405 MILLION YEARS AGO
CUT HERE SO THE STRIPS ARE THE SAME SIZE
400 MILLION YEARS AGO
395 MILLION YEARS AGO
390 MILLION YEARS AGO
385 MILLION YEARS AGO
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80 MILLION YEARS AGO
75 MILLION YEARS AGO
70 MILLION YEARS AGO
65 MILLION YEARS AGO
60 MILLION YEARS AGO
55 MILLION YEARS AGO
50 MYA
50 MILLION YEARS AGO
45 MILLION YEARS AGO
40 MILLION YEARS AGO
35 MILLION YEARS AGO
30 MILLION YEARS AGO
25 MILLION YEARS AGO
20 MILLION YEARS AGO
15 MILLION YEARS AGO
10 MILLION YEARS AGO
5 MILLION YEARS AGO
PRESENT


900 MILLION YEARS AGO
895 MILLION YEARS AGO
890 MILLION YEARS AGO
885 MILLION YEARS AGO
880 MILLION YEARS AGO
875 MILLION YEARS AGO
870 MILLION YEARS AGO
865 MILLION YEARS AGO
860 MILLION YEARS AGO
855 MILLION YEARS AGO
850 MILLION YEARS AGO
845 MILLION YEARS AGO
840 MILLION YEARS AGO
835 MILLION YEARS AGO
830 MILLION YEARS AGO
825 MILLION YEARS AGO
820 MILLION YEARS AGO
815 MILLION YEARS AGO
810 MILLION YEARS AGO
805 MILLION YEARS AGO
800 MILLION YEARS AGO
795 MILLION YEARS AGO
790 MILLION YEARS AGO
785 MILLION YEARS AGO
780 MILLION YEARS AGO
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765 MILLION YEARS AGO
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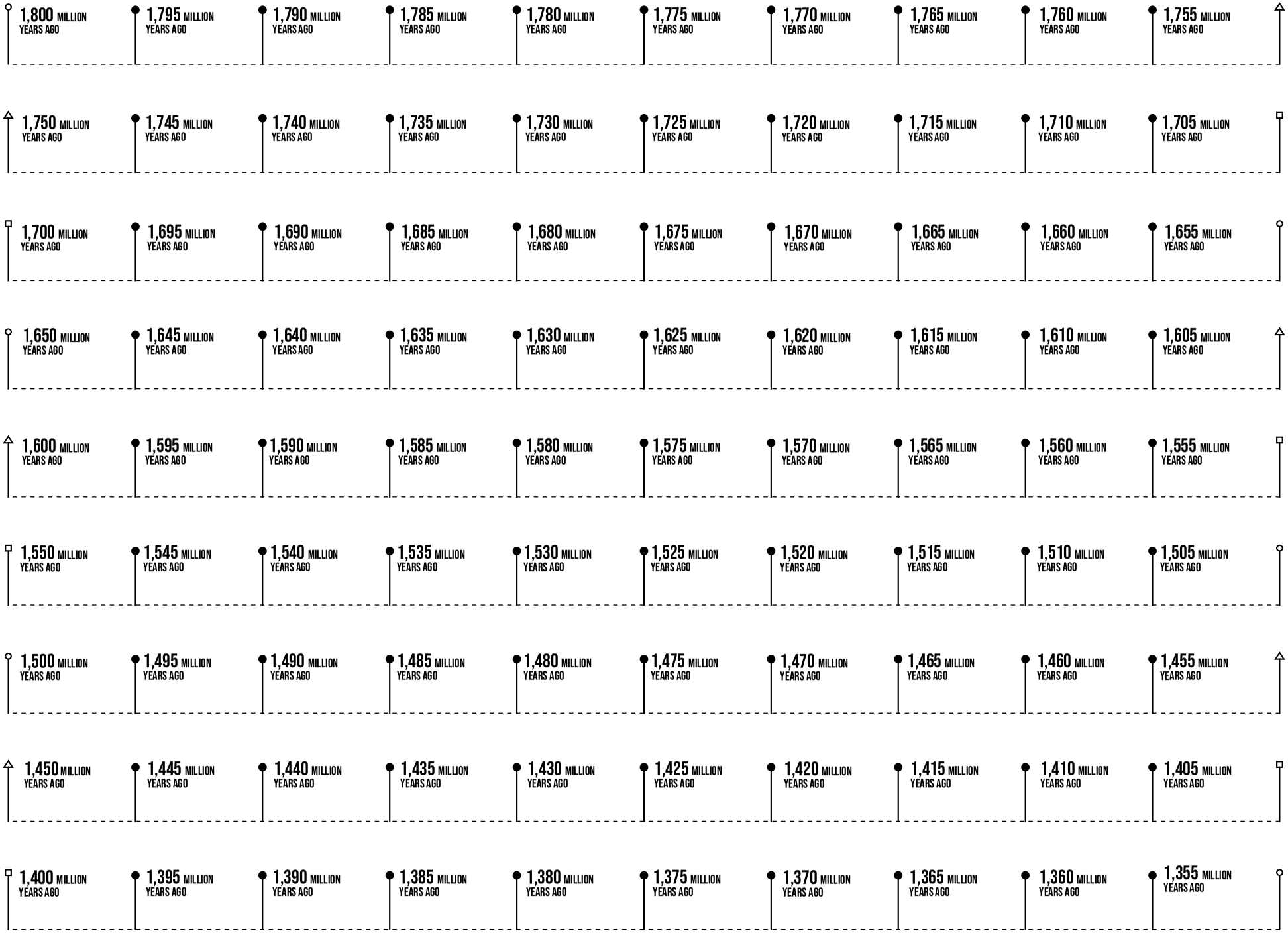
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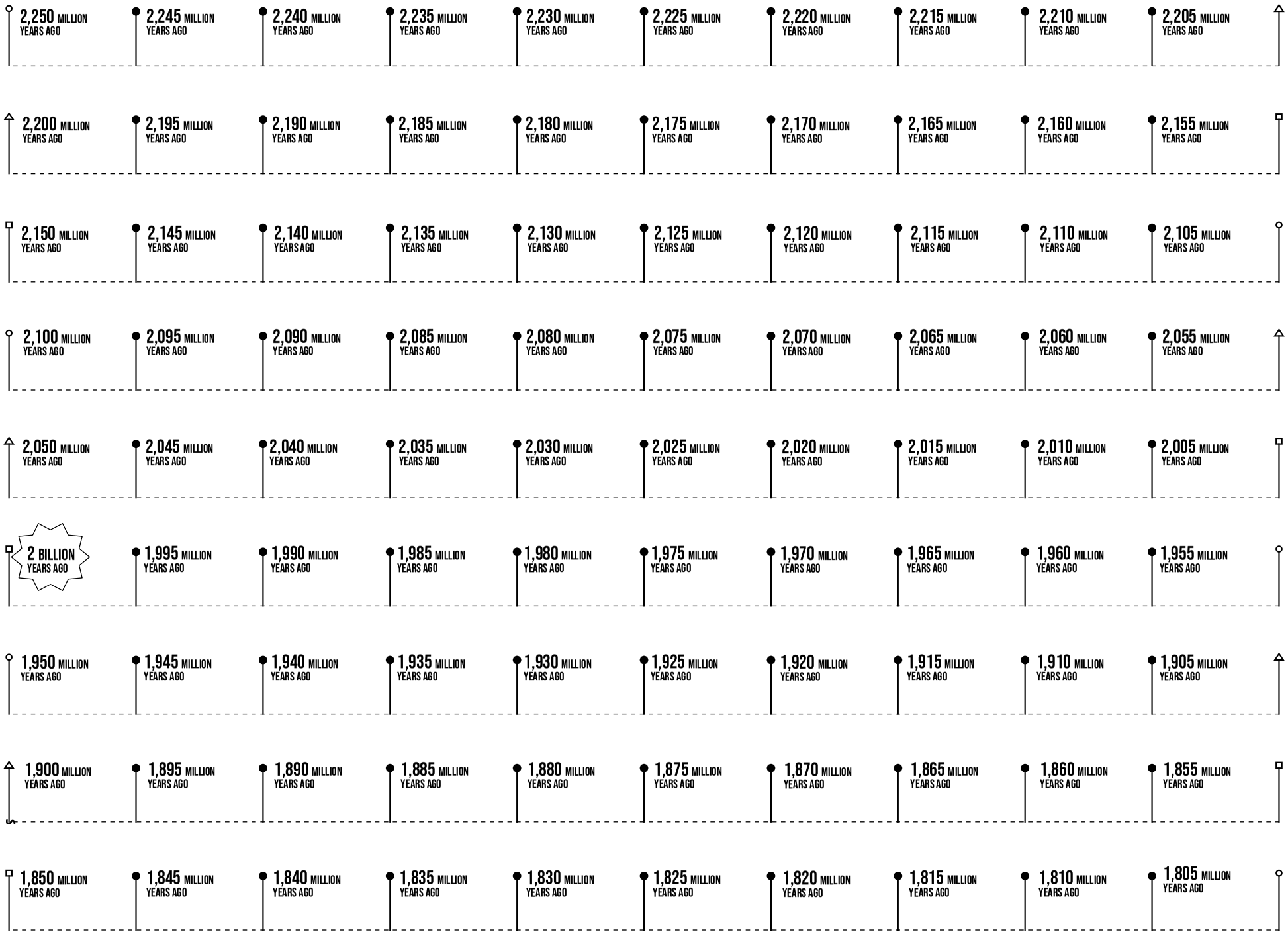
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3 BILLION YEARS AGO | 2,995 MILLION YEARS AGO | 2,990 MILLION YEARS AGO | 2,985 MILLION YEARS AGO | 2,980 MILLION YEARS AGO | 2,975 MILLION YEARS AGO | 2,970 MILLION YEARS AGO | 2,965 MILLION YEARS AGO | 2,960 MILLION YEARS AGO | 2,955 MILLION YEARS AGO

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4,455 MILLION YEARS AGO

4,450 MILLION YEARS AGO

4,445 MILLION YEARS AGO

4,440 MILLION YEARS AGO

4,435 MILLION YEARS AGO

4,430 MILLION YEARS AGO

4,425 MILLION YEARS AGO

4,420 MILLION YEARS AGO

4,415 MILLION YEARS AGO

4,410 MILLION YEARS AGO

34,405 MILLION YEARS AGO

4,400 MILLION YEARS AGO

4,395 MILLION YEARS AGO

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4,380 MILLION YEARS AGO

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4,210 MILLION YEARS AGO

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4,200 MILLION YEARS AGO

4,195 MILLION YEARS AGO

4,190 MILLION YEARS AGO

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4,150 MILLION YEARS AGO

4,145 MILLION YEARS AGO

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4,120 MILLION YEARS AGO

4,115 MILLION YEARS AGO

4,110 MILLION YEARS AGO

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4,100 MILLION YEARS AGO

4,095 MILLION YEARS AGO

4,090 MILLION YEARS AGO

4,085 MILLION YEARS AGO

4,080 MILLION YEARS AGO

4,075 MILLION YEARS AGO

4,070 MILLION YEARS AGO

4,065 MILLION YEARS AGO

4,060 MILLION YEARS AGO

4,055 MILLION YEARS AGO

Eon	Era	Period	Years *(millions of years ago or MYA)*
PHANEROZOIC	Cenozoic	Quaternary (Pleistocene/ Holocene)	2.588 to 0
		Neogene (Miocene/Pliocene)	23.03 to 2.588
		Paleogene (Paleocene/ Eocene/Oligocene)	66.0 to 23.03
	Mesozoic	Cretaceous	145.0 to 66.0
		Jurassic	201.3 to 145.0
		Triassic	252.17 to 201.3
	Paleozoic	Permian	298.9 to 252.17
		Carboniferous (Mississippian/ Pennsylvanian)	358.9 to 298.9
		Devonian	419.2 to 358.9
		Silurian	443.4 to 419.2
		Ordovician	485.4 to 443.4
		Cambrian	541.0 to 485.4
PROTEROZOIC	Neoproterozoic	Ediacaran	635 to 541
		Cryogenian	720 to 635
		Tonian	1,000 to 720
	Mesoproterozoic	Stenian	1,200 to 1,000
		Ectasian	1,400 to 1,200
		Calymmian	1,600 to 1,400
	Paleoproterozoic	Statherian	1,800 to 1,600
		Orosirian	2,050 to 1,800
		Rhyacian	2,300 to 2,050
		Siderian	2,500 to 2,300
ARCHEAN	Neoarchaean, Mesoarchean, Paleoarchean, Eoarchean	*Not divided into periods*	2,800 to 4,000
HADEAN	*Not divided into eras*		Formation of Earth to 4,000

**Some sources have slightly different start and end dates for different periods and eras, and that's okay! Remember that people invented periods, eras, and eons to help them study geologic history. Often the event that defines the end of one period and the beginning of another is an extinction event that spans hundreds of thousands or even millions of years.*