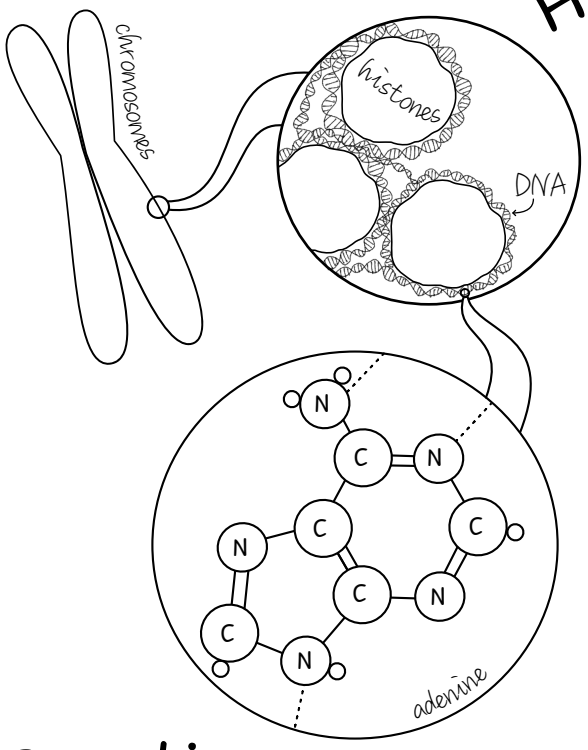
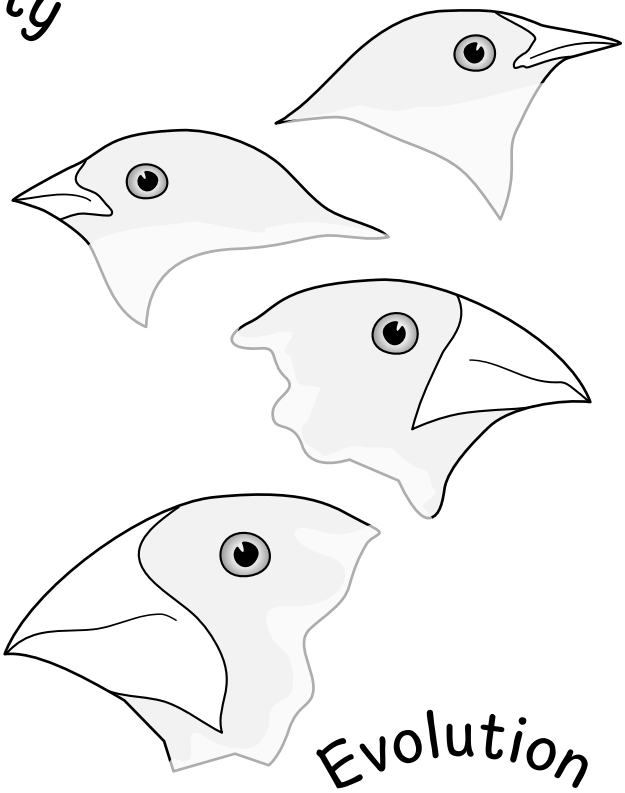
BIOLOGY TWO

	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

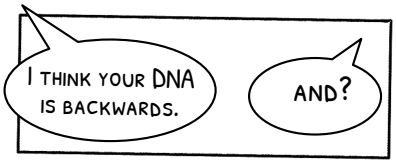
BIOLOGY

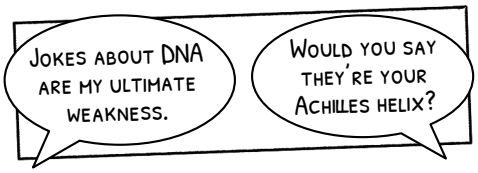
~ SPRING 2022 ~

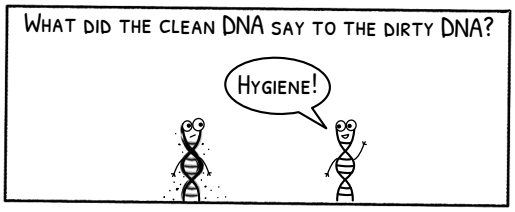
	Date	Topic	Page(s)
Week 1	Monday, Jan 24	What is a species?	6-7
	Wednesday, Jan 26	Life finds a way	8-9
	Friday, Jan 28	*Activity: Vegetative propagation with potato*	10-15
Week 2	Monday, Jan 31	Mendel's famous experiment	16-17
	Wednesday, Feb 2	Inheritance explained	18-21
	Friday, Feb 4	*Deep dive: 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: Red-green colorblindness*	
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 the 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.

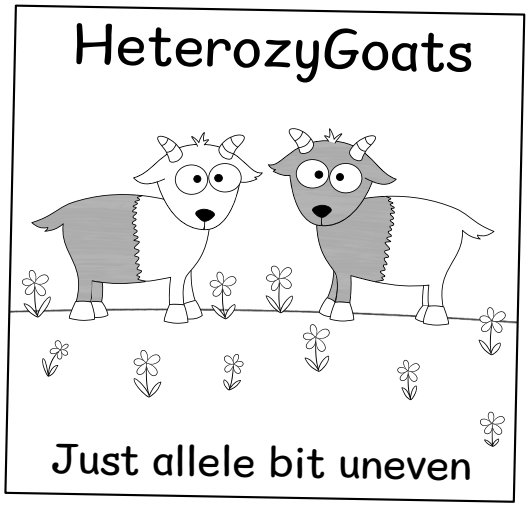
The classes are recorded and can be watched anytime after the recording date. Each week also has optional activities or reading assessments (deep dives). Students who complete and submit all activities and assignments will receive a bonus certificate of completion.

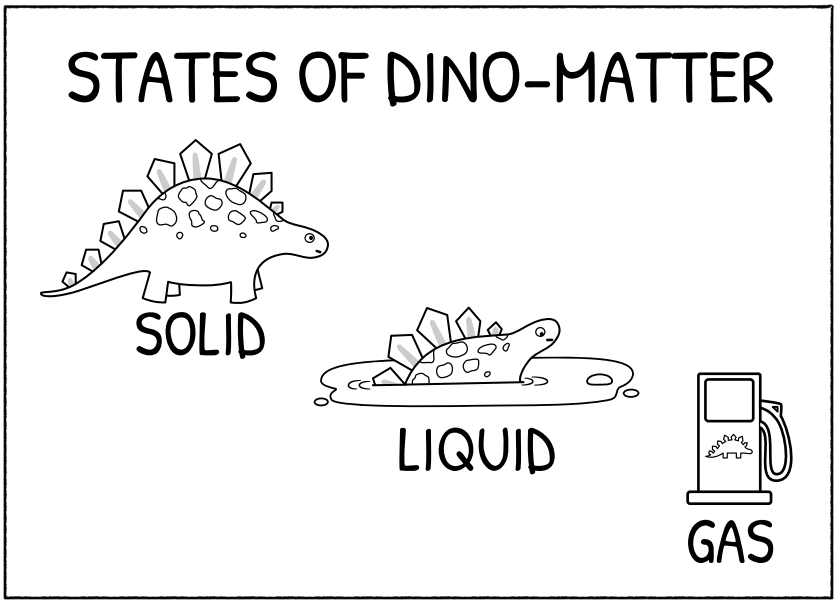






	Date	Topic	Page(s)
Week 12	Monday, Apr 11	Endangered vs invasive species	
	Wednesday, Apr 13	Darwin and the Galapagos	
	Friday, Apr 15	*Activity: Journey of the HMS Beagle*	
Week 13	Monday, Apr 18	Survival of the fittest	
	Wednesday, Apr 20	Color-changing moths	
	Friday, Apr 22	*Deep dive: When Sherpas climb Mt. Everest*	
Week 14	Monday, Apr 25	Genetic drift	
	Wednesday, Apr 27	Phylogenies and family trees	
	Friday, Apr 29	*Activity: Model a gene in a population*	
Week 15	Monday, May 2	What is a species really?	
	Wednesday, May 4	How are animals related?	
	Friday, May 6	*Deep dive: How DNA analysis rewrote phylogenetic trees*	
Week 16	Monday, May 9	Australia vs New Zealand	
	Wednesday, May 11	The fossil record	
	Friday, May 13	*Activity: Build your own phylogeny*	
Week 17	Monday, May 16	Timeline of life on Earth	
	Wednesday, May 18	**Evolution Quiz Show**	





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

Jan 24-Feb 18 - Heredity Anchor Diagram
- Paper and art supplies

Feb 25 - 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 4 - 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

Feb 21-Mar 25 - Genetics Anchor Diagram
- Paper and art supplies

April 8 - Journey of HMS Beagle
- Printable world map
- Paper and scissors
- Yarn or art supplies such as crayons, colored pencils, markers, or paint

April 22 - Model a Gene in a Population
- 20 black marbles and 20 white marbles (or other items that can be drawn randomly in a sample such as beans, candy, coins, or dice marked with tape, etc)

May 6 - Build your own phylogeny
- Paper and art supplies

Apr 4-May 13 - Evolution Anchor Diagram and Timeline
- Paper and art supplies

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 4, Apr 6, Apr 11, Apr 13***

MS-LS1-5. *Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.* ***Mar 14***

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, Feb 28, Mar 2, Mar 9, Apr 4***

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.* ***Apr 25, Apr 27, May 4, May 9***

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 20, Apr 27***

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.* ***Apr 20***

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 11, Apr 13***

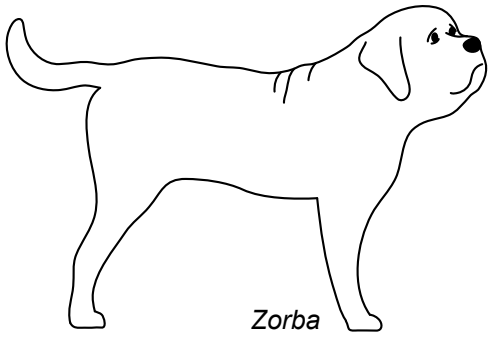
MS-LS4-5. *Gather and synthesize information about the technologies that have changed the way humans influence the inheritance of desired traits in organisms.* ***Mar 21***

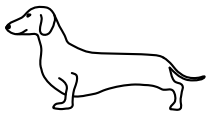
MS-LS4-6. *Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time.* ***Apr 18***

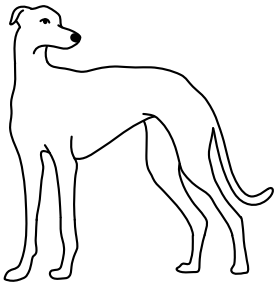
Date	Topic	NGSS	Page(s)
Wednesday, Jan 26	Life finds a way	MS-LS3-2	-
Monday, Jan 31	Mendel's Famous Experiment	MS-LS3-2	
Wednesday, Feb 2	The laws of heredity 1	MS-LS3-2	
Monday, Feb 7	The laws of heredity 2	MS-LS3-2	
Monday, Feb 14	Punnet squares	MS-LS3-2	
Monday, Feb 21	What is a gene?	MS-LS3-1	
Wednesday, Feb 23	Chromosomes and linked traits	MS-LS3-1	
Monday, Feb 28	Protein synthesis	MS-LS3-1	
Wednesday, Mar 2	Blood types explained	MS-LS3-1	
Wednesday, Mar 9	Mutations	MS-LS3-1	
Monday, Mar 14	Nature and nurture	MS-LS1-5,	
Monday, Mar 21	Modifying genes and gene therapy	MS-LS4-5	
Monday, Apr 4	Endangered vs invasive species	MS-LS1-4, MS-LS3-1	
Wednesday, Apr 6	Darwin and the Galapagos	MS-LS1-4	
Monday, Apr 11	Survival of the fittest	MS-LS1-4, MS-LS4-4	
Wednesday, Apr 13	Color-changing moths	MS-LS1-4, MS-LS4-4	
Monday, Apr 18	Genetic Drift	MS-LS4-6	
Wednesday, Apr 20	Phylogenies and family trees	MS-LS4-2, MS-LS4-3	
Monday, Apr 25	What is a species really?	MS-LS4-1	
Wednesday, Apr 27	How are animals related?	MS-LS4-1, MS-LS4-2	
Wednesday, May 4	The fossil record	MS-LS4-1	
Monday, May 9	Timeline of life on Earth	MS-LS4-1	

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

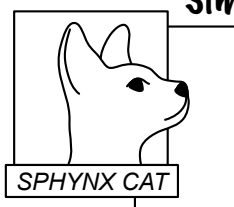
1. What makes a dog a dog? Share your opinion:

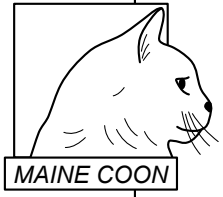
Answers will vary. Some possible characteristics to include could be that dogs are four legged, have fur, are carnivorous, and are social animals.

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*):



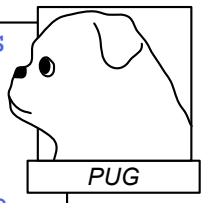


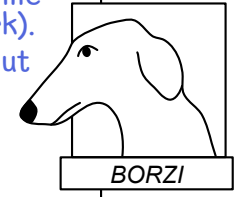
Similarities between cats and dogs:

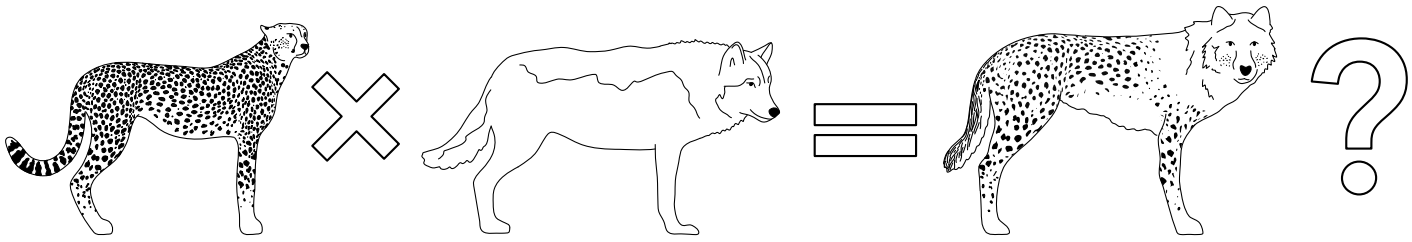
- Quadripeds (4 legs)
- Have fur
- Both kept as pets by humans
- Both have whiskers
- Both can be trained.
- Both have tails.
- Both have breeds with distinct traits.
- Both have wild relatives (wolf, coyote, lynx, bobcat)

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.



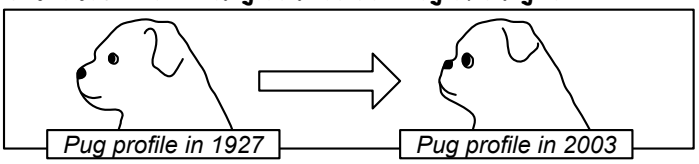




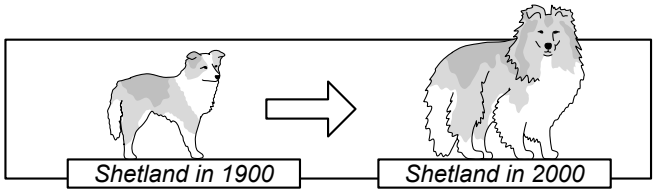
4. Coyotes, wolves, and dogs can all interbreed, creating hybrids like the wolfdog, coywolf, coydog or dogote. Lions and tigers can also be bred to create hybrids, which are called ligers or tigons. In your opinion, would it be possible to cross a cheetah with a wolf? If so, what would you call this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

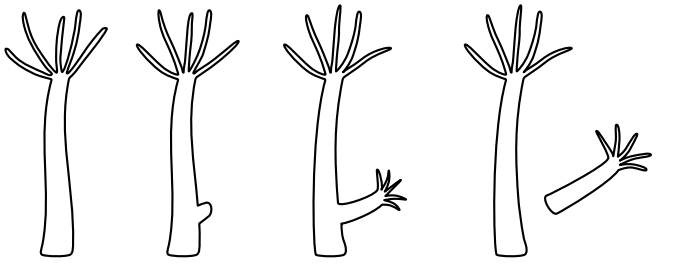
Martian Chihuahua in 3022

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

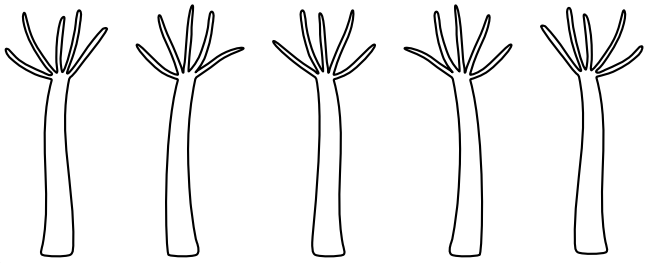
Life finds a way

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.

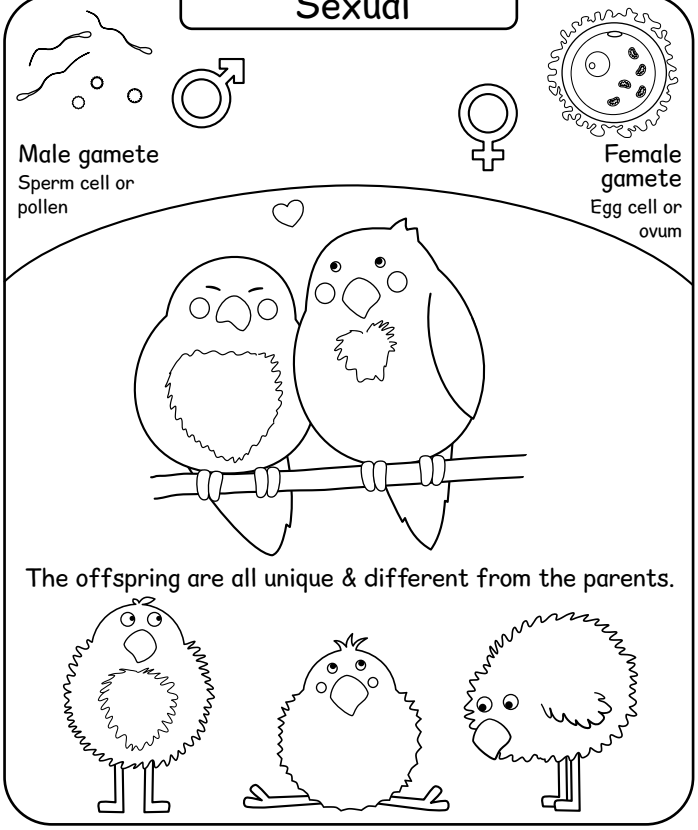
Asexual



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

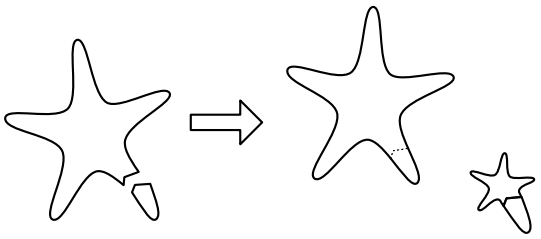
advantages:	disadvantages:
• No need for partner • Faster • One individual can form a colony or community of organisms.	• Low genetic diversity • More risk from disease

SEXUAL REPRODUCTION

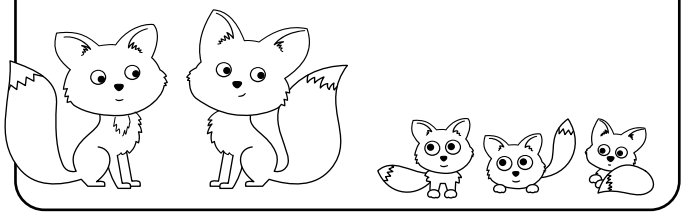
advantages:	disadvantages:
• High genetic diversity • Less risk from disease	• Need a partner to reproduce. • Generally takes more time to grow next generation

Match each reproductive strategy with the correct definition:

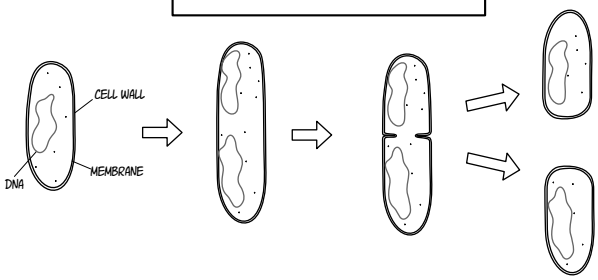
FRAGMENTATION



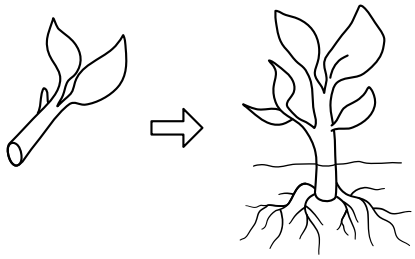
SEXUAL REPRODUCTION



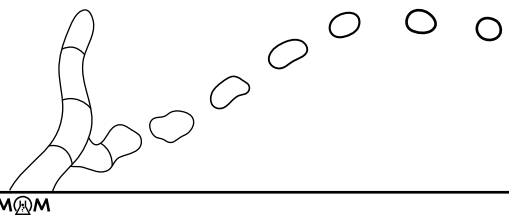
BINARY FISSION



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.

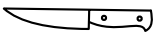
A form of reproduction occurring in plants where a fragment or cutting is separated from the parent plant and grows as a separate individual. Commonly used with food crops such as bananas, sweet potato, sugarcane, and pineapple.

Hands-on Science Project

PROPAGATE A POTATO

MATERIALS:

Potato or sweet potato



Knife

Rubbing Alcohol

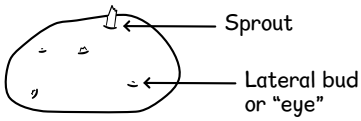
4 identically-sized pots or bags
Use a large pot or bucket with drainage holes, or a large burlap sack.

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.

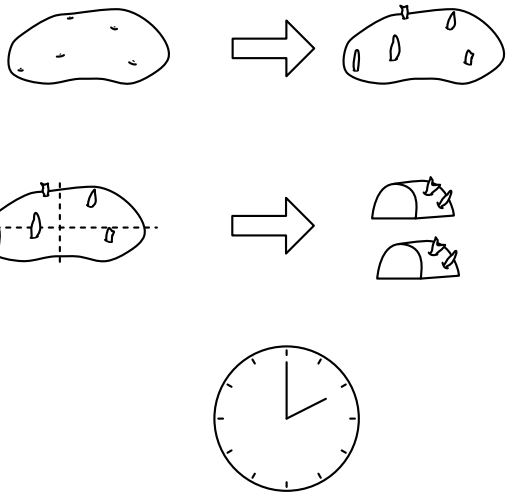
2. When the potato has sprouts, clean the knife with rubbing alcohol. Use the clean knife to cut the potato into 4 pieces that are roughly equal in size. Make sure that each piece of potato has at least one or two "eyes" with sprouts. If there are many sprouts on the piece of potato, break off some of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

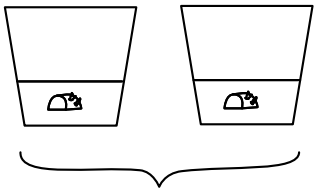
3. Let the cut pieces sit at room temperature for 24 hours. This drying process helps prevent mold from growing on the potatoes after they are planted.

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.

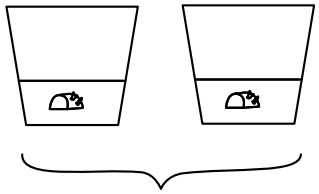
5. Water the soil in each pot so that it is moist. Place two of the pots in a very sunny location and the other two pots in a shady location.

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?

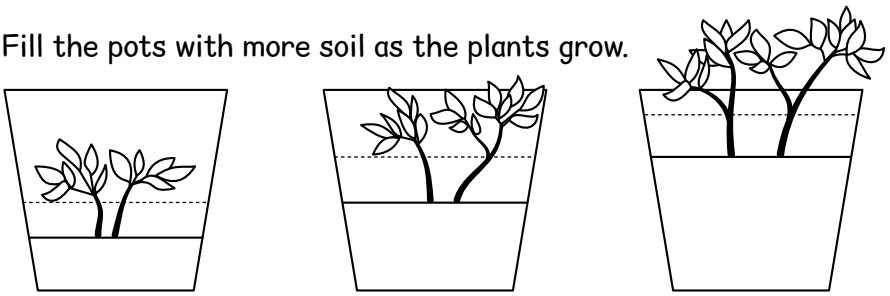
This activity can be done either indoors or outdoors. If you have space and it's winter time, we recommend indoors! If you have cats or dogs, take care that they don't eat the above-ground leaves and stems of the potato plant, which are poisonous. If you would prefer to plant your potatoes outdoors, 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.

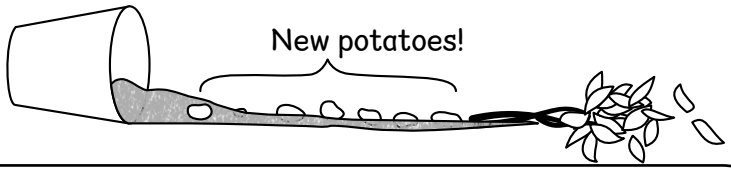
7. After sprouting, continue to add additional layers of potting soil until the pot is full. Record your observations about the size and appearance of the above-ground plants at regular intervals.

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.

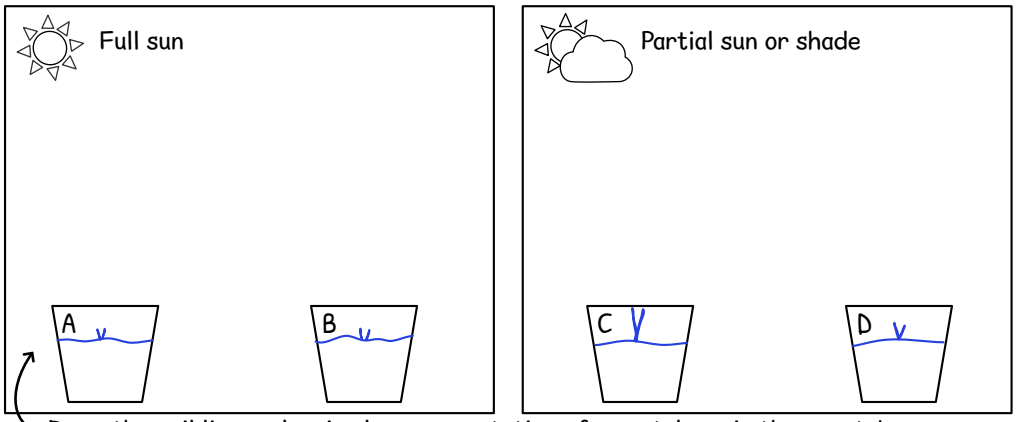




Observations just after the first sprouts emerge:

Noting the date is a vital part of recording research!

DATE:
1/02/2022



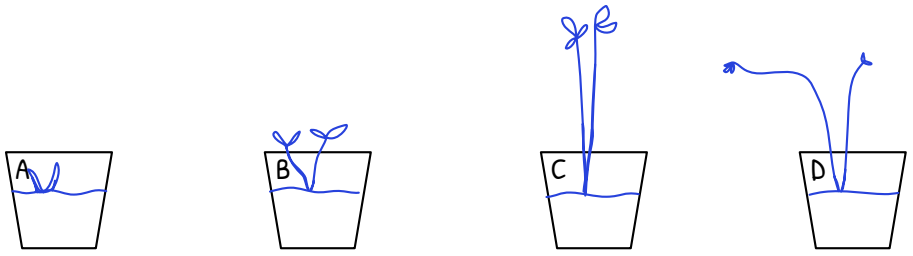
Draw the soil line and a simple representation of your tubers in these pots!

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

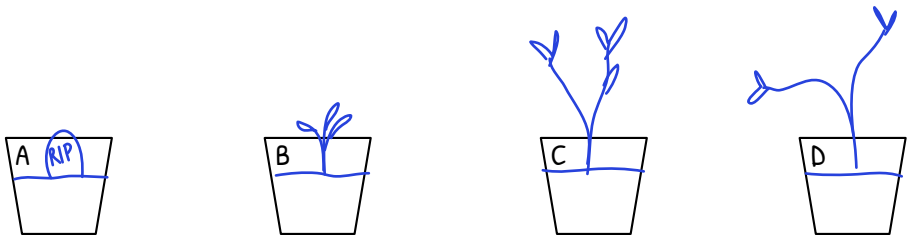


The leaves are starting to curl on the plant in pot A. I think it may be sick.

Observations 3 weeks after the first sprouts emerge:

DATE:

1/23/2022

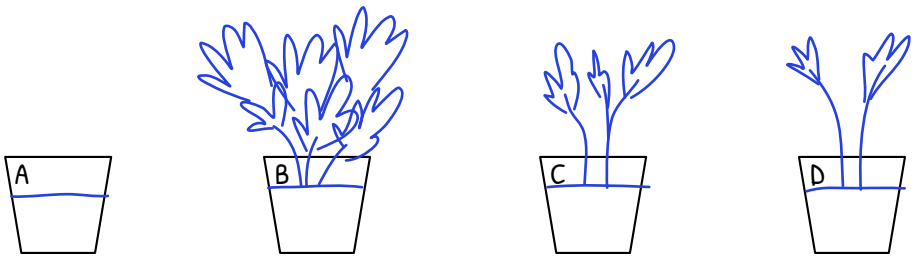


We added more soil at week 1. Plant A got sick with a fungus and died on 1/16/2022.

Observations 6 weeks after the first sprouts emerge:

DATE:

2/13/2022

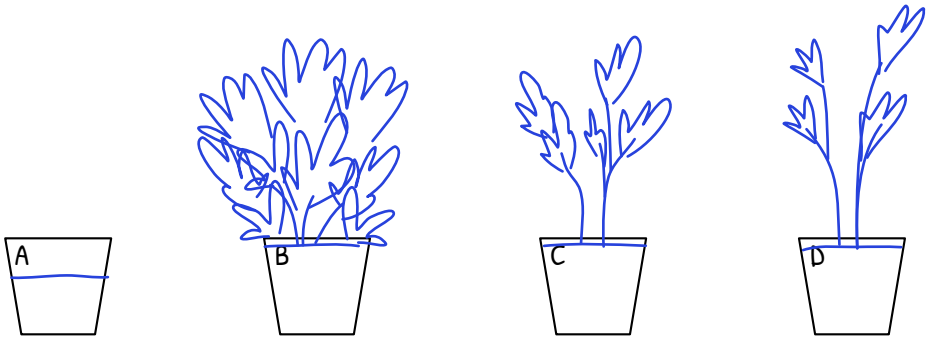


The full sun plant looks much more robust and larger than the part shade plants.

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

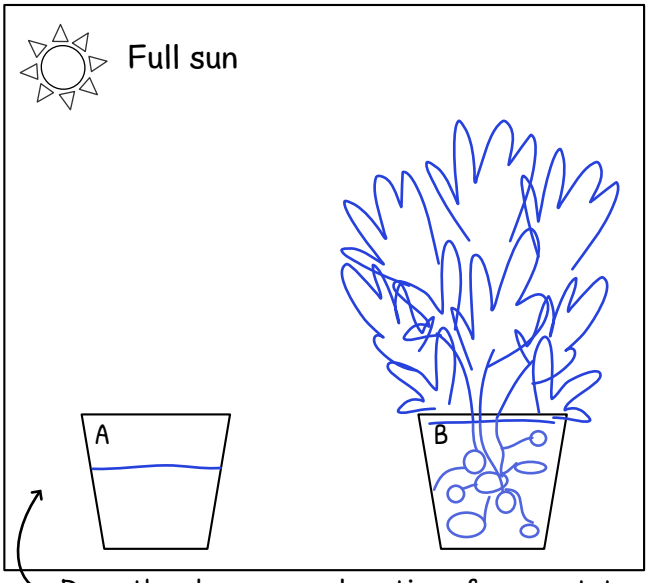
2. How different were the light conditions between your "full sun" and "partial sun" plants? If possible, study the locations for one day and count the number of hours of direct light each plant experienced.

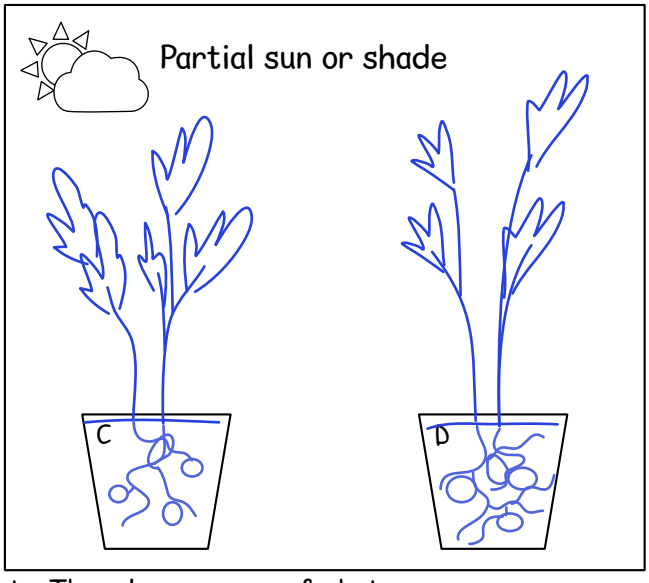
Full sun = window with 9 hours of direct light each day

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.

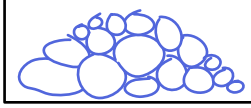
POTATO HARVEST

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

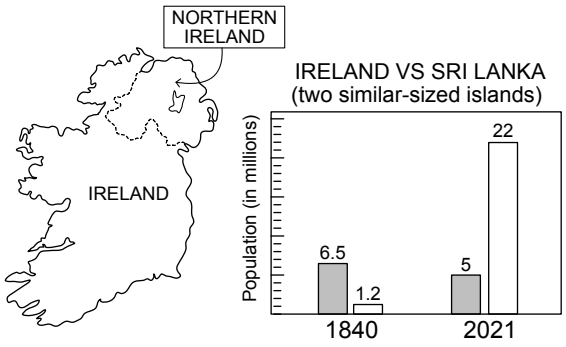
DATE: 3/10/2022

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.

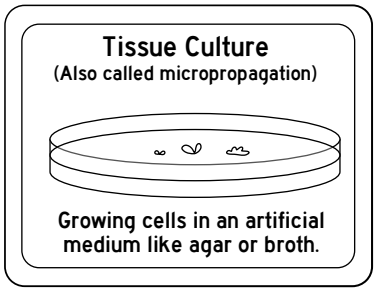
Potato Blight and the Irish Potato Famine

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

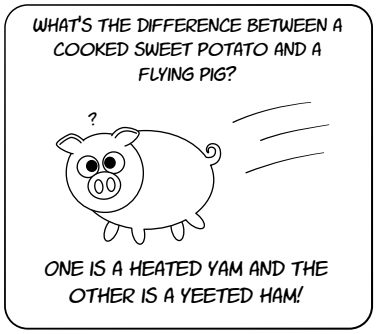
Potatoes can be infected by many different pathogens including viral, fungal, bacterial, and protozoan! Because they are susceptible to so many diseases, many of which are hard to detect, the crops of modern potato farmers actually start out in test tubes!



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.

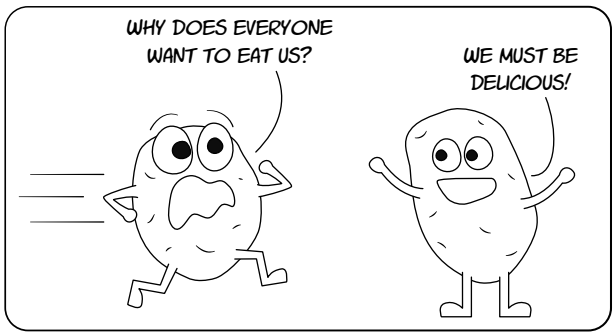
When the plantlets are large enough, they are moved to a greenhouse and planted in the ground. Then, just like regular potatoes, they grow for a few months, forming miniature tubers. After harvesting, these small tubers (called seed potatoes) are sorted and stored until it's time to plant the large crop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

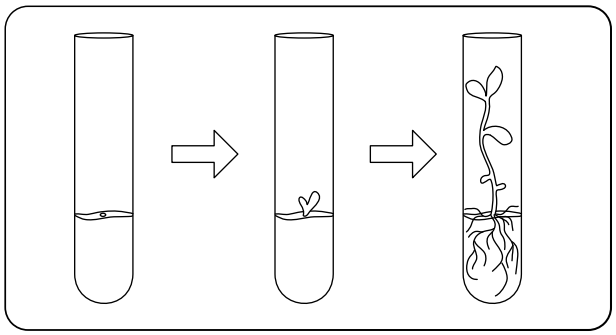


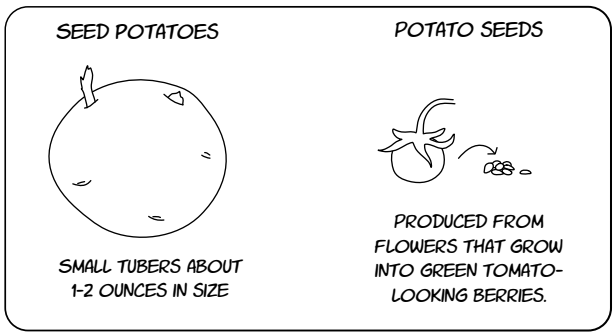
Certified seed potatoes have been tested multiple times to be sure they are free from bacterial, fungal, and viral infections.

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.

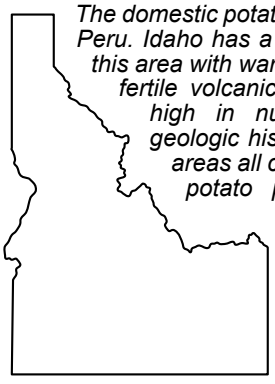
The buds on the seed potatoes sprout into plants and as the plants grow, so does their network of tubers underground. it is now up to the farmer to care for the potatoes by irrigating and fertilizing them. They'll be ready to harvest between 80 to 115 days after planting. At harvest, they're carefully 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!

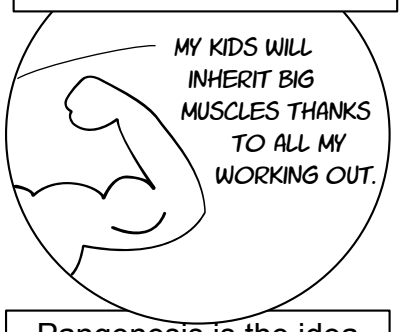
The question of inheritance

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

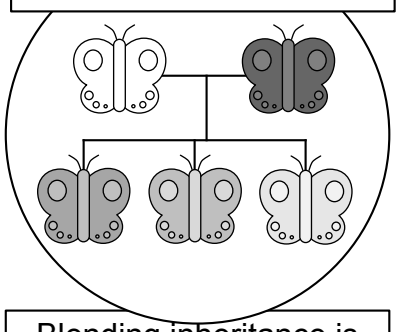
Lamarckism is the belief that acquired traits can be inherited. Giraffes are able to lengthen their necks by constantly stretching, so their offspring will inherit a longer neck.

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.

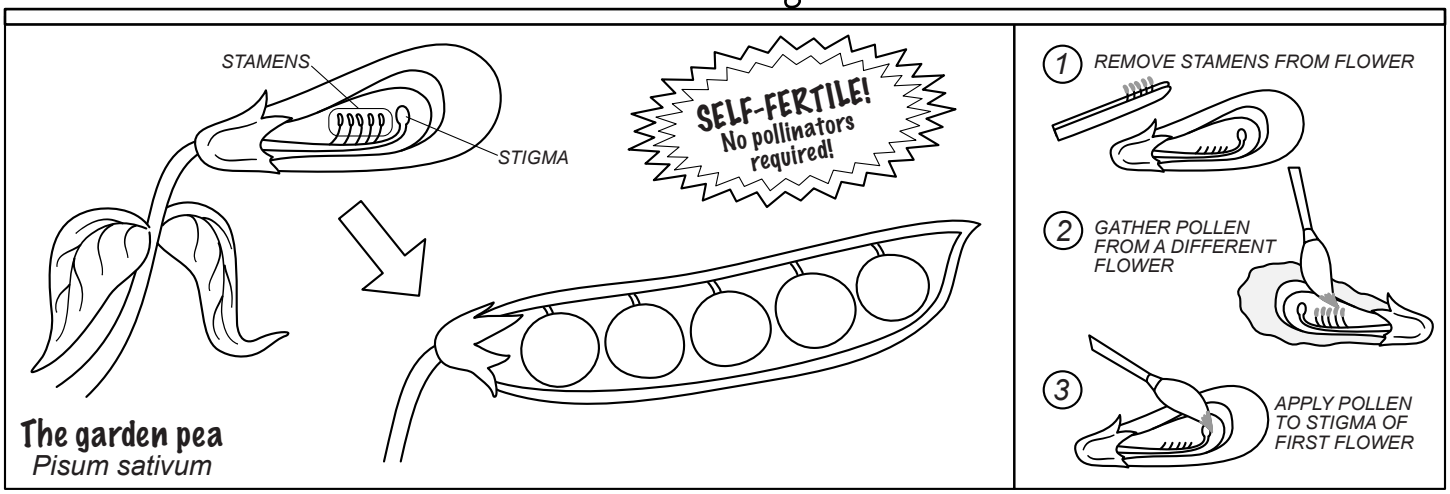
In the 1850s, Mendel conducted experiments to discover how inheritance worked. He studied the characteristics of pea plants, such as green and yellow seeds. His experiments were conducted in a small garden next to the abbey.

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

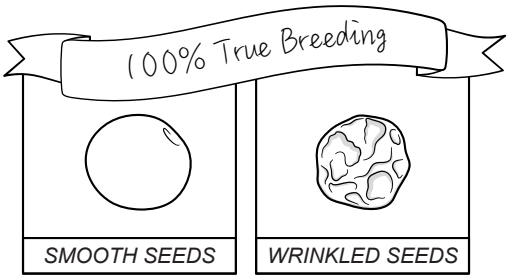
A famous experiment

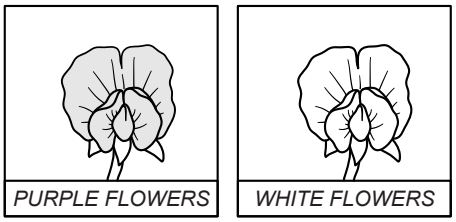


The garden pea
Pisum sativum

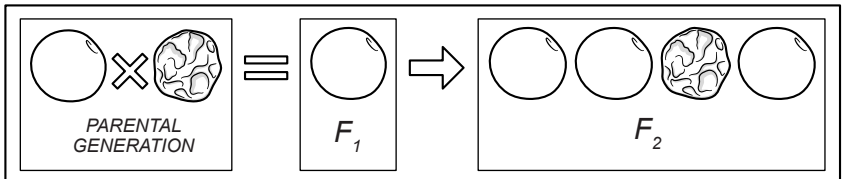
Peas are self-fertile. They do not need pollinators and unless a person intervenes, the pollen on the stamens will fertilize the stigma and produce a pea pod filled with seeds. To cross-pollinate two different pea plants, Mendel used tweezers to remove the stamens from one flower (1) and used a paintbrush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





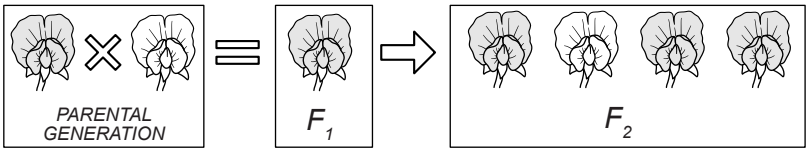
THE EXPERIMENT



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

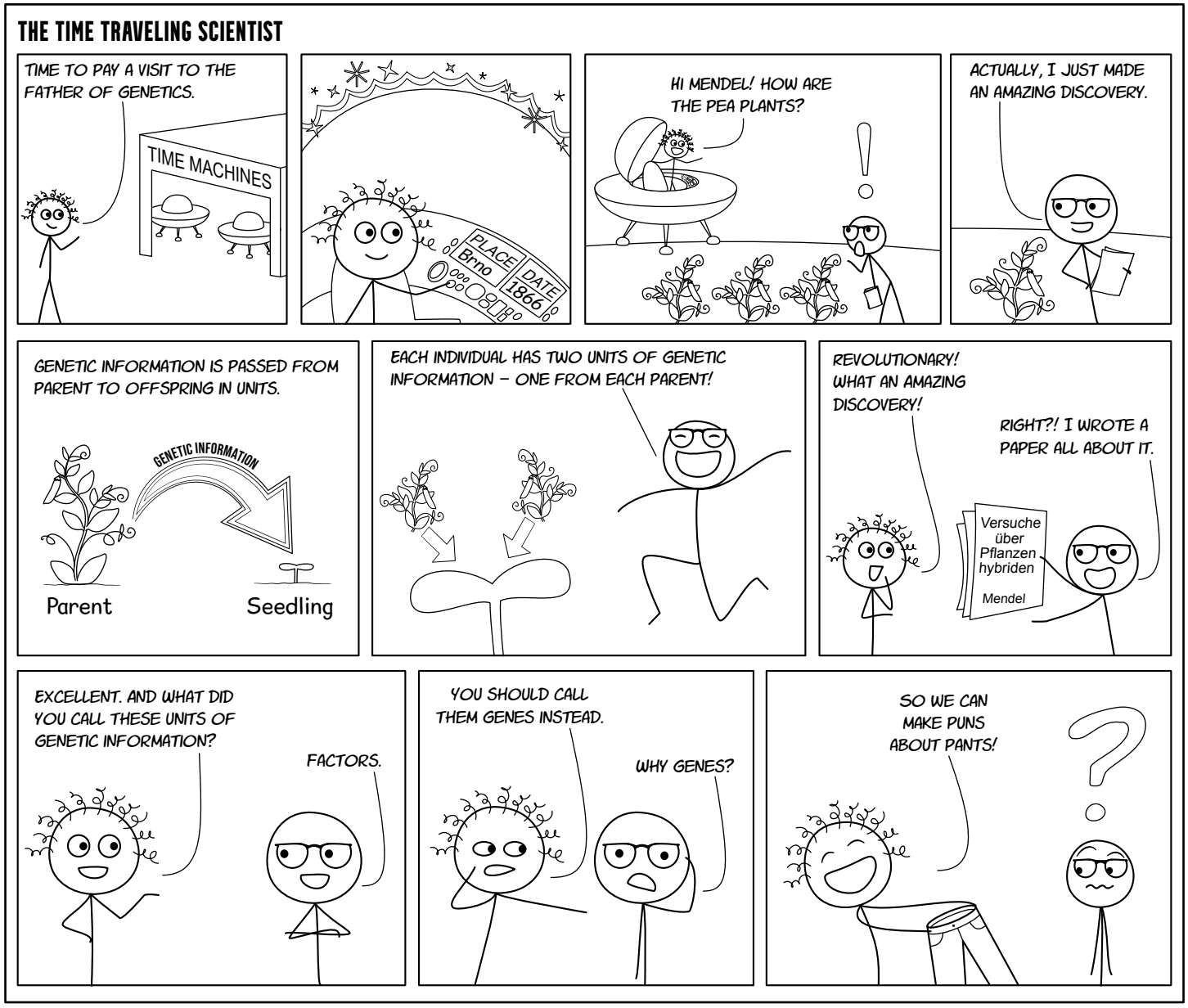
FILL IN THE BLANKS USING THESE WORDS:

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.

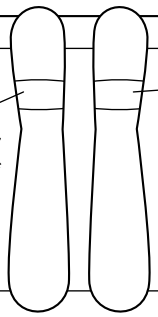
He published his research, but it was ignored for more than thirty years. Mendel wasn't recognized for his work until other scientists discovered the same facts in the 1900s.



Genotype

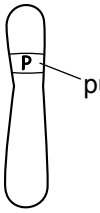
the genetic information

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.*

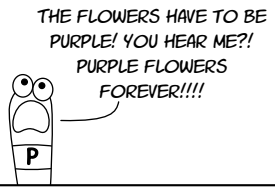
There isn't just one gene for flower color! There are different versions of this gene. One has instructions for purple flowers. Another version has instructions for white flowers. Different versions of the same gene are called **alleles**.



purple allele

white allele

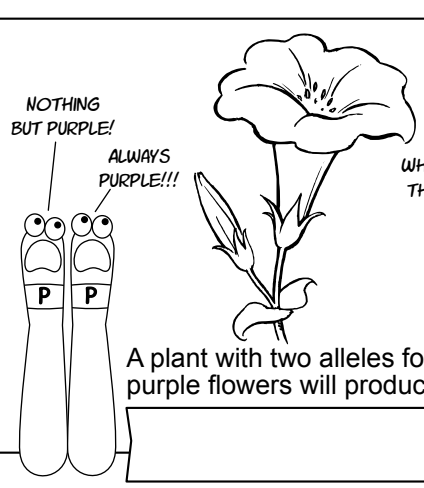
*We'll learn more about what genes are (segments of DNA) and where they are located (on chromosomes) in the next unit. For now, we can think of them as little bosses telling the organism what to do.



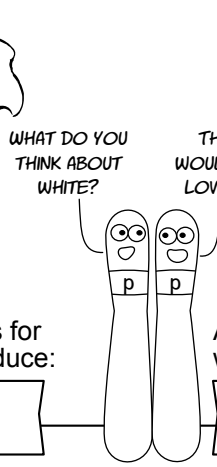
Phenotype

the observed trait

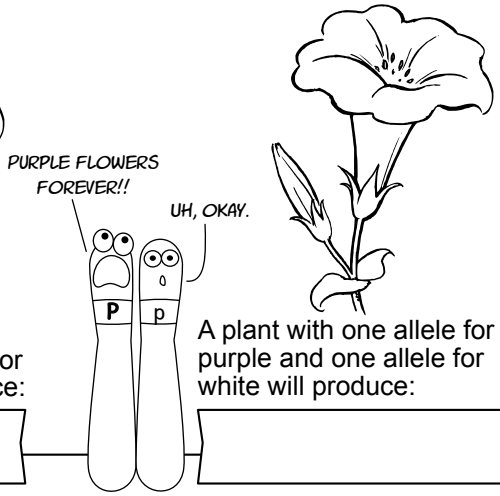
In this example, there are two phenotypes: purple flowers and white flowers. Write the expected phenotype in each box below. Then color the flowers accordingly.



A plant with two alleles for purple flowers will produce:

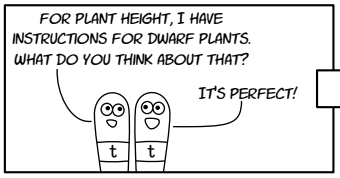


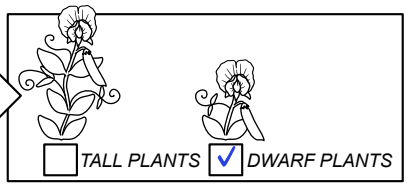
A plant with two alleles for white flowers will produce:



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

*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.*



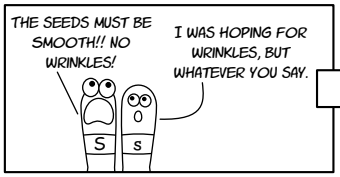


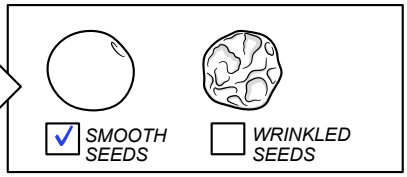
For plant height, if the **genotype** is:

Tt

The **phenotype** will be:

tall



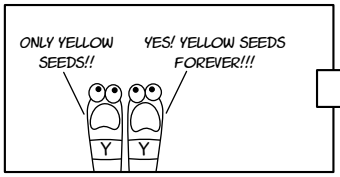


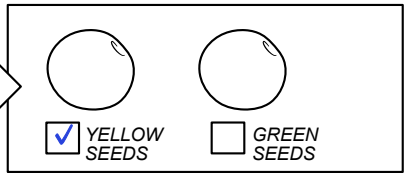
For seed texture, if the **genotype** is:

Ss

The **phenotype** will be:

smooth





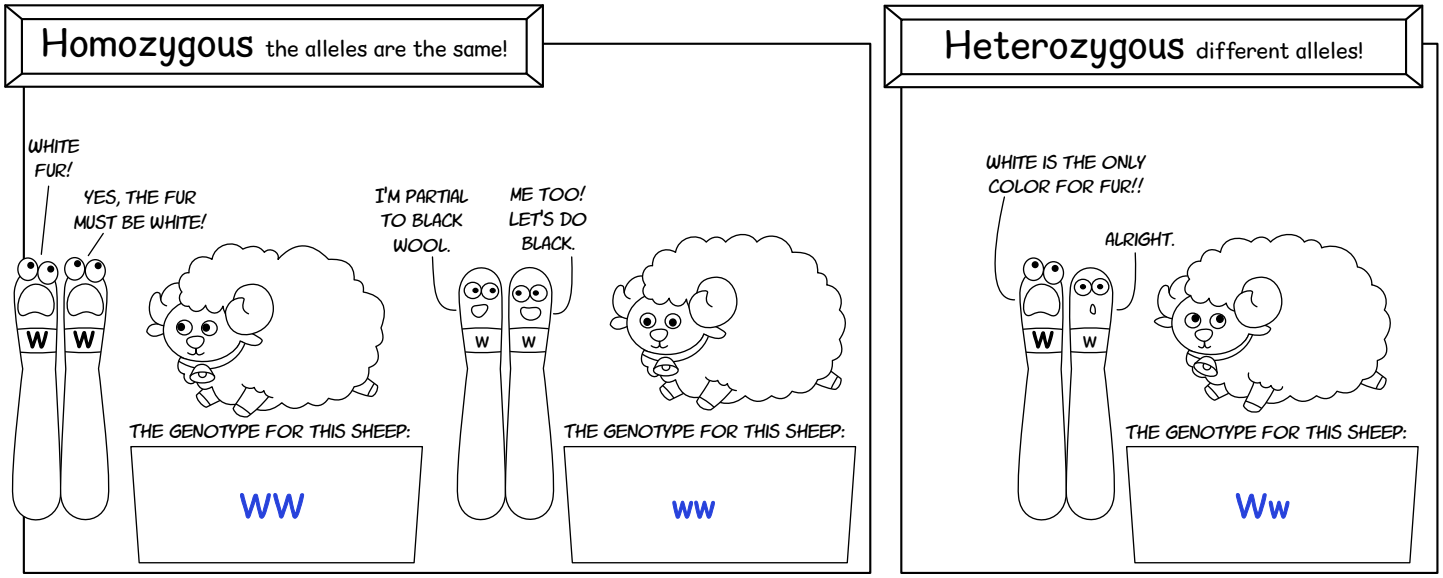
For seed color, if the **genotype** is:

yy

The **phenotype** will be:

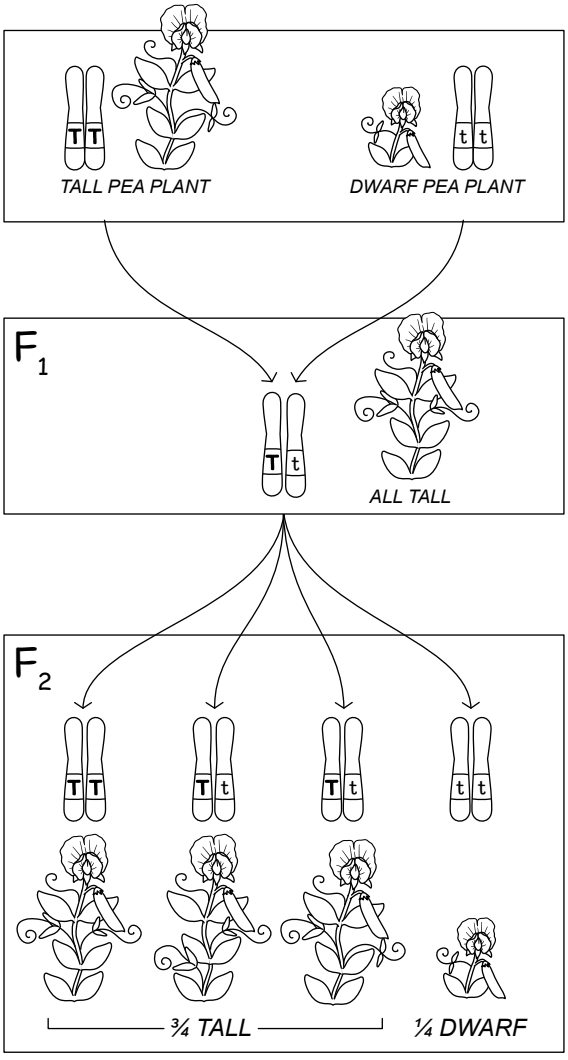
green

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)

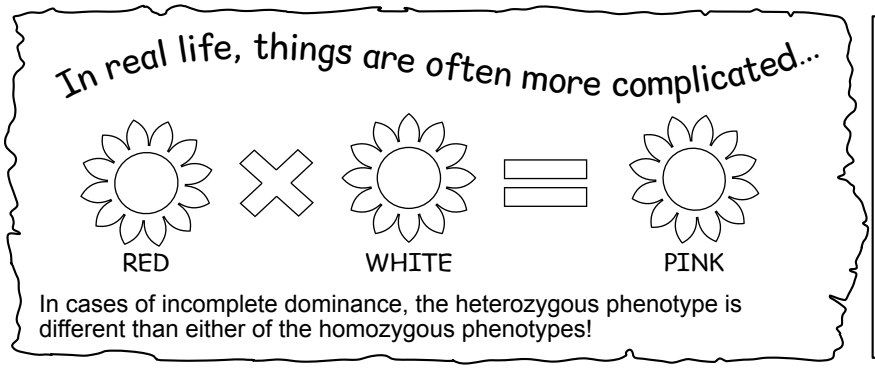
Write either "heterozygous" or "homozygous" in each of the labels below.

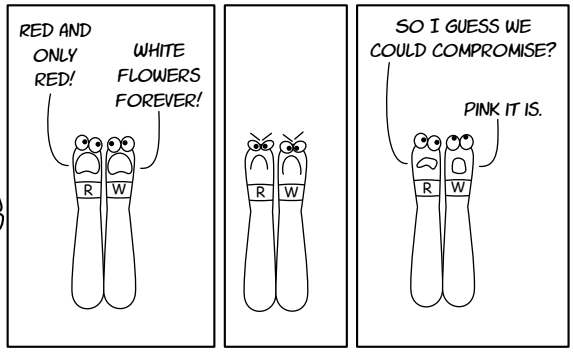


The plants in the parent generation are true-breeding or ___homozygous___ for their trait, which is plant height. The tall plants always produce seeds that grow into tall plants. The dwarf plants always produce seeds that grow into dwarf plants.

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.

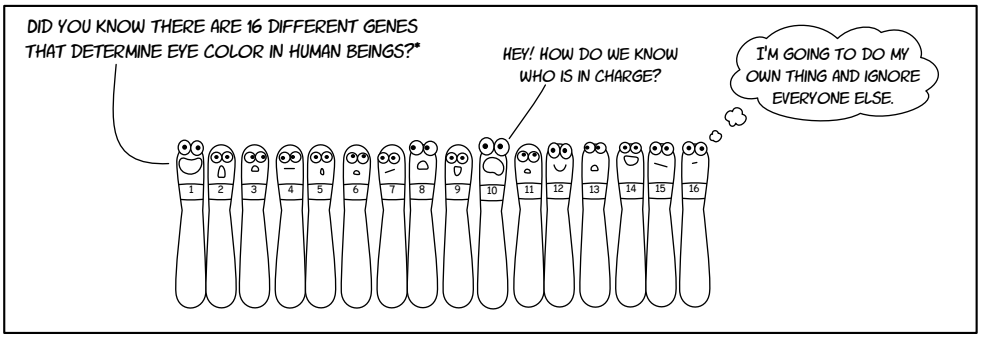
In the F_2 generation, a quarter of the plants show the phenotype of dwarfism. These plants are ___homozygous___ recessive. Two of the three tall plants are ___heterozygous___, which means they are no longer true-breeding for the trait of plant height.





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

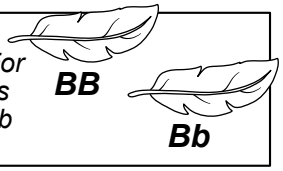
Homozygous

Heterozygous

Genotype

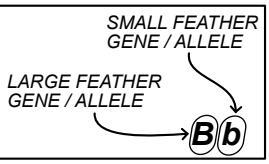
Phenotype

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.



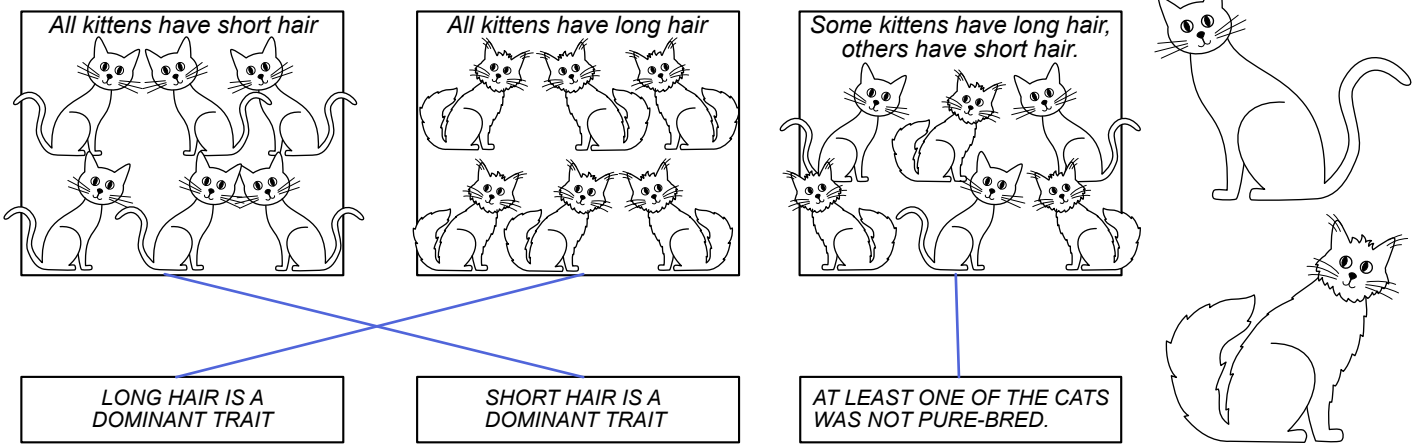
There are two different versions (alleles) of the gene. This word comes from the Greek words "heteros," which means different, and "zugos," which means yoked.

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.

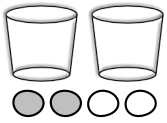


1. SEGREGATION - the alleles are distributed randomly

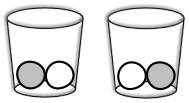
Mendel's first law states that the chance of inheriting an allele (or genetic factor) is random. For example, in the case of yellow or green seeds in pea plants, if the parent is heterozygous (Yy) there is a 50% chance the offspring will receive the dominant yellow (Y) allele and a 50% chance they will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

Try it yourself!

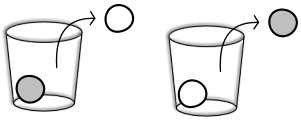
Supplies: *2 cups and 4 objects to represent dominant and recessive alleles. The objects should have the same shape and size but different colors. You could use dried peas, beans, marbles, dice, marshmallows or any items of the same size. Just make sure they are marked or colored so that you can tell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



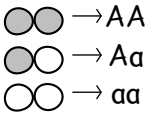
STEP 1 Place 1 object of each color in each cup. Assign one of the colors to be dominant (A) and the other to be recessive (a).



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

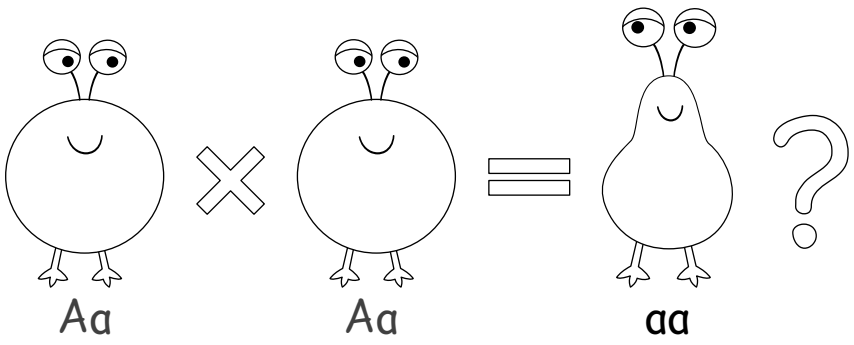
Count the number of yellow and green cells in your table. 26 Yellow 14 Green
Answers will vary! The first time we did this, we had 26 yellow and 14 green. Our second attempt had 31 yellow and 9 green.

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.

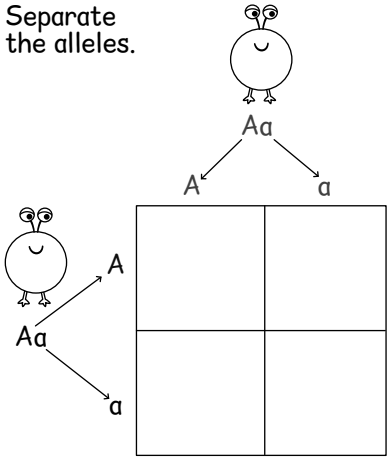
Punnett Squares

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:

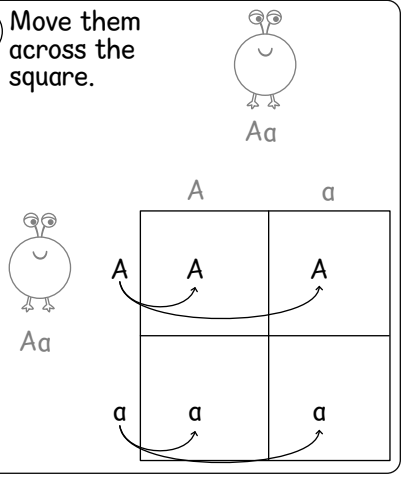


Round body shape (A) is dominant and pear body shape (a) is recessive. How many of the offspring will be pear-shaped (aa) from a heterozygous cross (Aa x Aa)? A Punnett square can tell us the answer!

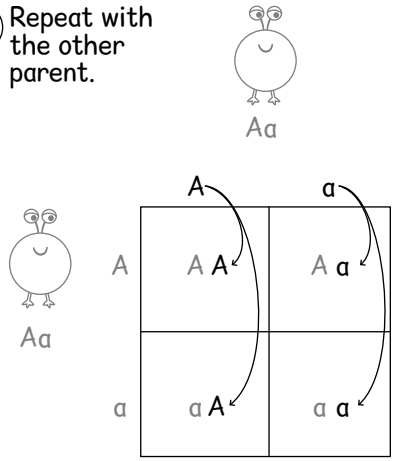
1 Separate the alleles.



2 Move them across the square.



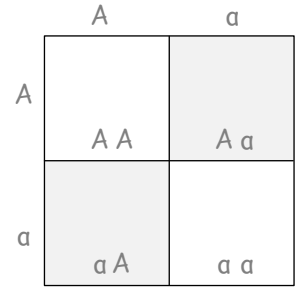
3 Repeat with the other parent.



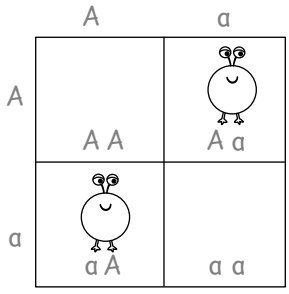
4 Evaluate your results!

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

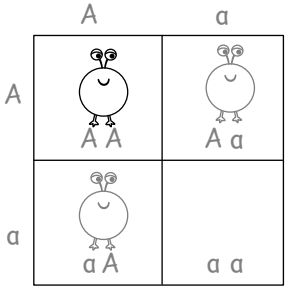
Aa = aA



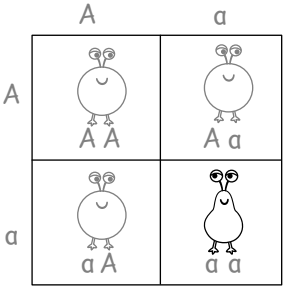
5 The phenotype for Aa is round.



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

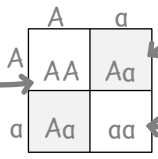


7 The phenotype for aa is pear-shaped.



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.

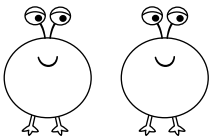


Round heterozygous aliens have a ½ chance of producing another heterozygous round alien.

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%.

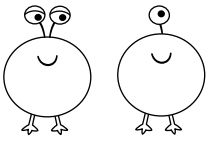


We usually just write "bB" as "Bb" so that all the heterozygous genotypes look alike.

Bb x Bb

	B	b
B	BB	Bb
b	Bb	bb

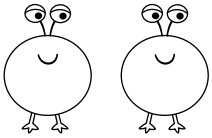
25 % chance of bb



BB x bb

	b	b
B	Bb	Bb
B	Bb	Bb

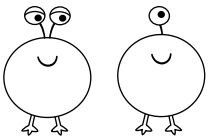
0 % chance of bb



BB x BB

	B	B
B	BB	BB
B	BB	BB

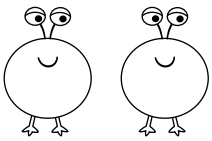
0 % chance of bb



Bb x bb

	b	b
B	Bb	Bb
b	bb	bb

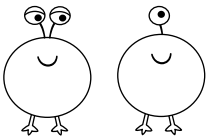
50 % chance of bb



BB x Bb

	B	b
B	BB	Bb
B	BB	Bb

0 % chance of bb

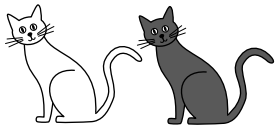


bb x bb

	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

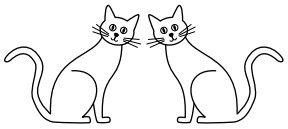
Will there be black kittens?

☑ yes ☐ no

	w	w
W	Ww	Ww
w	ww	ww

Black kittens produced:

☐ 0% ☐ 25% ☑ 50% ☐ 75% ☐ 100%



WW x Ww

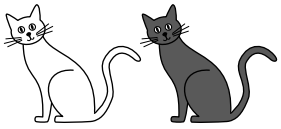
Will there be black kittens?

☐ yes ☑ no

	W	w
W	WW	Ww
W	WW	Ww

Black kittens produced:

☑ 0% ☐ 25% ☐ 50% ☐ 75% ☐ 100%



WW x ww

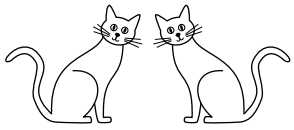
Will there be black kittens?

☐ yes ☑ no

	w	w
W	Ww	Ww
W	Ww	Ww

Black kittens produced:

☑ 0% ☐ 25% ☐ 50% ☐ 75% ☐ 100%



Ww x Ww

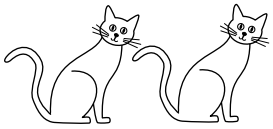
Will there be black kittens?

☑ yes ☐ no

	W	w
W	WW	Ww
w	Ww	ww

Black kittens produced:

☐ 0% ☑ 25% ☐ 50% ☐ 75% ☐ 100%



WW x WW

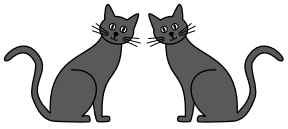
Will there be black kittens?

☐ 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:

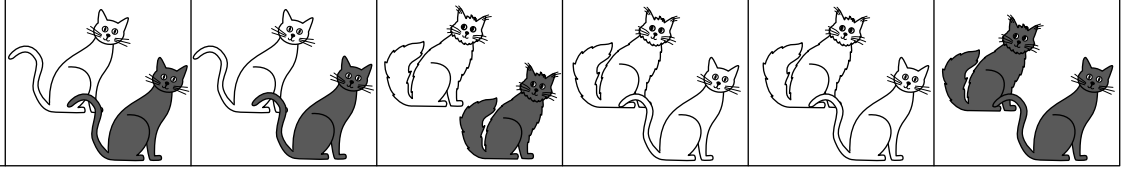
☐ 0% ☐ 25% ☐ 50% ☐ 75% ☑ 100%

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.*

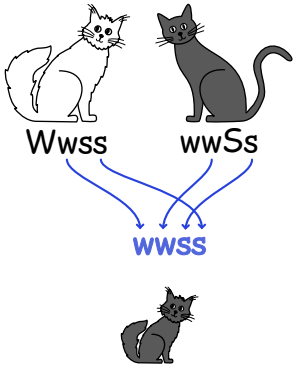
Genotype	SS	Ss	ss	WW	Ww	ww
Phenotype	*SHORT HAIR*	*SHORT HAIR*	*LONG HAIR*	*WHITE HAIR*	*WHITE HAIR*	*DARK HAIR*



*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.

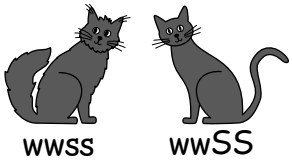
- [x] YES
- [ ] NO



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.

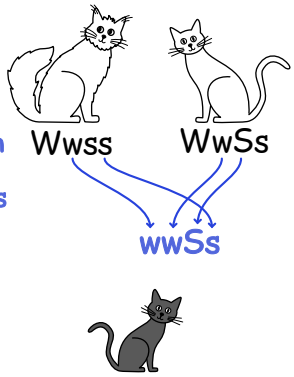
- [ ] YES
- [x] NO



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.

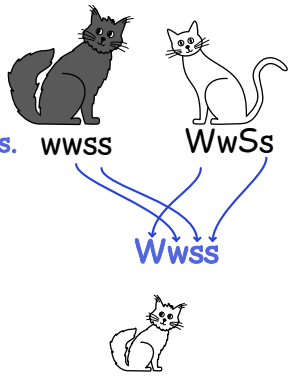
- [x] YES
- [ ] NO



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.

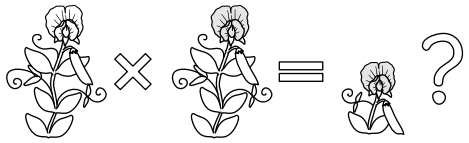
When talking about flower color, it doesn't matter if the plants are tall or dwarf; peas with the **P** *allele will be purple while peas with the* **pp** *genotype will be white.*

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.

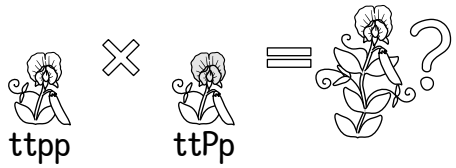
- [x] YES
- [ ] NO



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.

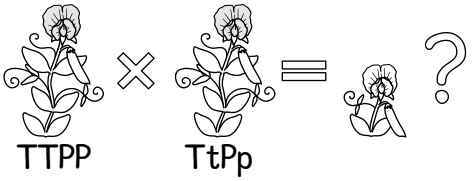
- [ ] YES
- [x] NO



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.

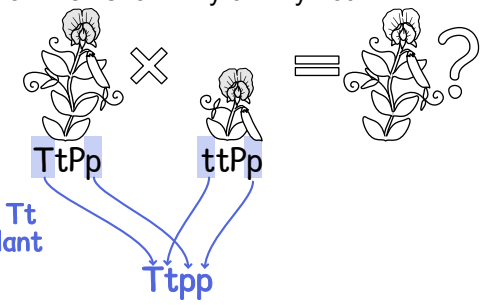
- [ ] YES
- [x] NO



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.

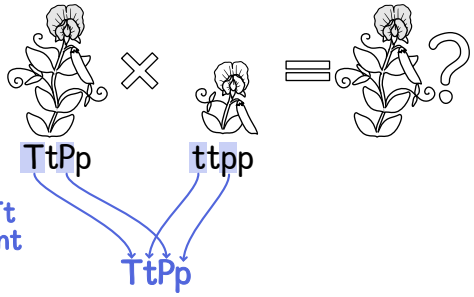
- [x] YES
- [ ] NO



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.

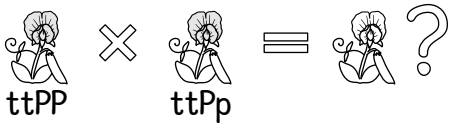
- [x] YES
- [ ] NO



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

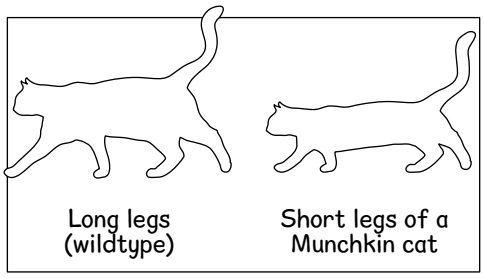


All of the offspring will be dwarf plants (tt), but the genotype for color will be either PP or Pp, resulting in a purple plant.

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.

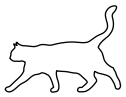


Possibility 1: Munchkin x Munchkin cross

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.

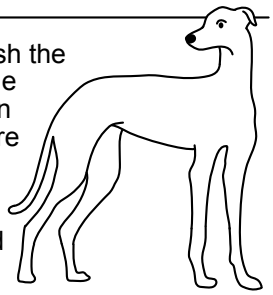
If Percy is pregnant with only two kittens, what are the possible outcomes for this litter?
Mark all genotype combinations that are possible.

- [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.



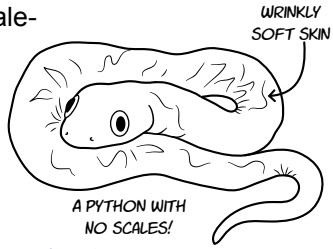
A group of dog breeders have developed a new dog breed called a Tardal.* In working to establish the Tardal as an officially recognized breed, full health histories are completed for all Tardal dogs. The studies reveal that Tardals are intelligent, loyal, and have the fastest running speed of any dog 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.

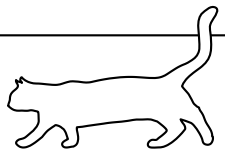
**The Tardal is an imaginary dog breed invented for this lesson.*

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.

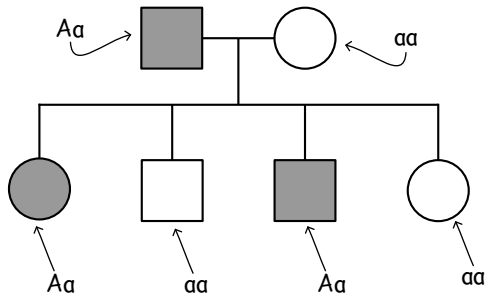
**An organization that registers pedigreed cats in the United Kingdom*

How to Read A Pedigree Chart

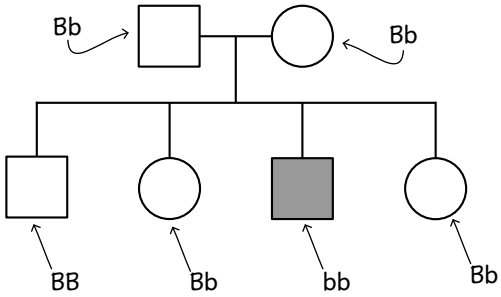
A pedigree chart is a family tree that tracks how a trait has been passed along. It typically follows the rules below:

- 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.

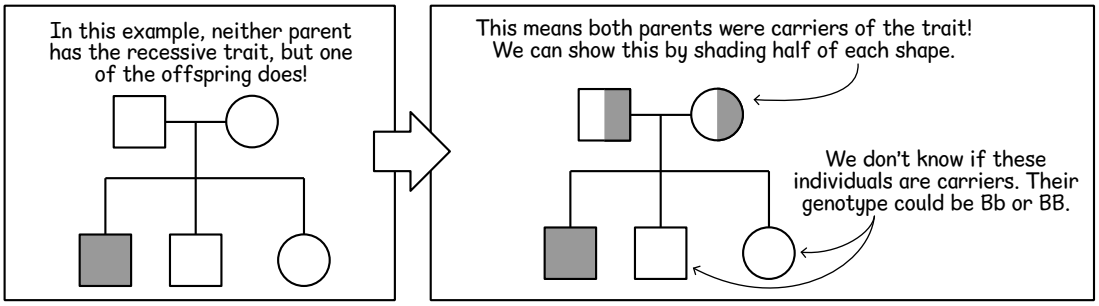
Example of a pedigree tracking the dominant trait ***A***



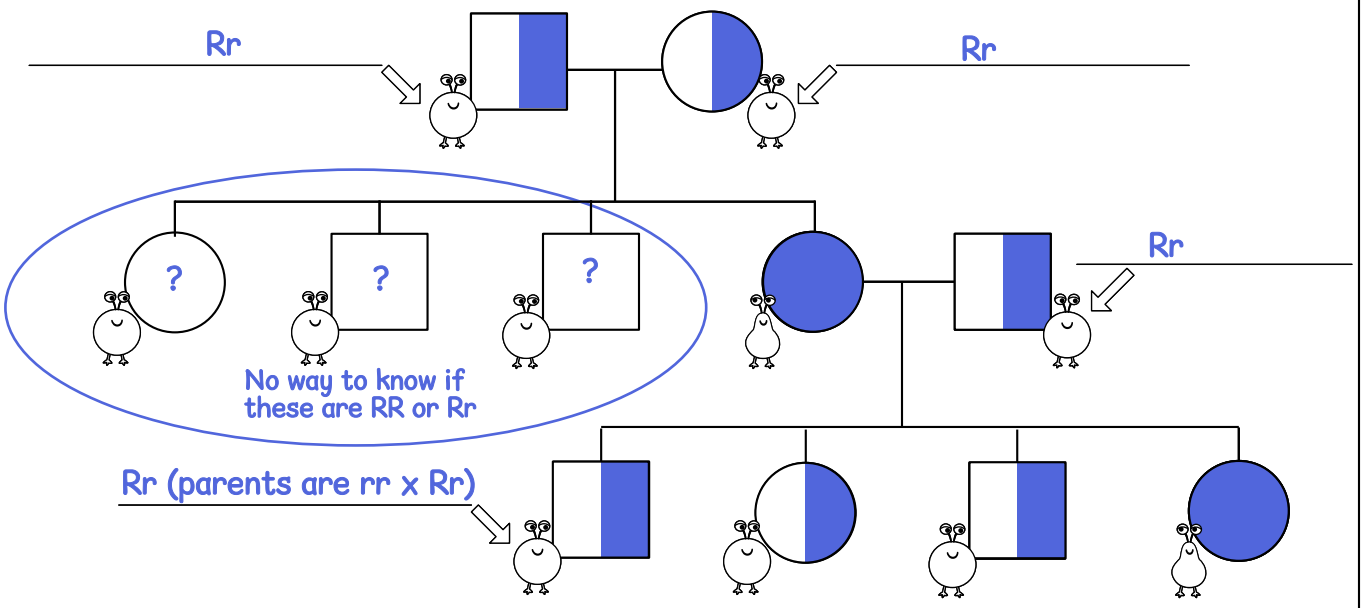
Example of a pedigree tracking the recessive trait ***b***



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.

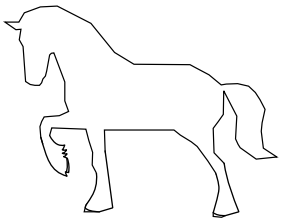


Color in this pedigree for tracking **pear shape** in the aliens. Remember, round body shape is dominant (RR) and pear shape is recessive (rr). The phenotype is known for all individuals. Can you determine the genotypes of the aliens indicated by the arrows?

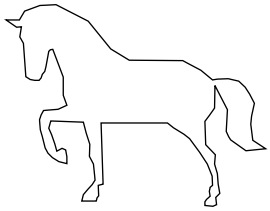


Pet Pedigree Puzzle #1

Profile of a breed with feathered feet



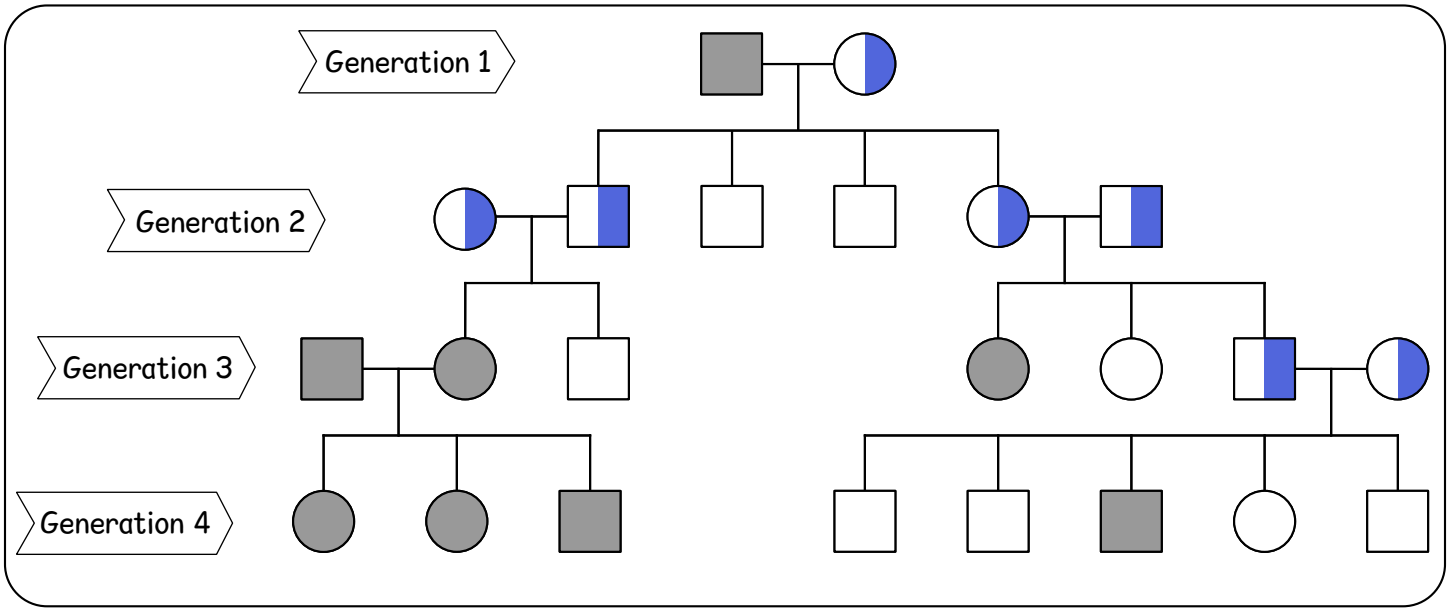
Profile of a breed without feathered feet



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

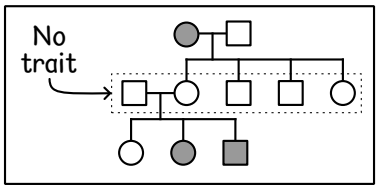
A non-feathered foot has short hair.

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.



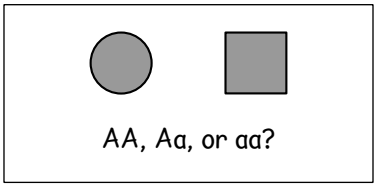
Can a dominant trait skip a generation? What about a recessive trait? Explain.

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.

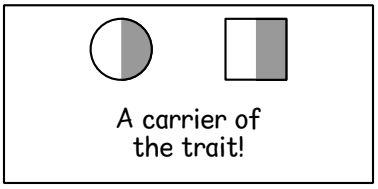


Is the trait mapped in this pedigree chart dominant or recessive? Explain how you know.

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

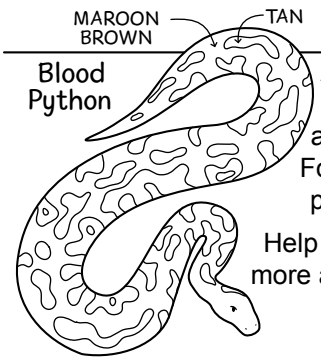


When tracking a recessive trait, a half-shaded shape is used to indicate a carrier. Can you identify a horse or horses in this pedigree that must be carriers of the trait? If yes, shade in their shapes.



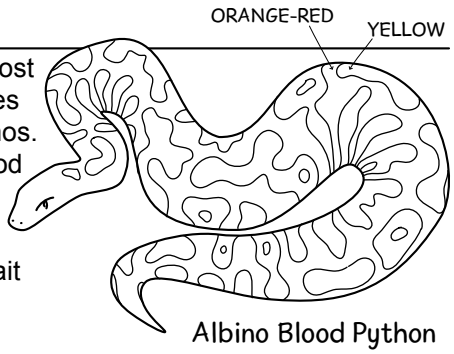
While a cross between a feathered horse (such as a Clydesdale) and a non-feathered horse (such as a Thoroughbred) will result in a horse that is non-feathered, the genetics of feathering have not been studied in detail. It's likely to include more than one gene and be more complicated than the hypothetical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

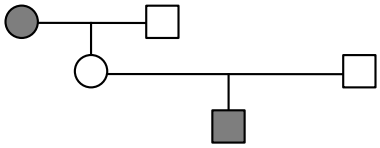
Pet Pedigree Puzzle #2



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.

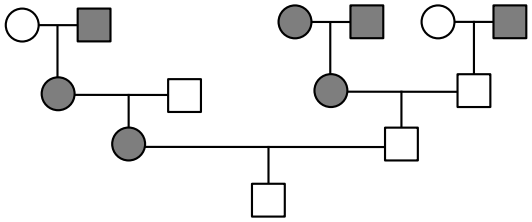
Help Ella make the choice that will give the highest chance of more albino pythons! Remember that albinism is a recessive trait and the pedigrees only show phenotype, not genotype.





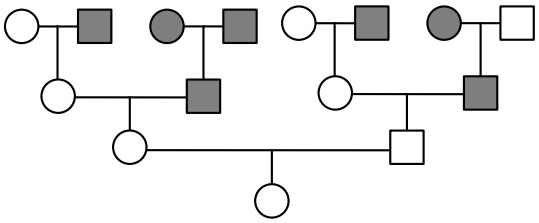
Julius Squeezer

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



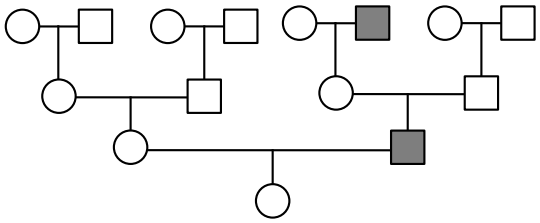
Basil

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**

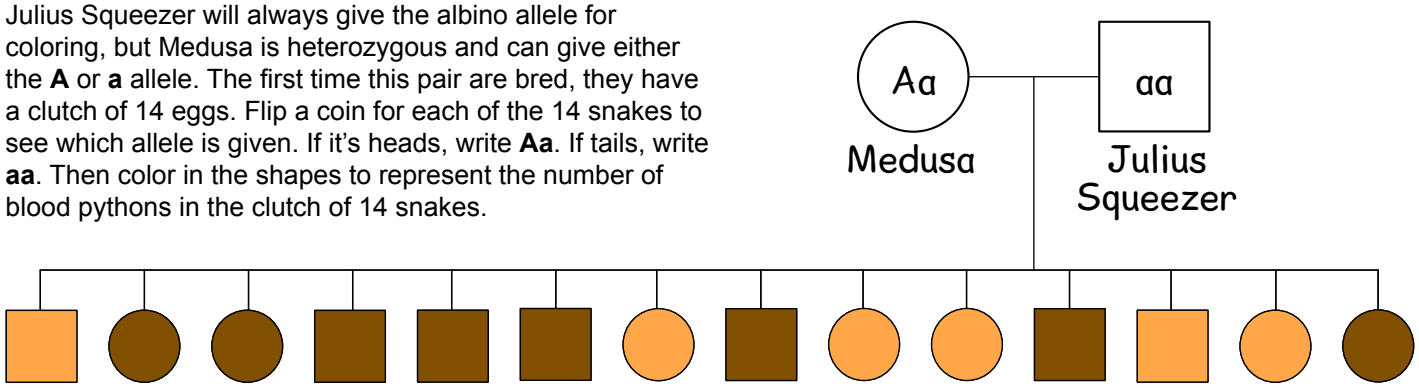
Which snakes should Ella select for breeding and why?

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...

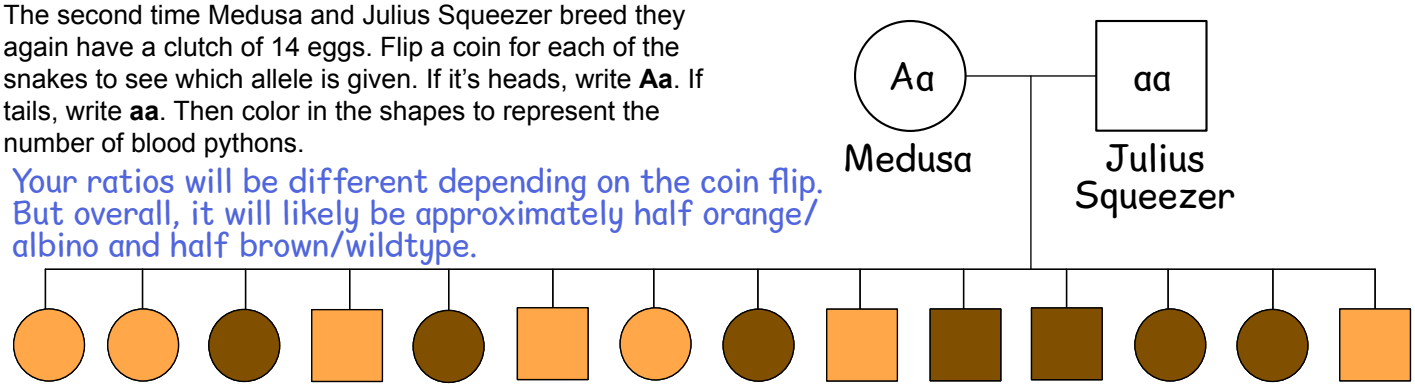
The probability of an aa x Aa cross giving albino snakes may be 50/50, but that doesn't mean you'll see that exact ratio in real life! Explore Mendel's first law by using a coin to determine whether these snakes produce albino blood pythons. Color the albinos (**aa**) orange. Use brown to mark the standard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



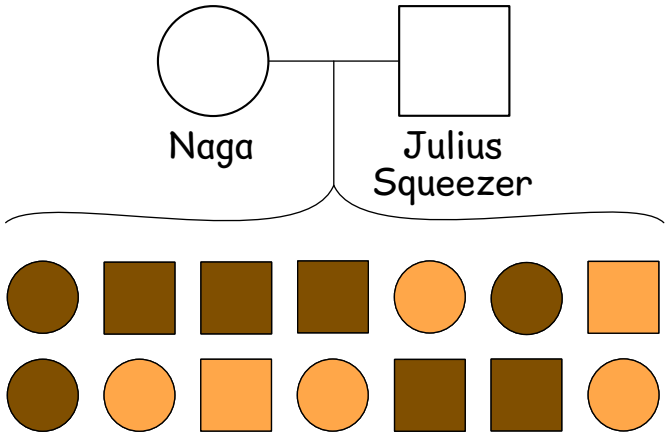
The second time Medusa and Julius Squeezer breed they again have a clutch of 14 eggs. Flip a coin for each of the snakes to see which allele is given. If it's heads, write **Aa**. If tails, write **aa**. Then color in the shapes to represent the number of blood pythons.

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



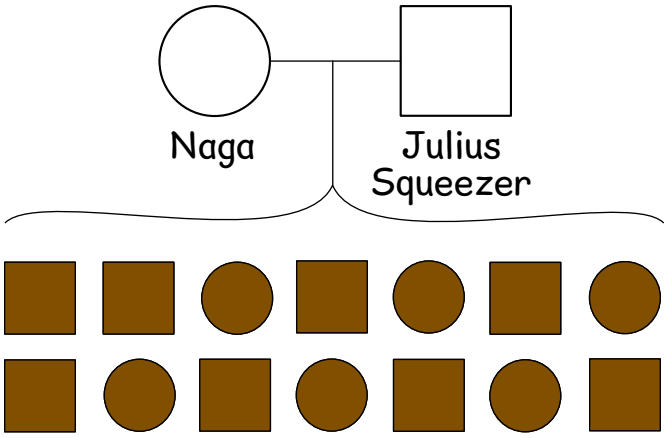
Assuming Naga is heterozygous (**Aa**), flip a coin to see what proportion of this clutch of eggs would be expected to be albinos. Then color in the results.

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?

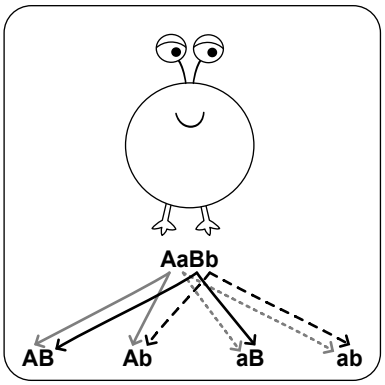
All the offspring will be Aa, so there is no need to flip a coin.

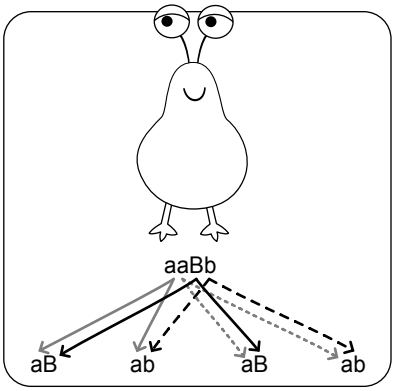


Bigger Punnett Squares!

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.**

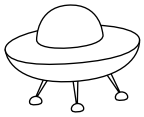
The double heterozygous alien has an equal chance of passing along each of the 4 allele pairs: **AB**, **Ab**, **aB**, and **ab**. The pear-shaped alien also has an equal chance of passing on each of the 4 possible allele pairs.





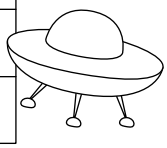
Fill in the punnet square below by drawing the correct number of eyes on each alien for the cross AaBb x aaBb. Remember BB or Bb result in the phenotype of two eyes, and only bb gives the phenotype of one eye.

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

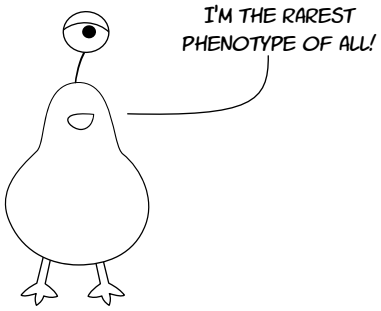


Genotype:	Phenotype:
AA	Round body shape
Aa	Round body shape
aa	Pear body shape

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



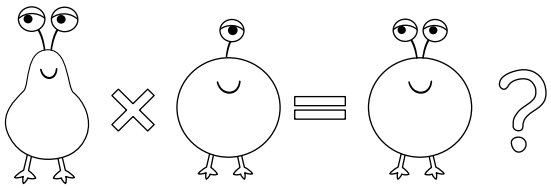
Create a Punnett square for the cross **AaBb×AaBb.** Will you see the rare pear-shaped one-eyed alien (**aabb**) from this cross? If so, what is the chance of seeing it? 1/16, 2/8, 1/4 or 1/2?



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

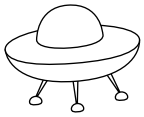
	AB	Ab	aB	ab
AB	AaBB	AABb	AaBB	AaBb
Ab	AAbB	AAbb	AabB	Aabb
aB	aABB	aABb	aaBB	aaBb
ab	aAbB	aAbb	aabB	aabb

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



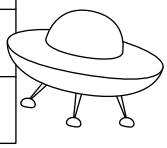
All 4 possible phenotypes occur ¼ of the time with this cross.

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

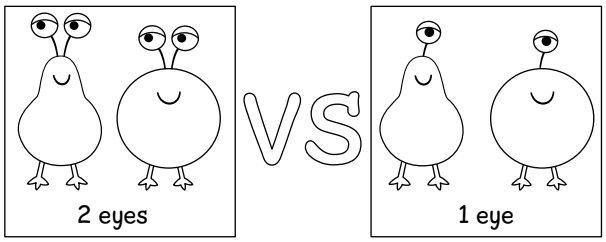


Genotype:	Phenotype:
AA	Round body shape
Aa	Round body shape
aa	Pear body shape

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

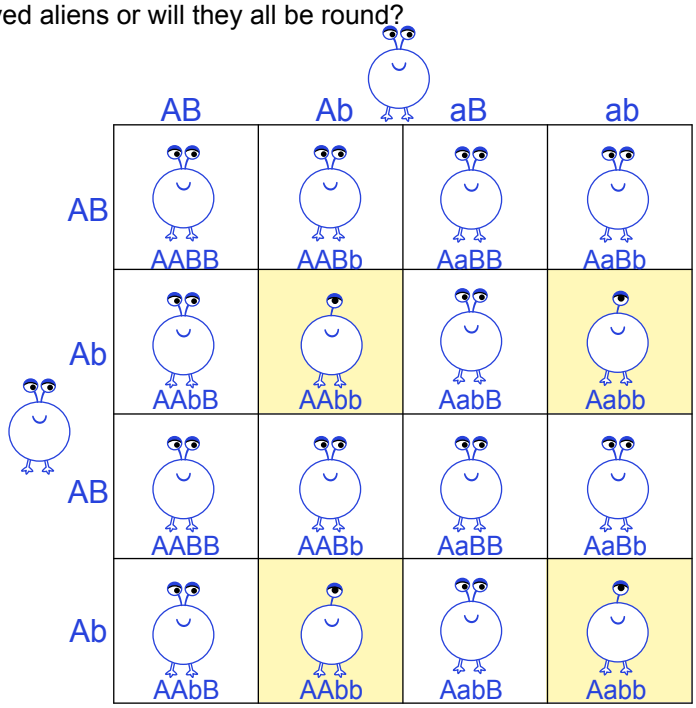


Create a Punnett square for the cross **AABb×AaBb.** How many of the offspring, on average, will have one eye? 1/16, 2/8, 1/4 or 1/2? Will there be any pear-shaped one-eyed aliens or will they all be round?

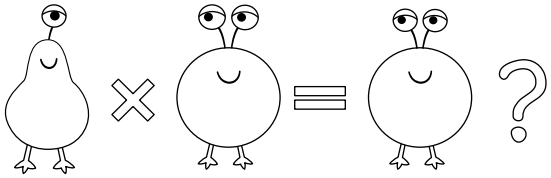


Only 1 in 4 will have one eye.

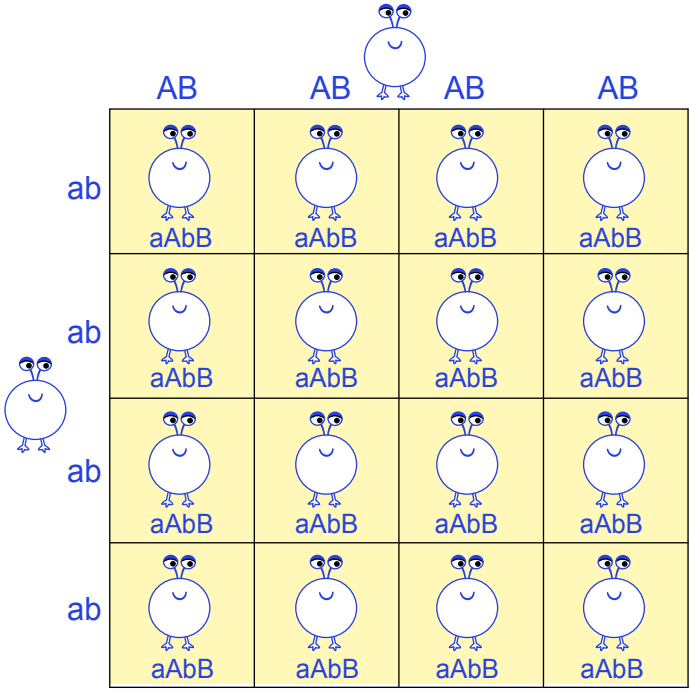
All aliens will be round. There will be no pear-shaped aliens.

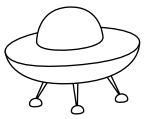


Create a Punnett square for the cross **aabb × AABB.** What is the chance of seeing a round two-eyed alien that is heterozygous for both traits (**AaBb**)?



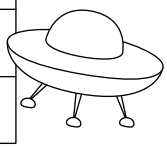
All the offspring will be AaBb because they inherit the dominant alleles form one parent and the recessive alleles from the other.



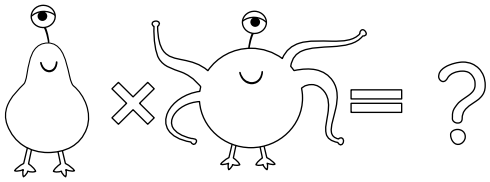


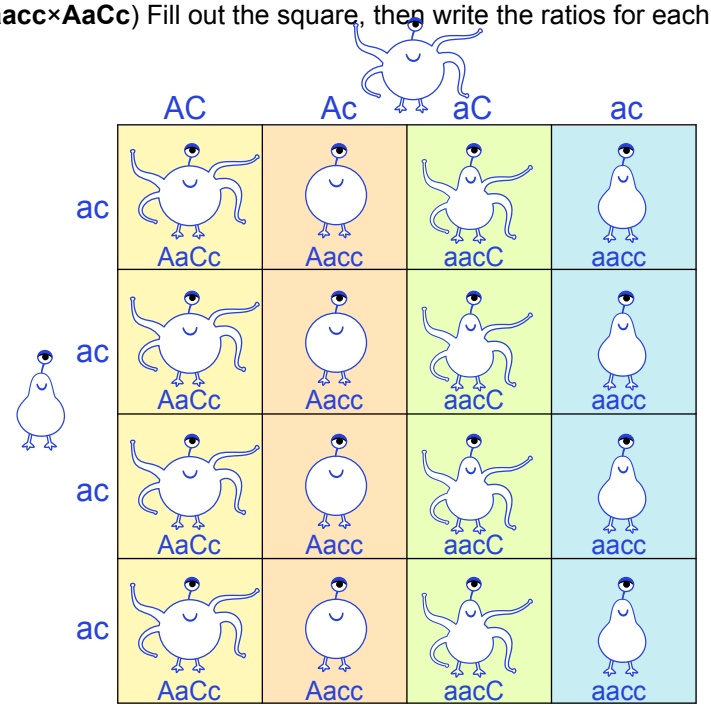
Genotype:	Phenotype:
AA	Round body shape
Aa	Round body shape
aa	Pear body shape

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.





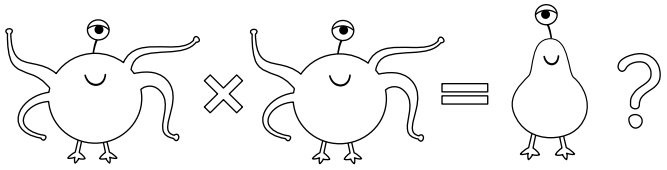
1 in 4 are round with tentacles.

1 in 4 are round without tentacles.

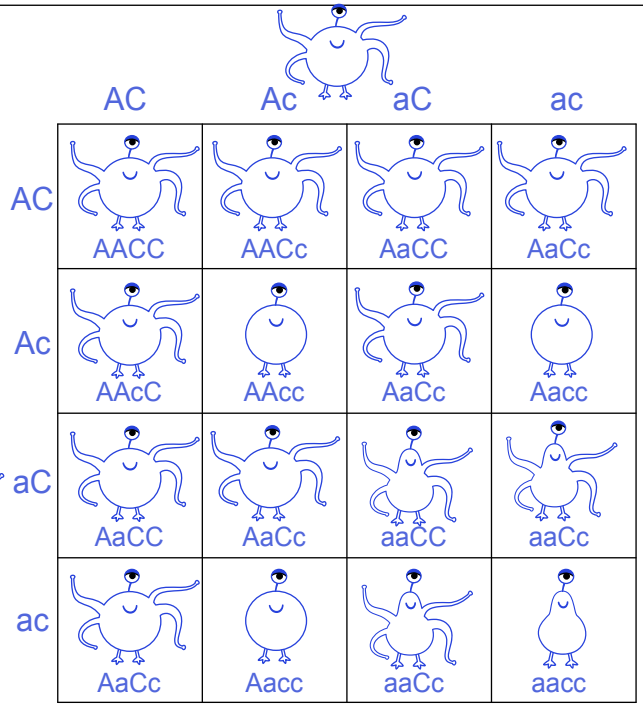
1 in 4 are pear-shaped with tentacles.

1 in 4 are pear-shaped without tentacles.

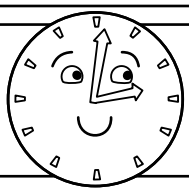
Can two round-eyed tentacle-arm aliens produce a pear-shaped no-arms alien? If yes, what do the genotypes need to be for this cross, and what is the chance of the pear-shaped no-armed offspring?



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.



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.

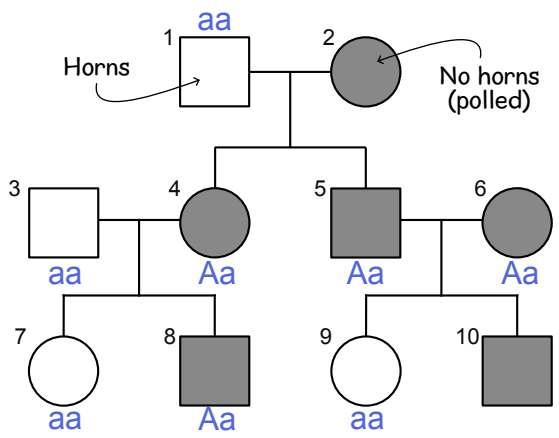
9. An organism that has two different alleles for a single trait is said to be heterozygous for that trait.

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.

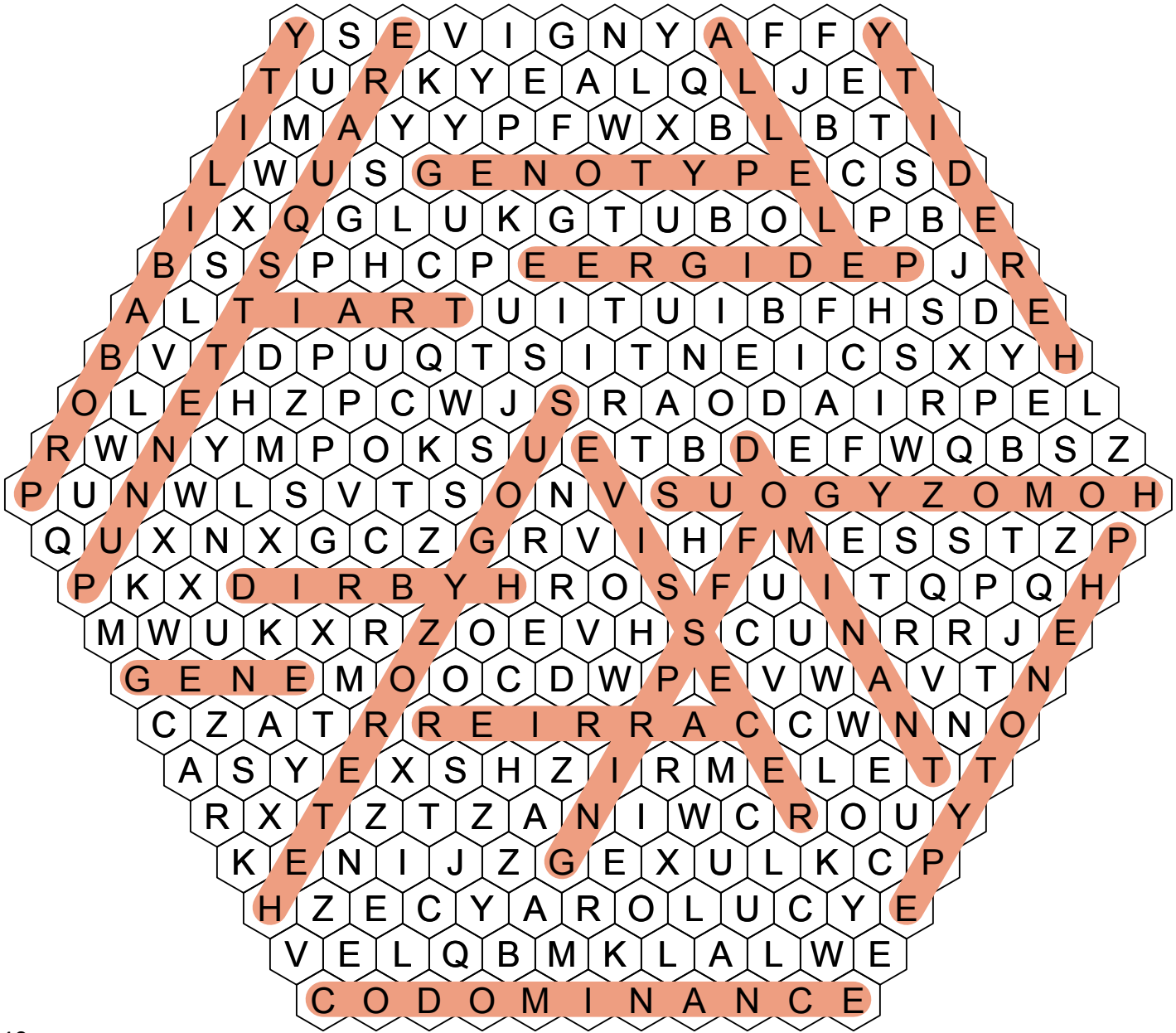
19 If we cross two cattle with no horns, could the offspring have horns? Explain.

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.

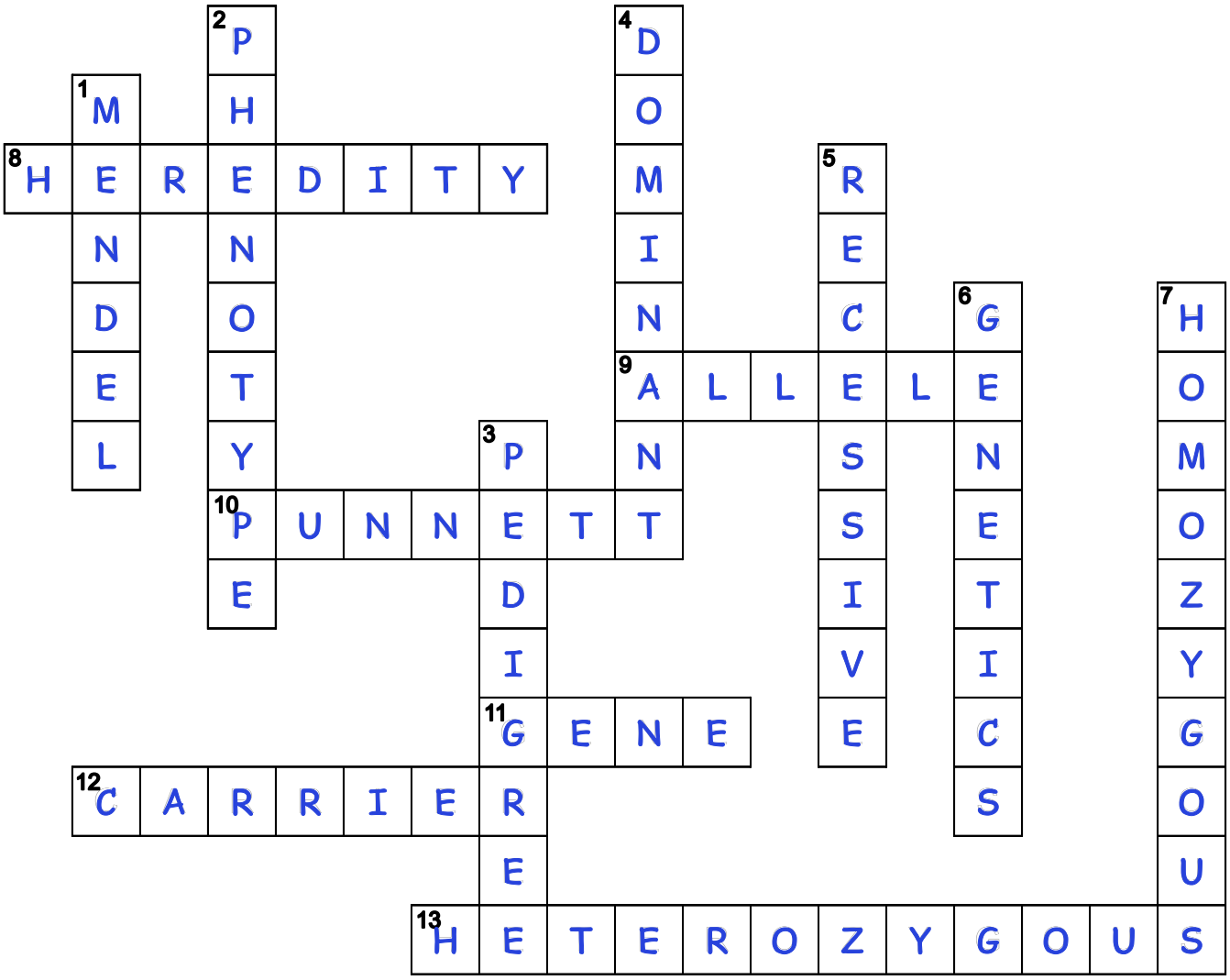
Heredity Word Search

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



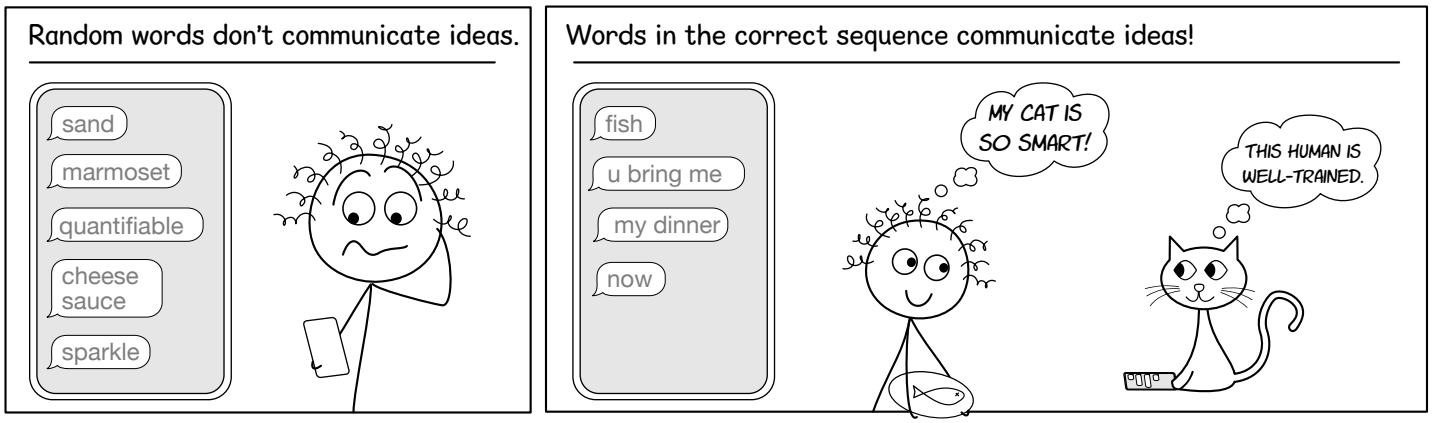
VERTICAL Words

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.

The Genetic Code



FILL IN THE BLANKS USING THESE WORDS:

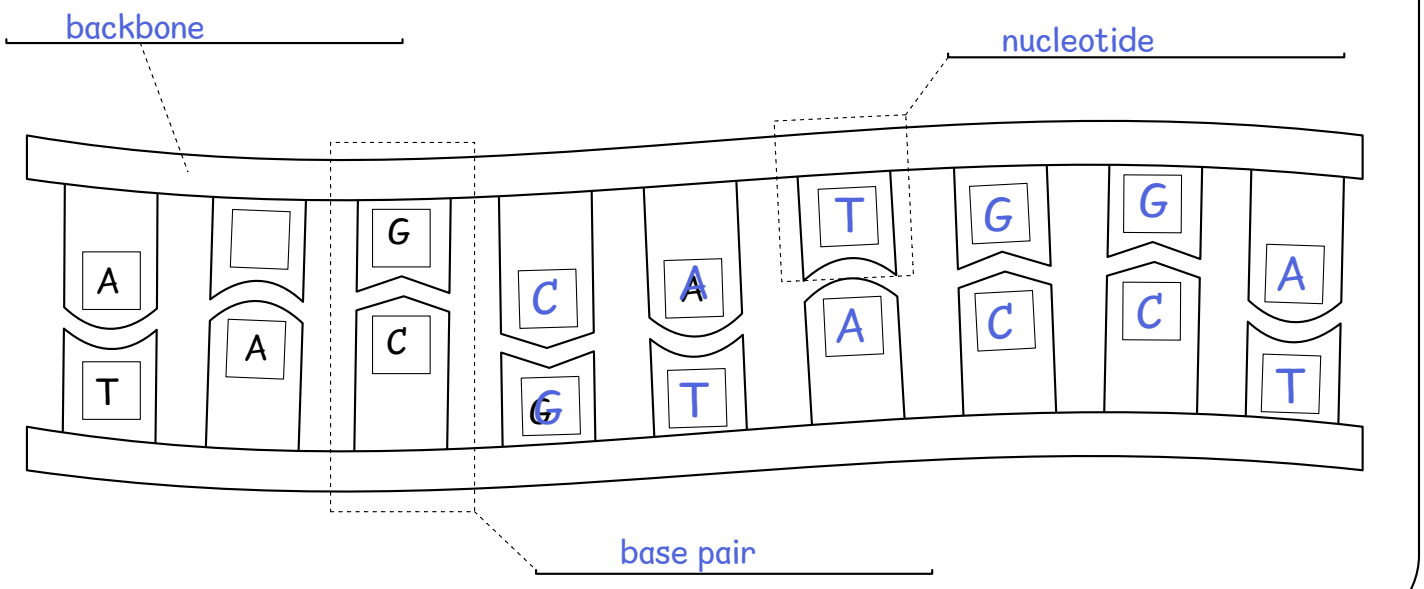
four thymine garage repeating genome trees

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."

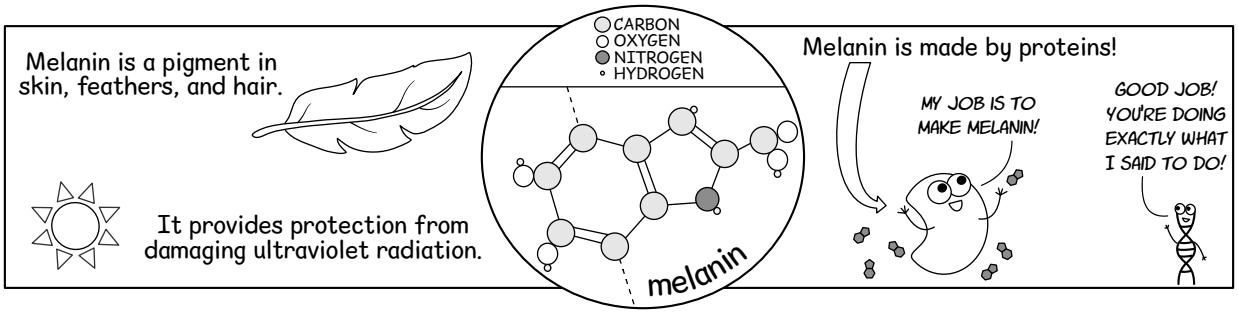
*LABEL THE **BASE PAIR**, **BACKBONE**, AND **NUCLEOTIDE** IN THIS CARTOON REPRESENTATION OF DNA. THEN WRITE **A**, **T**, **C**, OR **G** IN EACH BOX TO FILL IN THE CODE!*



What's a gene?

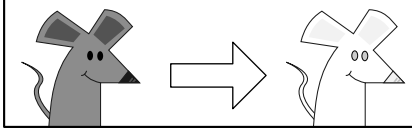
A gene is a specific sequence of DNA that contains information to make a gene product such as a protein. Most organisms have thousands of genes. There are approximately 20,000 genes in the human genome!

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



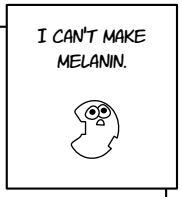
Albinism

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.

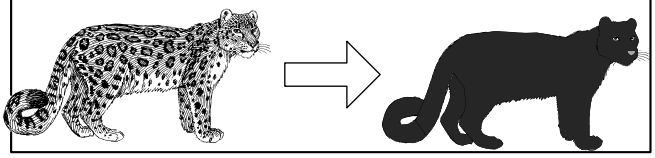
Why would this result in a recessive trait?



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.

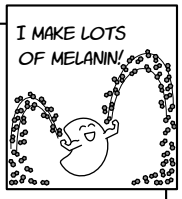
Melanism

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.



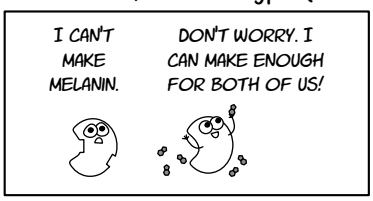
The cause: a mutation in the DNA causes a protein that makes melanin to work overtime!

Why would this result in a dominant trait?

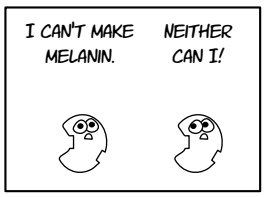


If there is one working copy of the gene, the result will be an over-abundance of melanin pigment.

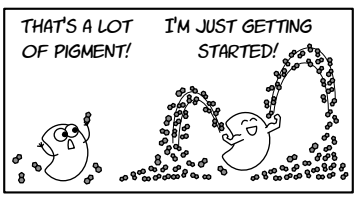
Write the correct phenotype below the cartoon representing each genotype. Possible phenotypes include albino, melanistic, or wild type (average melanin levels).*



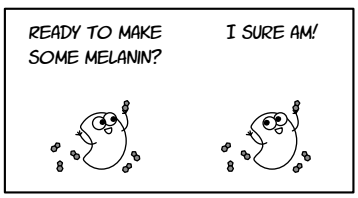
wild type



albino



melanistic



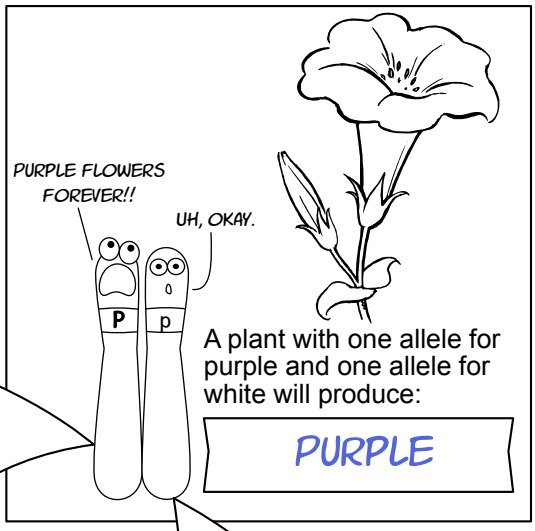
wild type

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.

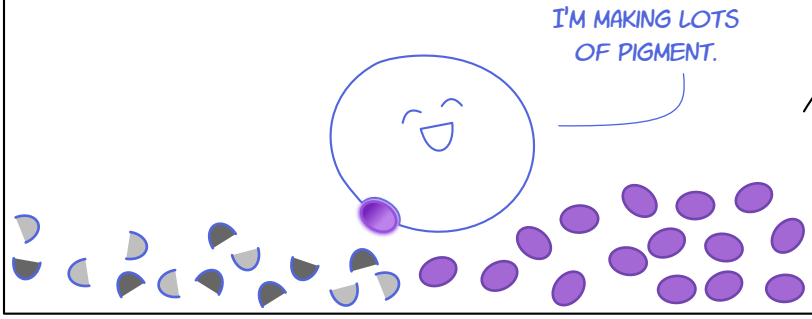
Draw pictures in the boxes below representing the working protein that makes purple pigment and the mutated protein that can't make the pigment:

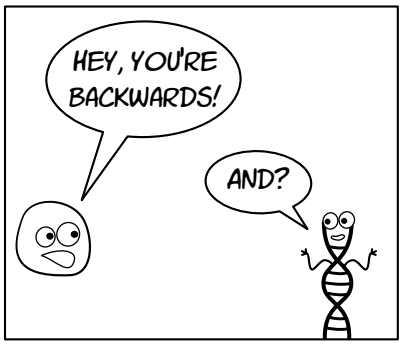


A plant with one allele for purple and one allele for white will produce:

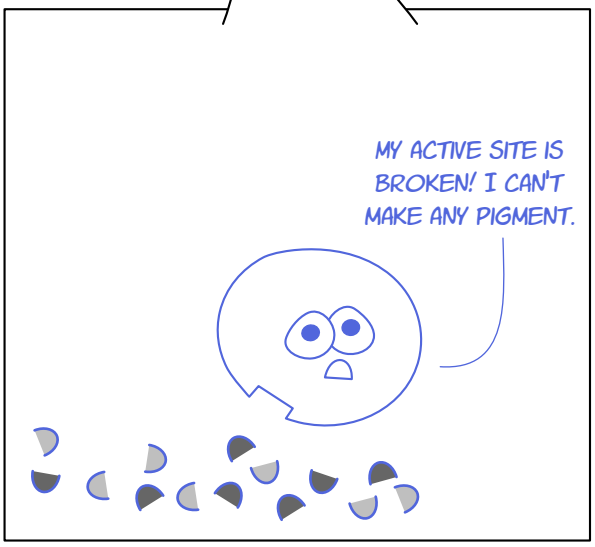
PURPLE

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.



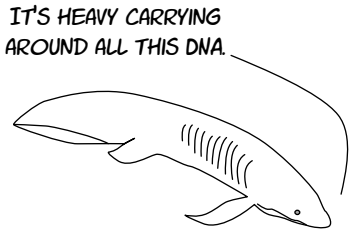


What did the clean DNA say to the dirty DNA?



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

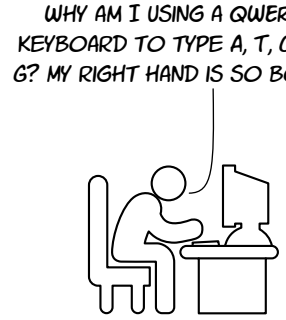
The Australian lungfish has the largest genome of any animal.



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!

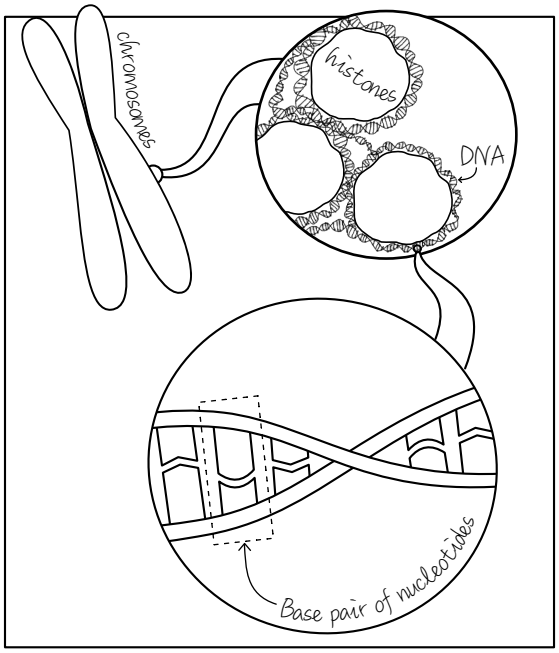
It all depends on what you mean by identical!

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

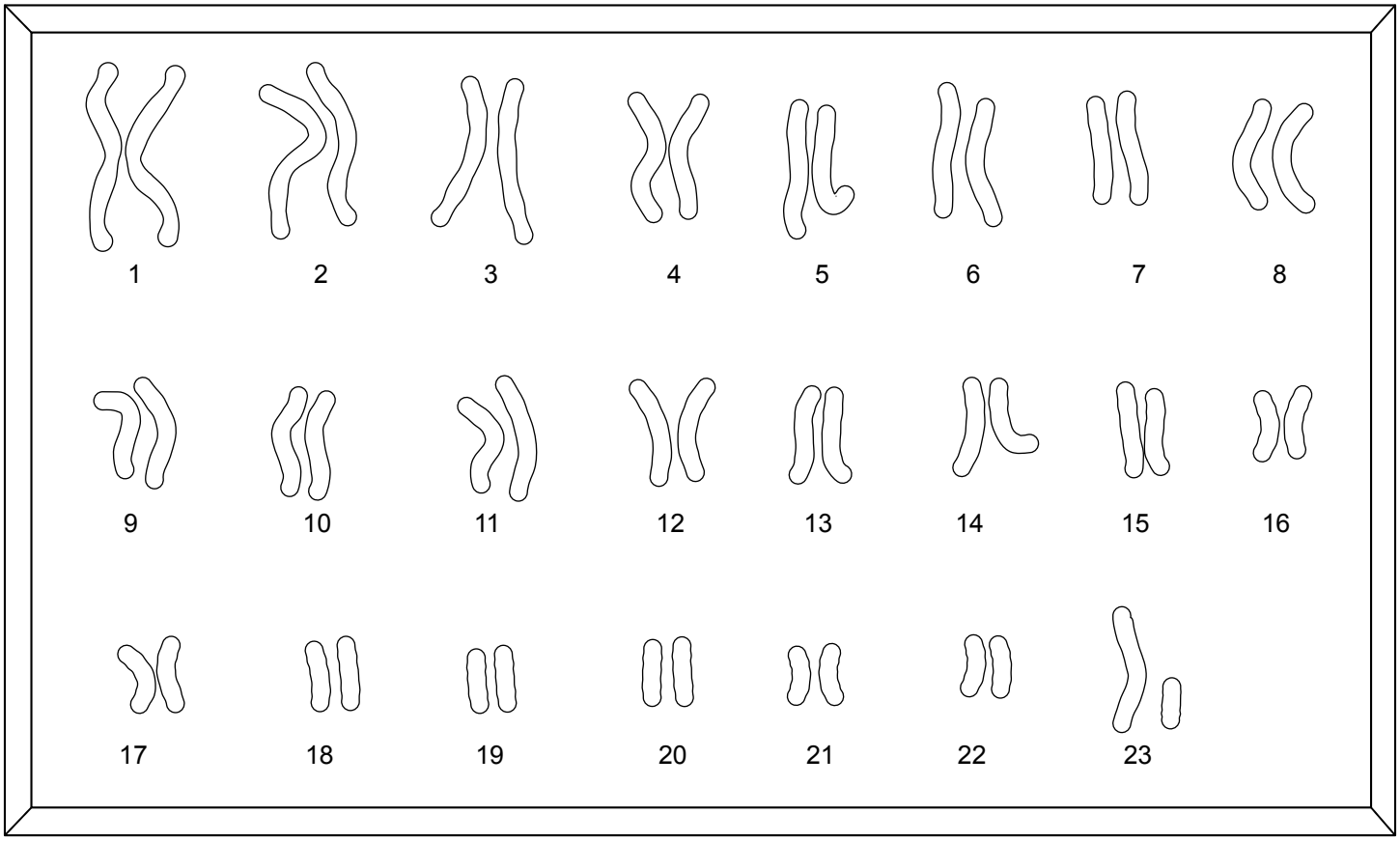
The human genome

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:

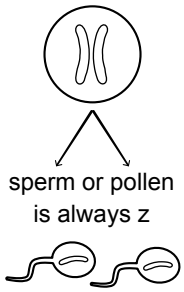
male 50 eyesight 900 females birds

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.

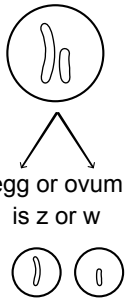
In birds, some fish, and most reptiles, the sex determination is different. Males have two copies of the same chromosome and females have two different sex chromosomes. This system is called the ZW system.

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

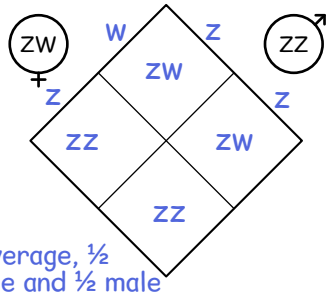
Male bird is ZZ



female bird is ZW



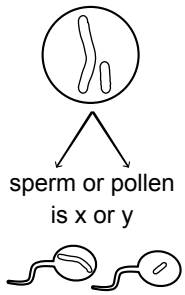
Fill out the Punnett square for ZW. On average, how many birds will be male, and how many will be female?



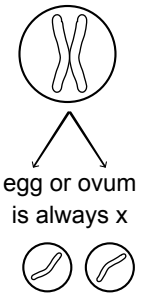
On average, ½ female and ½ male

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

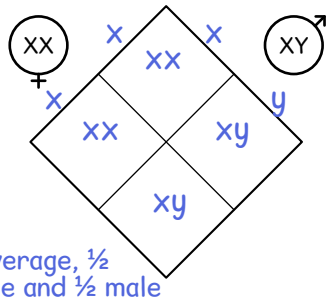
Male mammal is XY



female mammal is XX



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

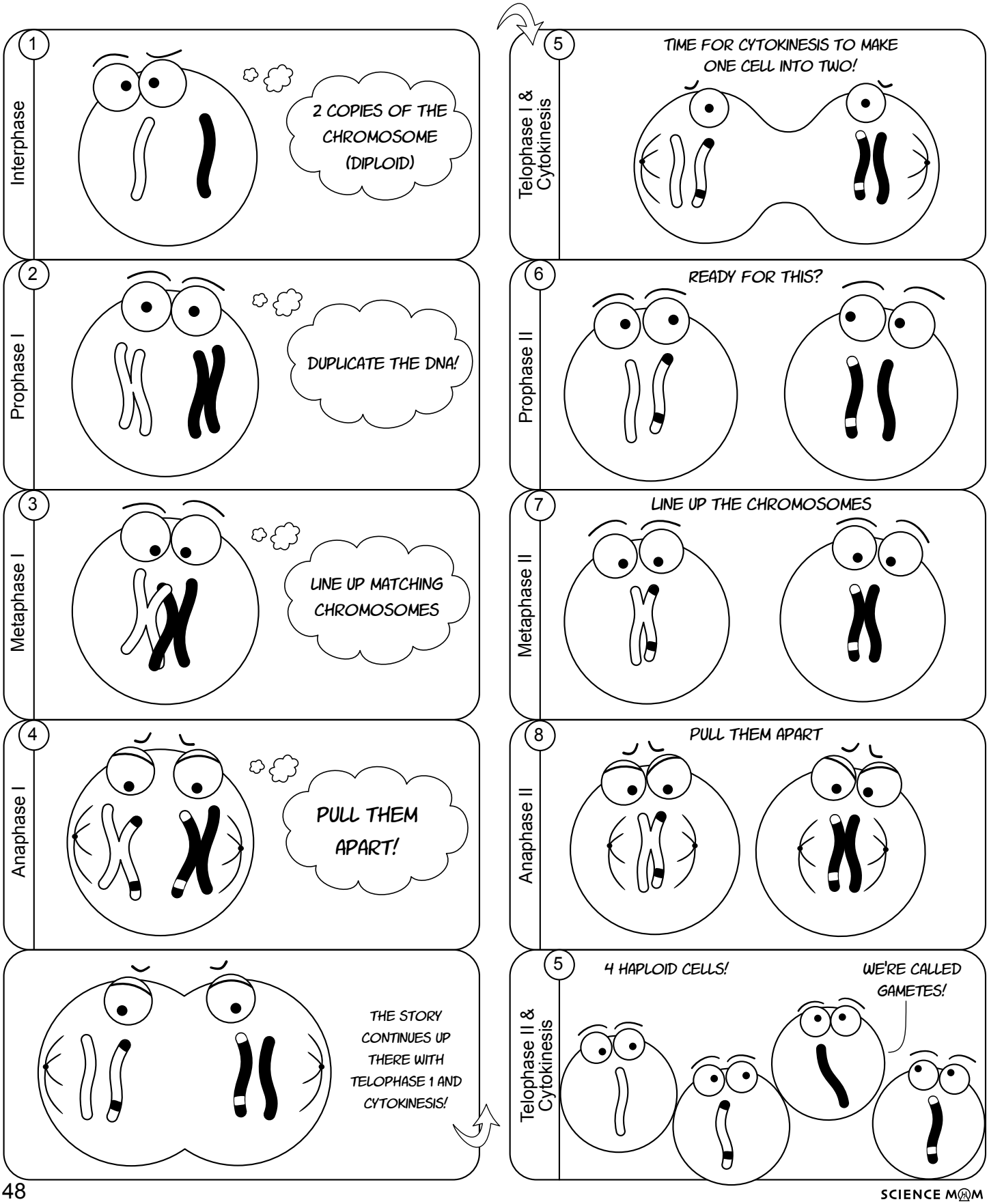


On average, ½ female and ½ male

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.

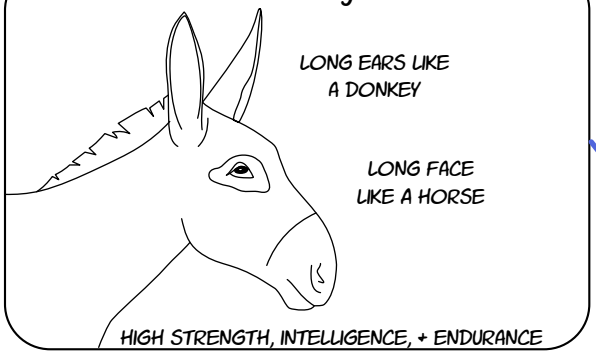


Meiosis Mysteries

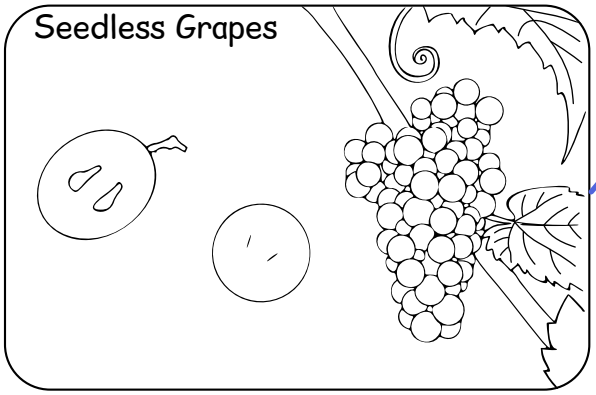
Seedless watermelons, bananas, and mules all have something in common. They can't reproduce!* Match each organism with the corresponding explanation for why it is sterile or infertile.

**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.*

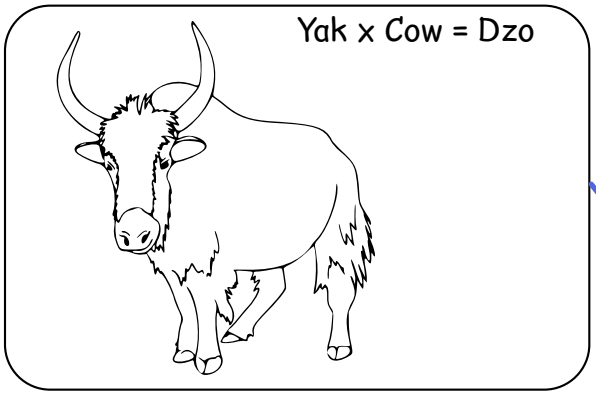
Horse x Donkey = Mule



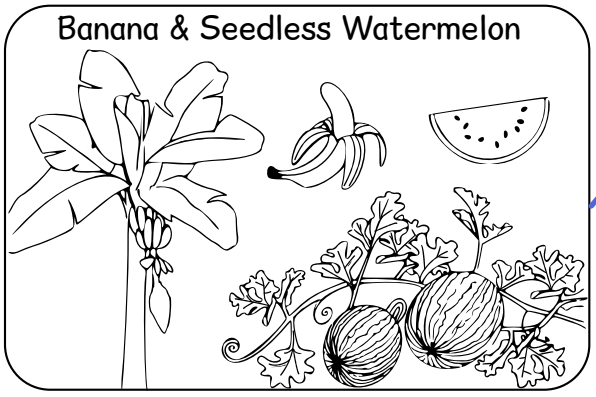
Seedless Grapes



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!

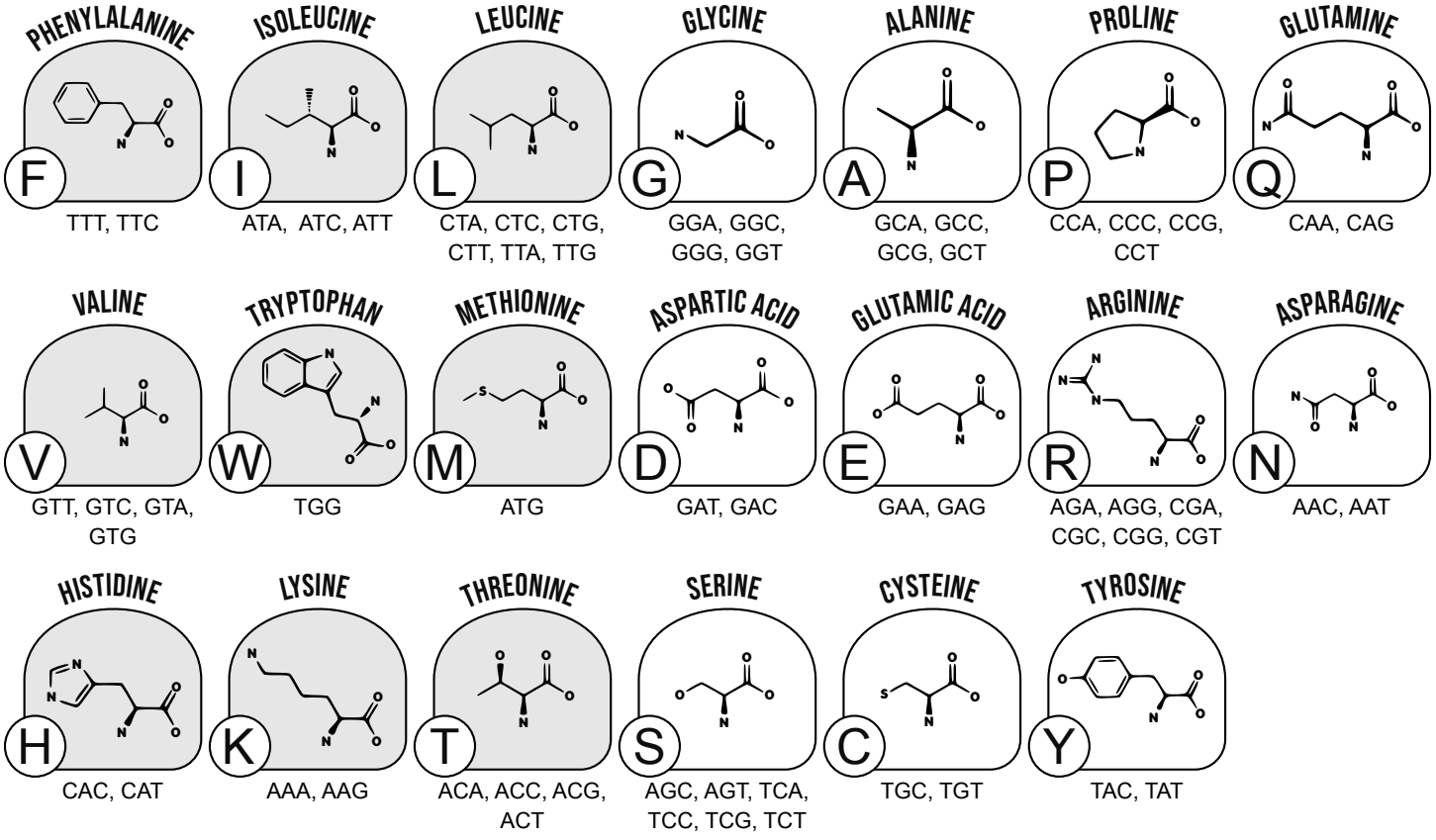
The molecules that run things in the cell

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.



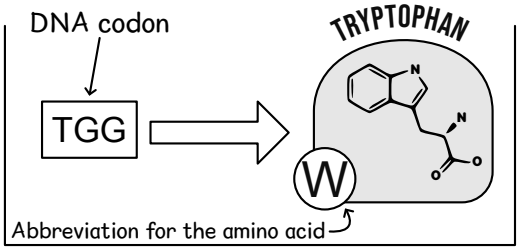
Label Hunt: *Check some food labels. Can you can find amino acids listed in the ingredients?*

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

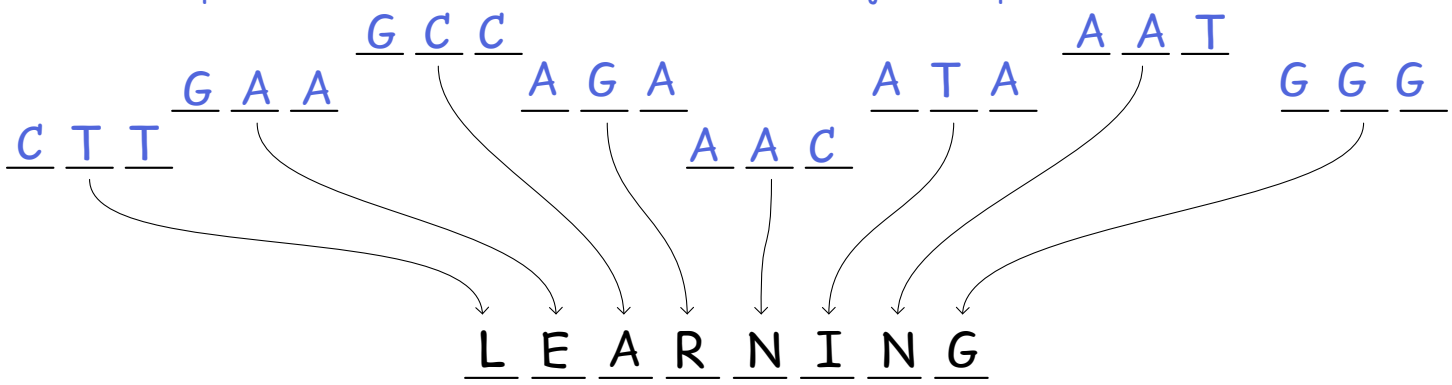
S C I E N C E I S I N M Y D N A

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

DNA Encryption Challenge

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!

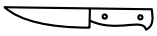
There are multiple correct answers. The letters below show just one possible code.



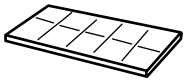
Hands-on Science Project

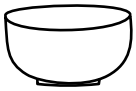
GUMMY WORM KARYOTYPES

MATERIALS:


knife or scissors


gummy worms


chocolate

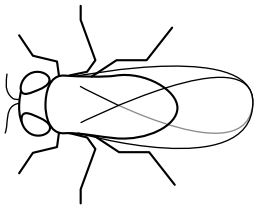

Small bowl for melting chocolate

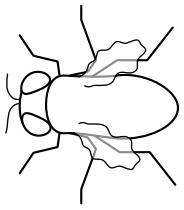
Make a fruit fly karyotype

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:

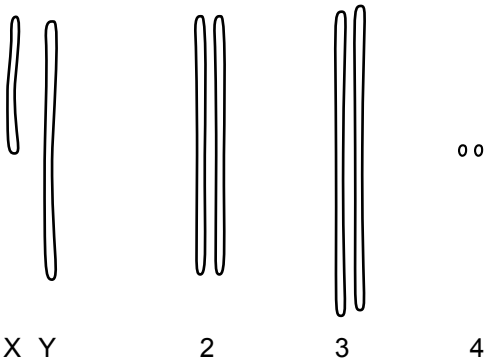
1. Using the picture on the right as a guide, cut the gummy worms to the appropriate relative lengths. Make multiple copies of each chromosome type.

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.

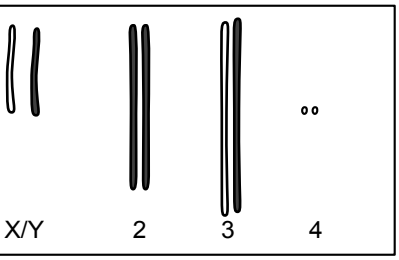
5. Rearrange the gummy worms to create another karyotype. Repeat the exercise again.



Karyotype Key

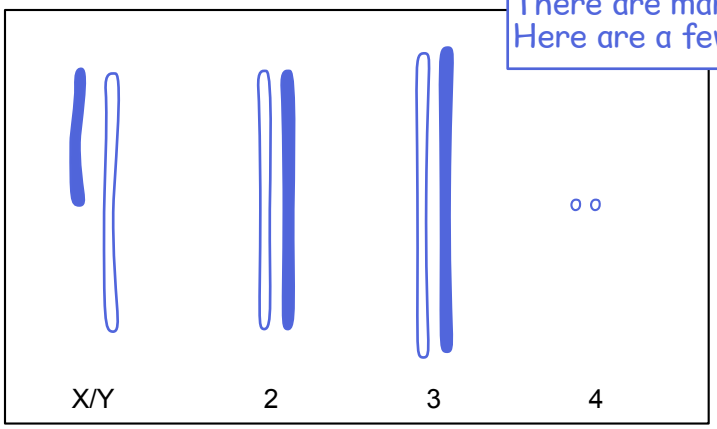
XX chromosomes = female
XY chromosome pair = male
Dominant trait in X = red eyes
Recessive trait in X = white eyes
Dominant trait in 2 = functional wings
Recessive trait in 2 = miniature wings (flightless)
Dominant trait in 3 = yellow body color
Recessive trait in 3 = ebony or black body color

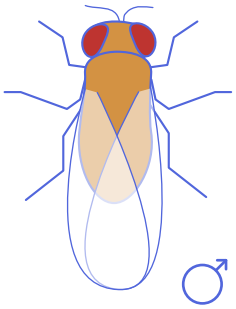
FOR EXAMPLE:

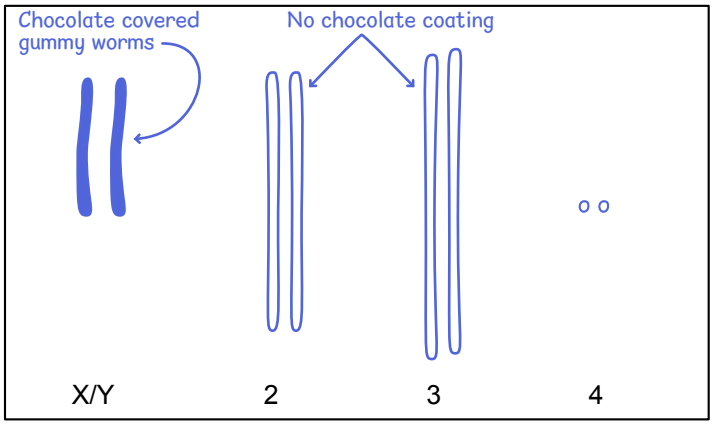


This karyotype matches a female red-eyed, flying, yellow fruit fly.

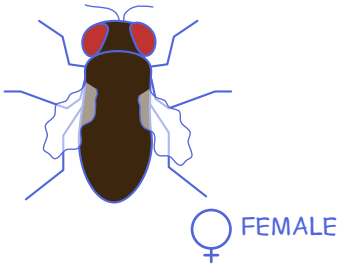
There are many different ways to arrange a fruit fly puzzle!
Here are a few examples of potential karyotypes and answers.

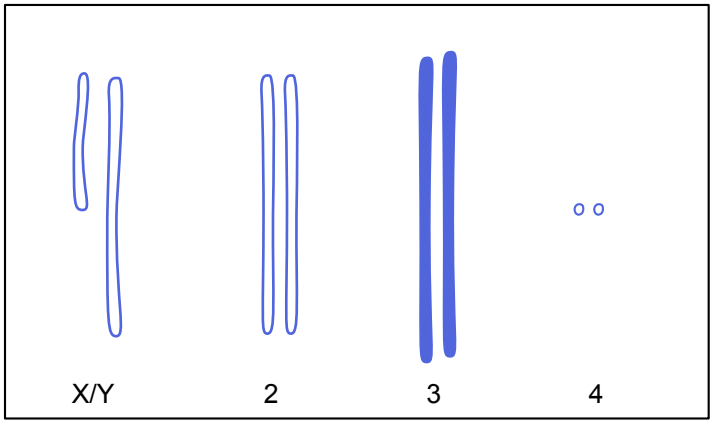




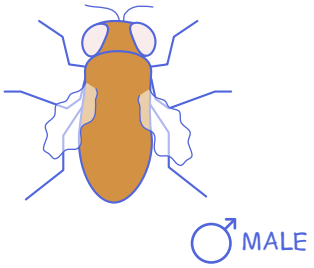


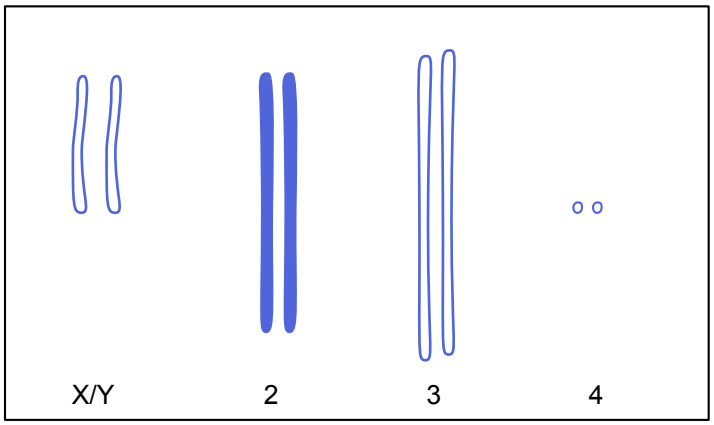
Color and describe the fruit fly that matches this karyotype!
Don't forget to draw in the wings.



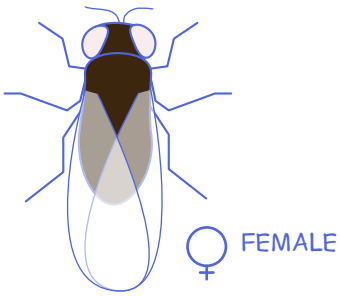


Color and describe the fruit fly that matches this karyotype!
Don't forget to draw in the wings.





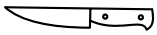
Color and describe the fruit fly that matches this karyotype!
Don't forget to draw in the wings.



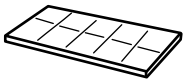
Hands-on Science Project

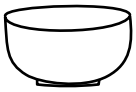
GUMMY WORM MEIOSIS

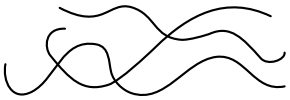
MATERIALS:


knife or scissors


gummy worms

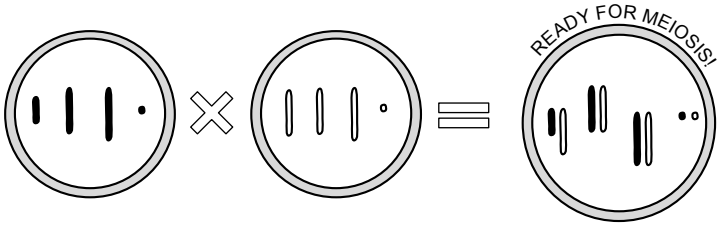

chocolate


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.

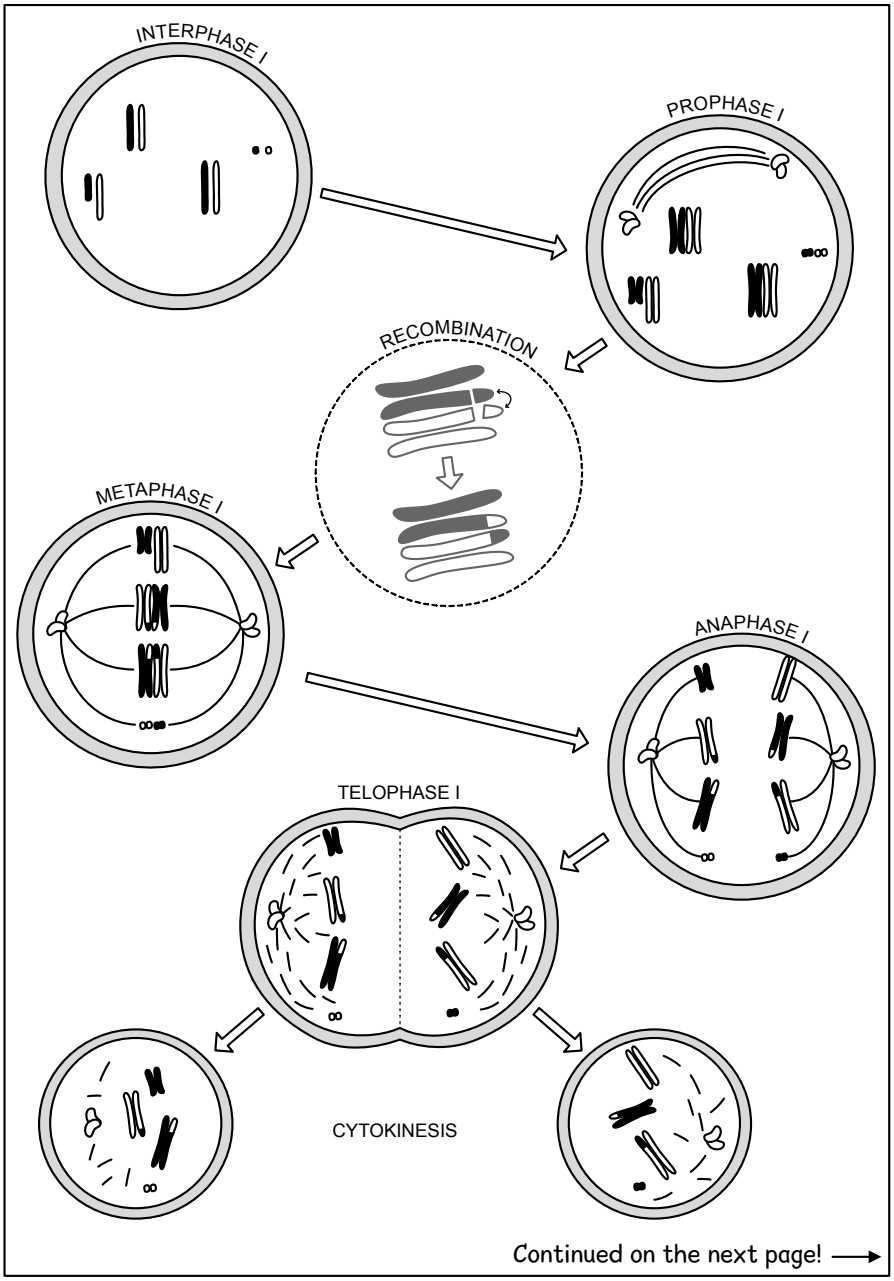
2. Prophase I: When duplicated, the identical chromosomes are linked together and called sister chromatids. Represent this step by adding an identical gummy worm to each gummy worm on the plate.

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.

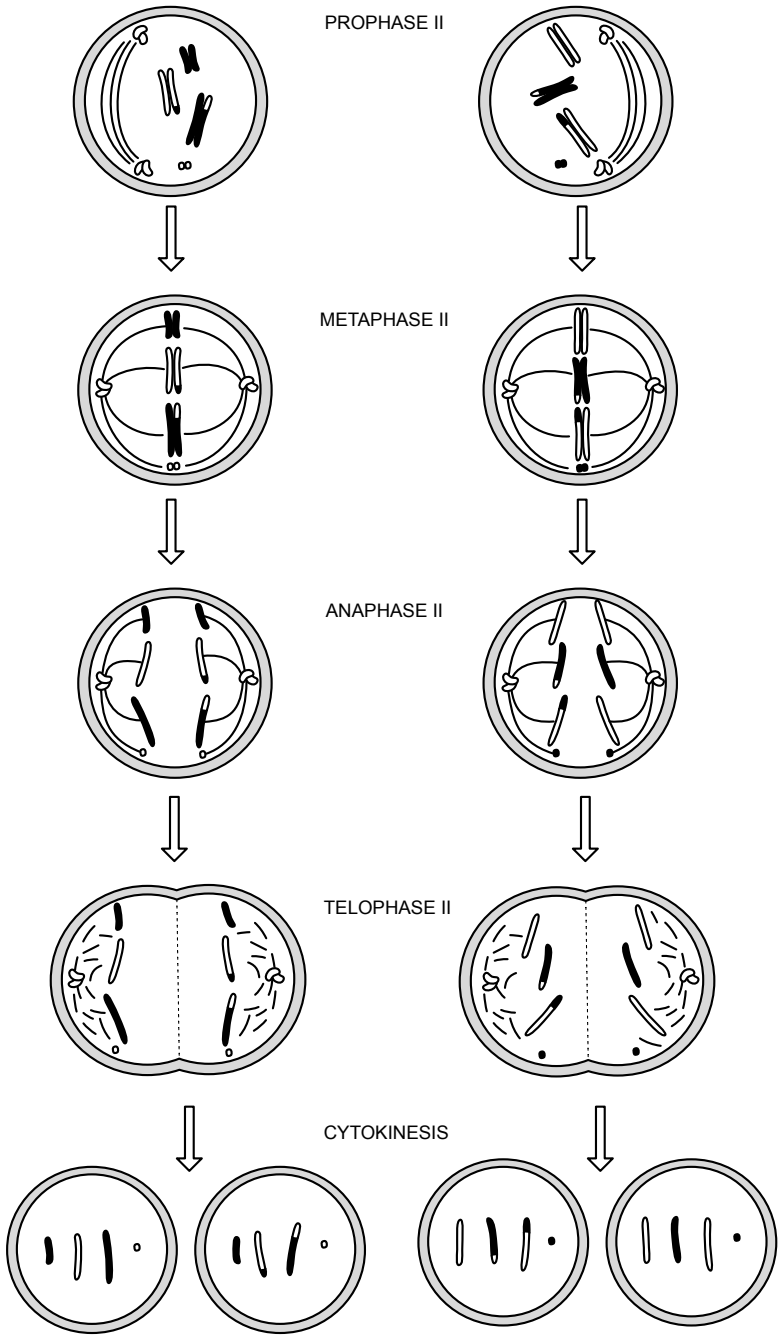
10. Telophase II and cytokinesis: Each cell splits into two cells, with one copy of each chromosome. Notice how the cells produced (gametes) have half the number of chromosomes as the starting cell.

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?

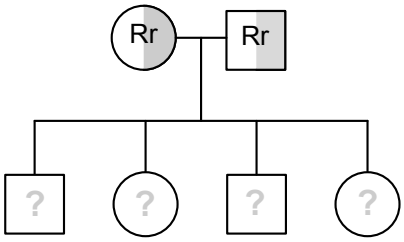
COUNTRY	*INCIDENCE OF PKU**
United States	*1 in 25,000*
Austria	*1 in 5,764*
Finland	*1 in 112,000*
France	*1 in 9,091*
Italy	*1 in 4,000*
Japan	*1 in 125,000*
Philippines	*1 in 116,006*
Thailand	*1 in 227,273*

☑ 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.*

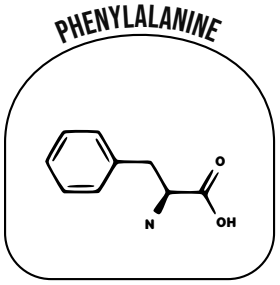
If both parents are carriers for PKU, what are the probabilities of their offspring experiencing the following outcomes?

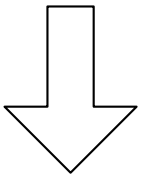


25 % CHANCE UNAFFECTED (RR)

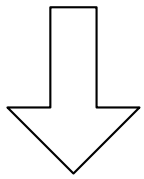
50 % CHANCE CARRIER (Rr)

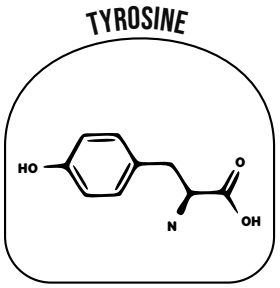
25 % CHANCE PKU (rr)

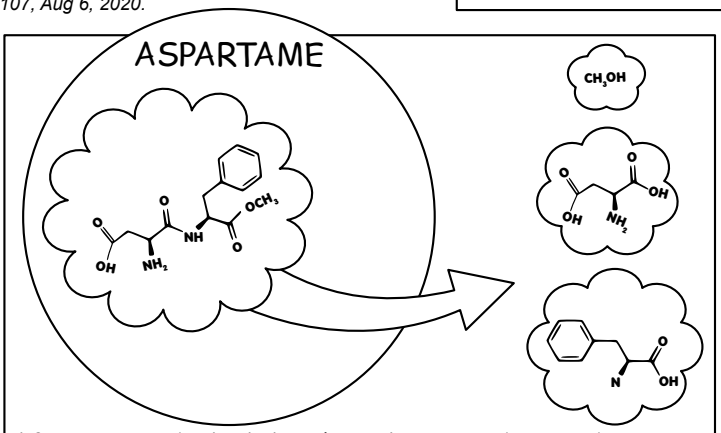




PHENYLALANINE HYDROXYLASE







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?

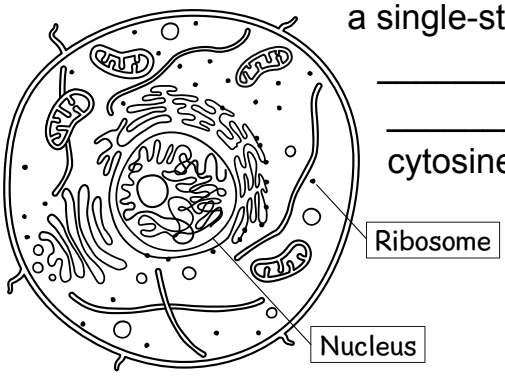
Because foods containing aspartame will be broken down into phenylalanine. High amounts of phenylalanine are dangerous to people with PKU. Because they cannot convert it into tyrosine, it can build up to toxic levels in the bloodstream.

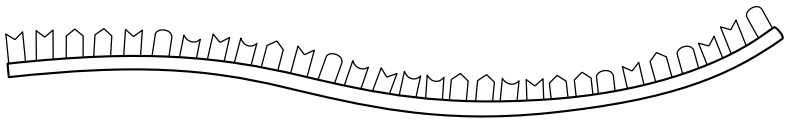
Transcription - from DNA to RNA

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

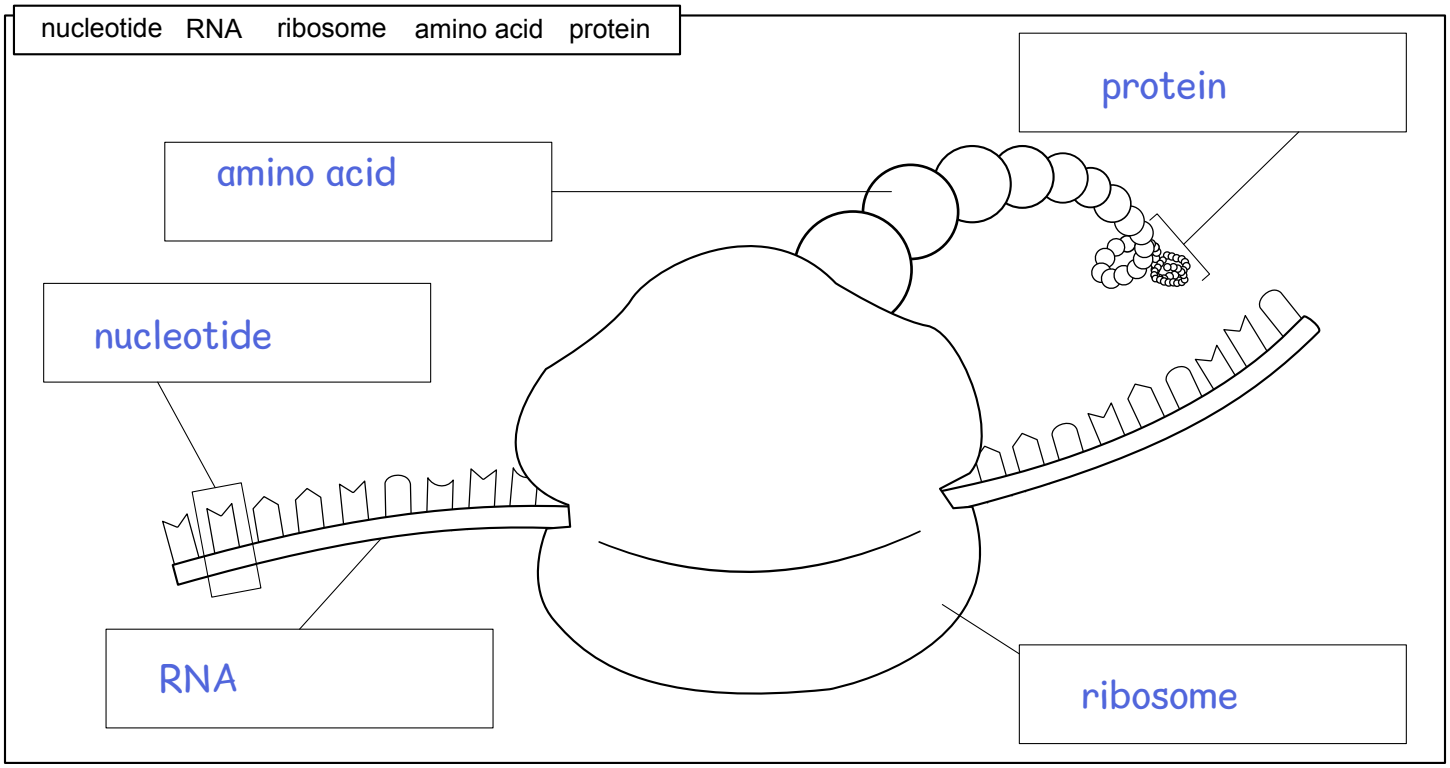
FILL IN THE BLANKS USING THESE WORDS:

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:

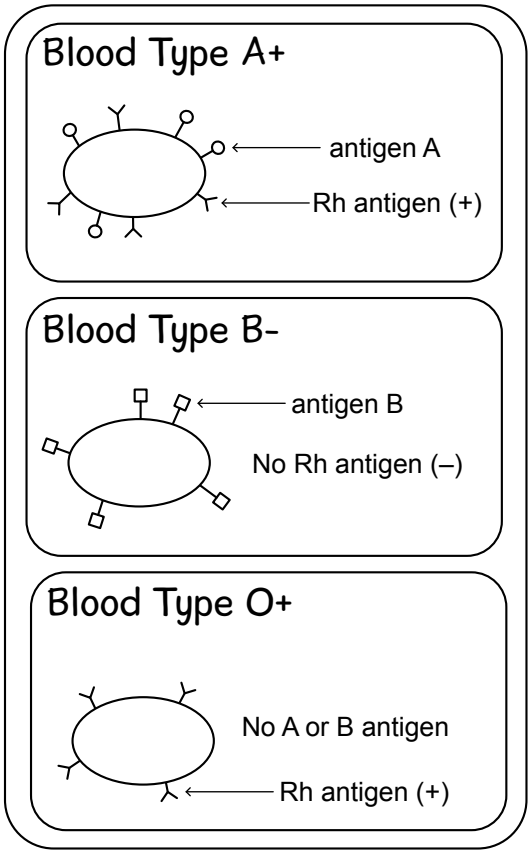
nucleotide RNA ribosome amino acid protein



Blood Types

FILL IN THE BLANKS USING THESE WORDS:

recessive	codominant	type	proteins	antigens	AB



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.

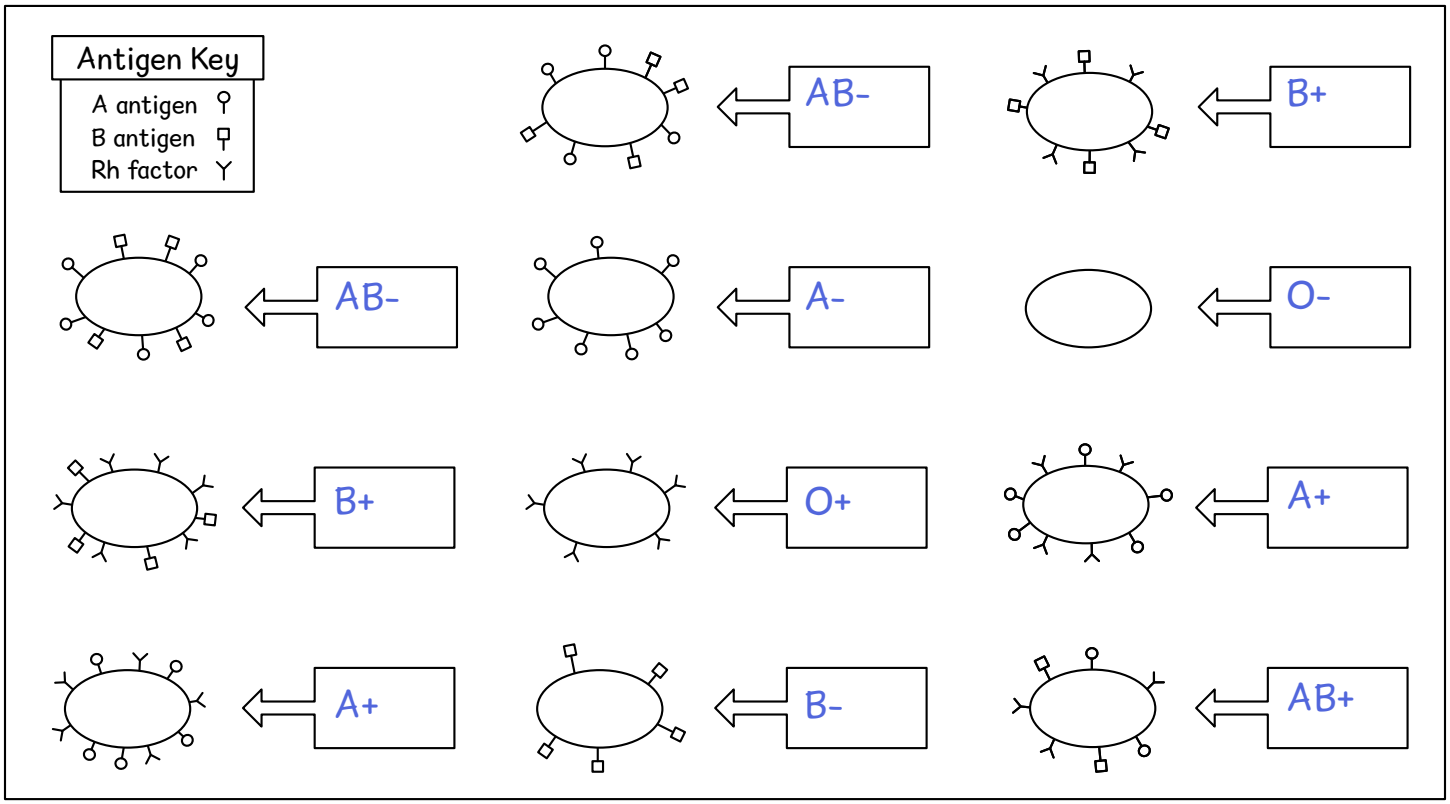
Blood type is essential to know for performing surgery and other medical procedures. The most well known blood __type__ systems are ABO and Rh.

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.

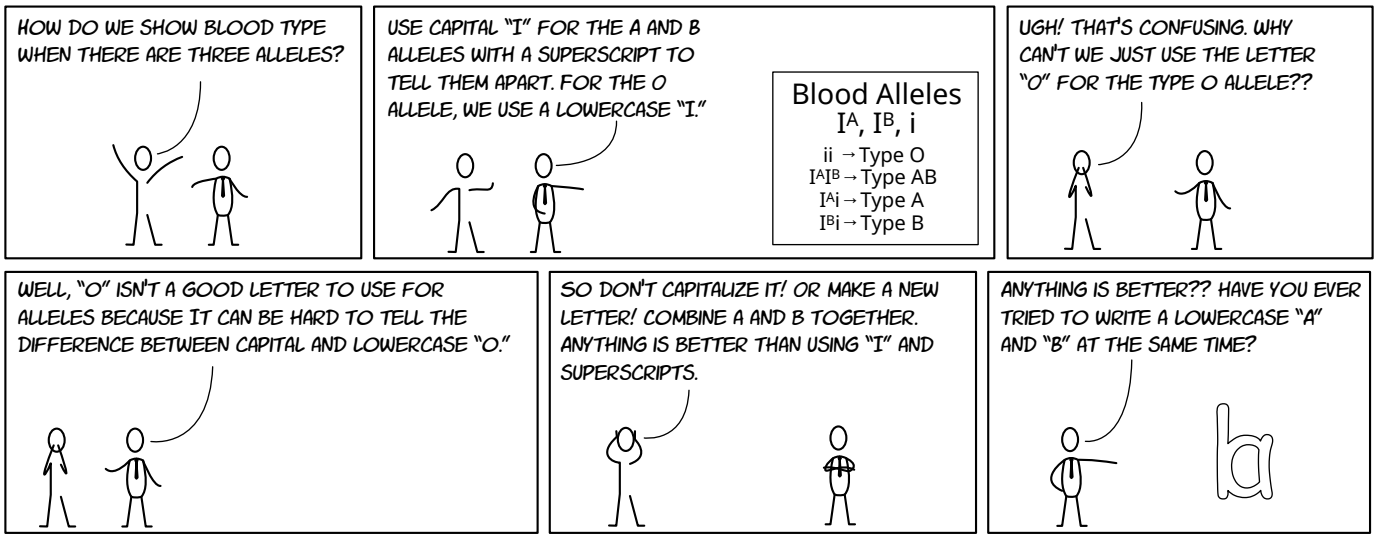
The Rh gene has a dominant allele (+) and a recessive allele (-). The dominant allele produces a small protein on the surface of the blood cells. Someone with this protein is called “Rh positive.” Two copies of the __recessive__ allele results in cells with no Rh protein on their surfaces, a condition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

Decipher the blood type!

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

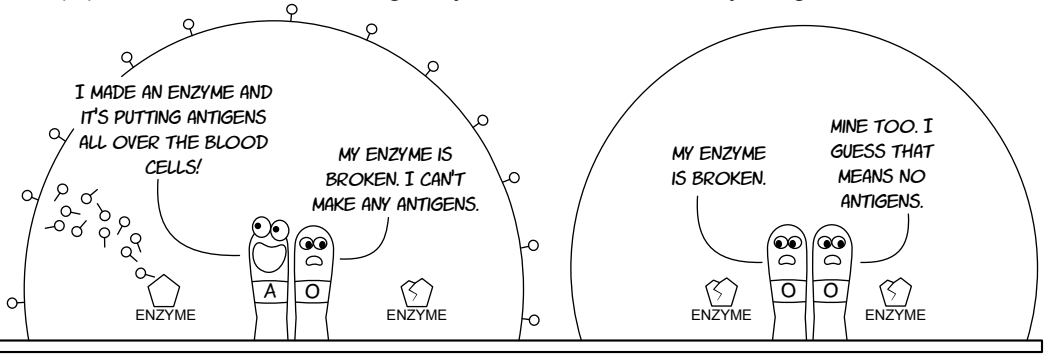


Genotype & Phenotype

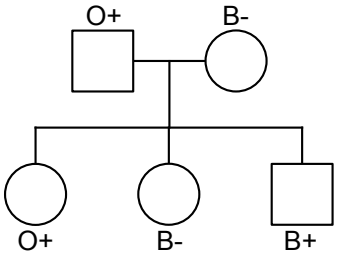


We are using A, B, and O to represent the ABO blood types. Someone with type A blood can either be homozygous (AA) with two alleles that code for enzymes that make the A antigen or they can be heterozygous (AO) with one functional allele. The recessive allele (O) creates a non-functioning enzyme that 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?



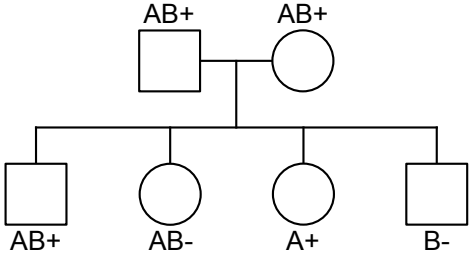
The genotype of parent with O+ blood is:

- ☐ 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

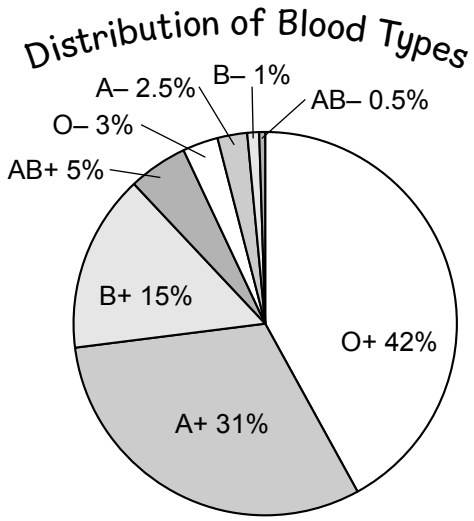
Not all blood types are equally likely! Use the distribution chart for human blood types to fill in the blanks below. As a bonus question, do you know what blood type is called the "universal donor?"

The most common blood type is O+.

The least common blood type is AB-.

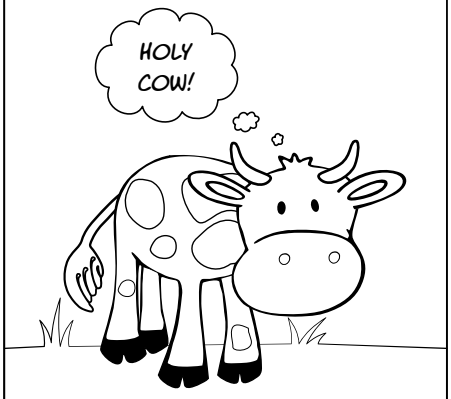
Rh positive blood types are more common than Rh negative blood types.

The universal donor blood type is O-.



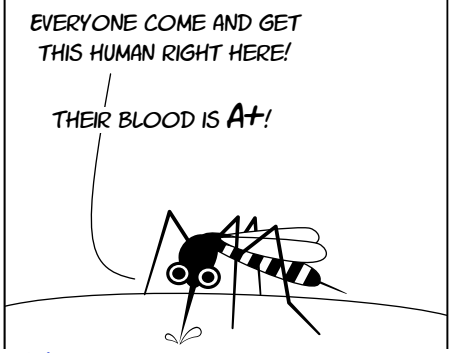
Are these FACT or FICTION? *Write your verdict below each statement:*

Cows can have more than 800 possible blood types.



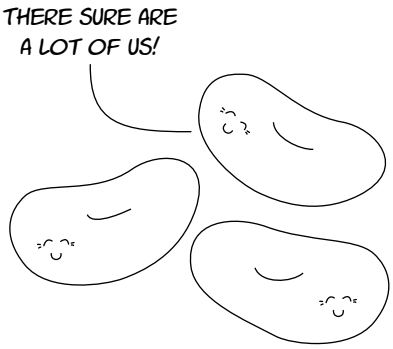
FACT

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

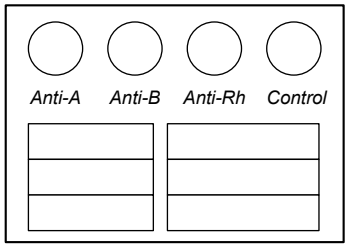
Hands-on Science Project

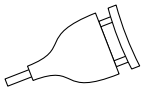
WHAT'S YOUR BLOOD TYPE?

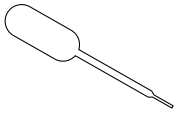
SAFETY FIRST!

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:

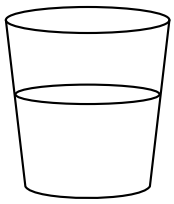



lancet


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.

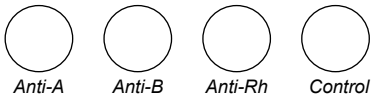
WHY IS THERE A 'CONTROL' CIRCLE?

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.

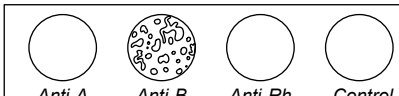
HOW IT WORKS

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.

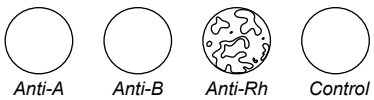
When you see the agglutination in your sample, you are witnessing the antigens and antibodies bonding together, thus making it visible what the blood type is.



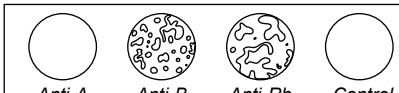
No agglutinates = type O-



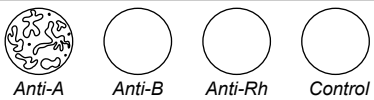
Only agglutinates in B = type B-



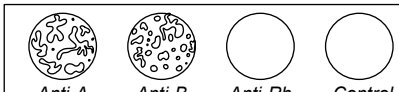
Only agglutinates in Rh = type O+



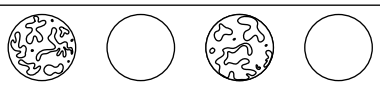
Agglutinates in B and Rh = type B+



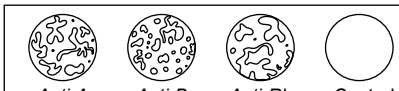
Only agglutinates in A = type A-



Agglutinates in A and B = type AB-

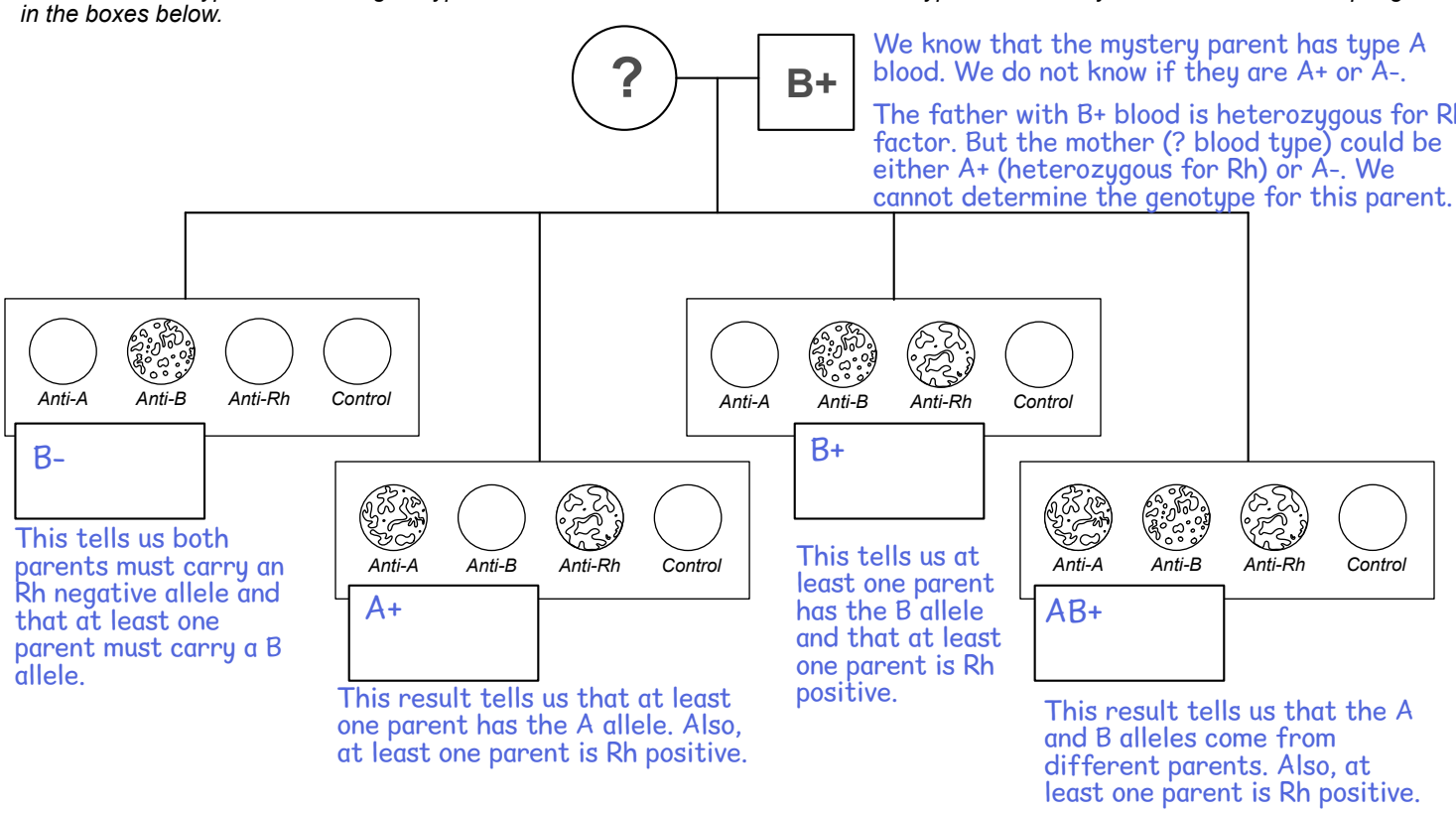


Agglutinates in A and Rh = type A+



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.

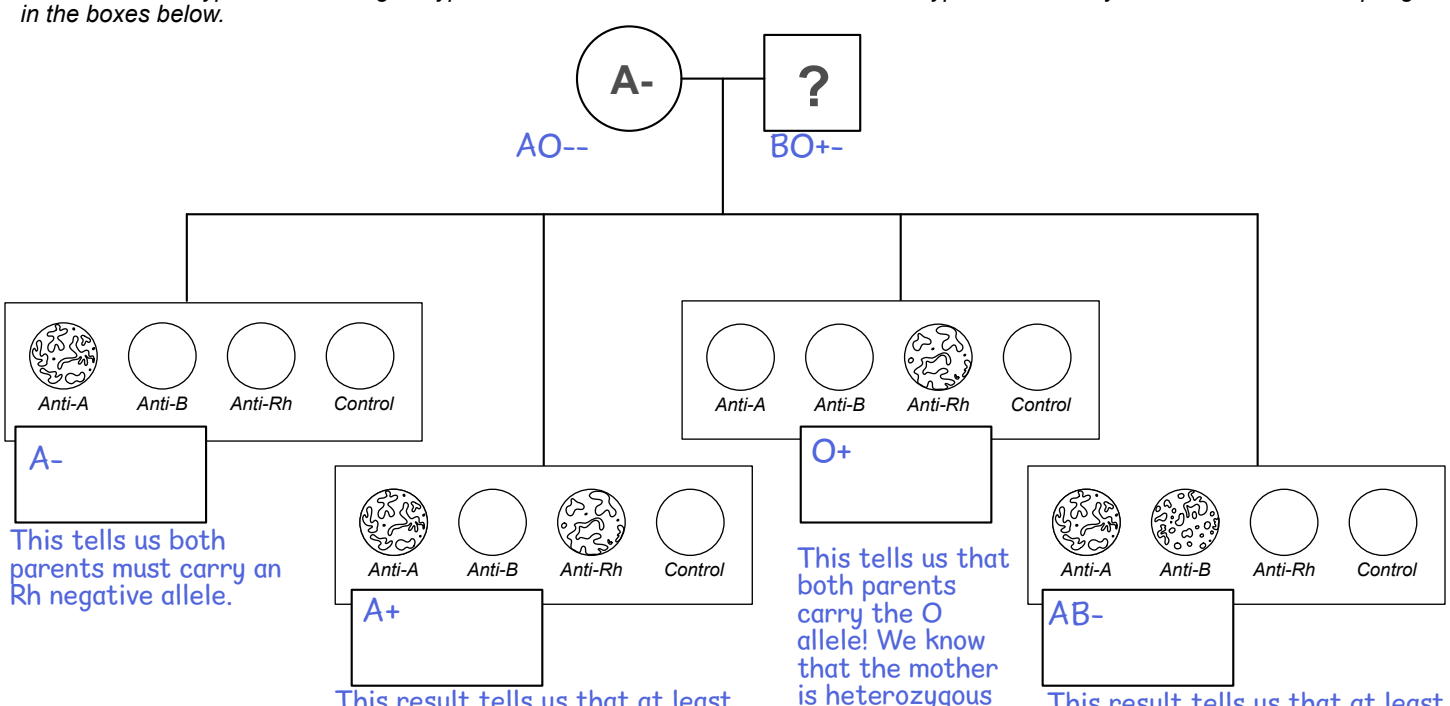
This tells us both parents must carry an Rh negative allele and that at least one parent must carry a B allele.

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--

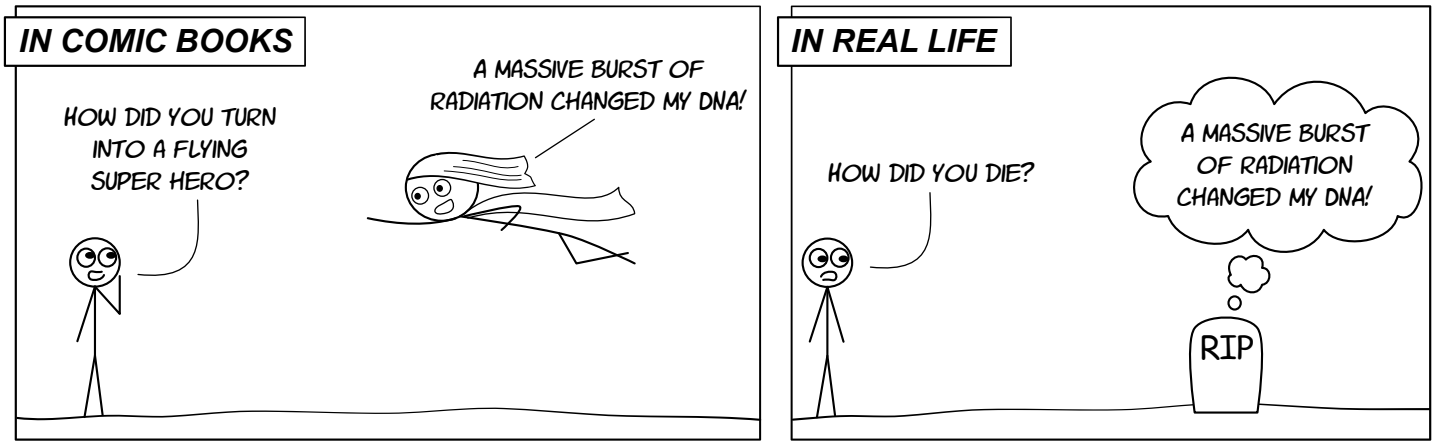
1/4 (or 4/16) will have AB+ blood.

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

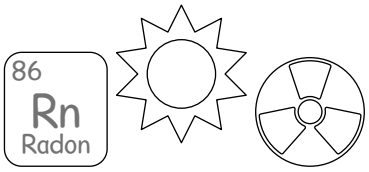


FILL IN THE BLANKS USING THESE WORDS:

growing replicates enzymes sequence

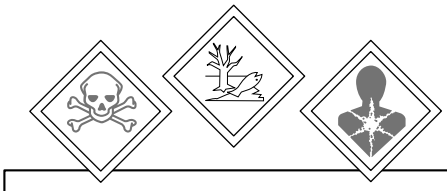
DNA replication is an essential part of living and ___growing___. It is happening right now inside millions of cells in your own body! Every time a cell ___replicates___, DNA polymerase and other enzymes are there to duplicate the DNA. If something damages or breaks the DNA, repair enzymes are there 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



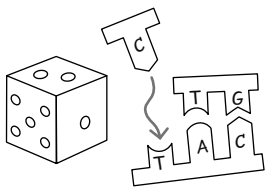
Radiation

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



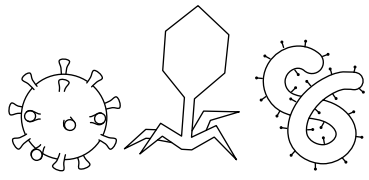
Mutagens

Chemicals that damage DNA or increase the likelihood of mutations



Random Chance

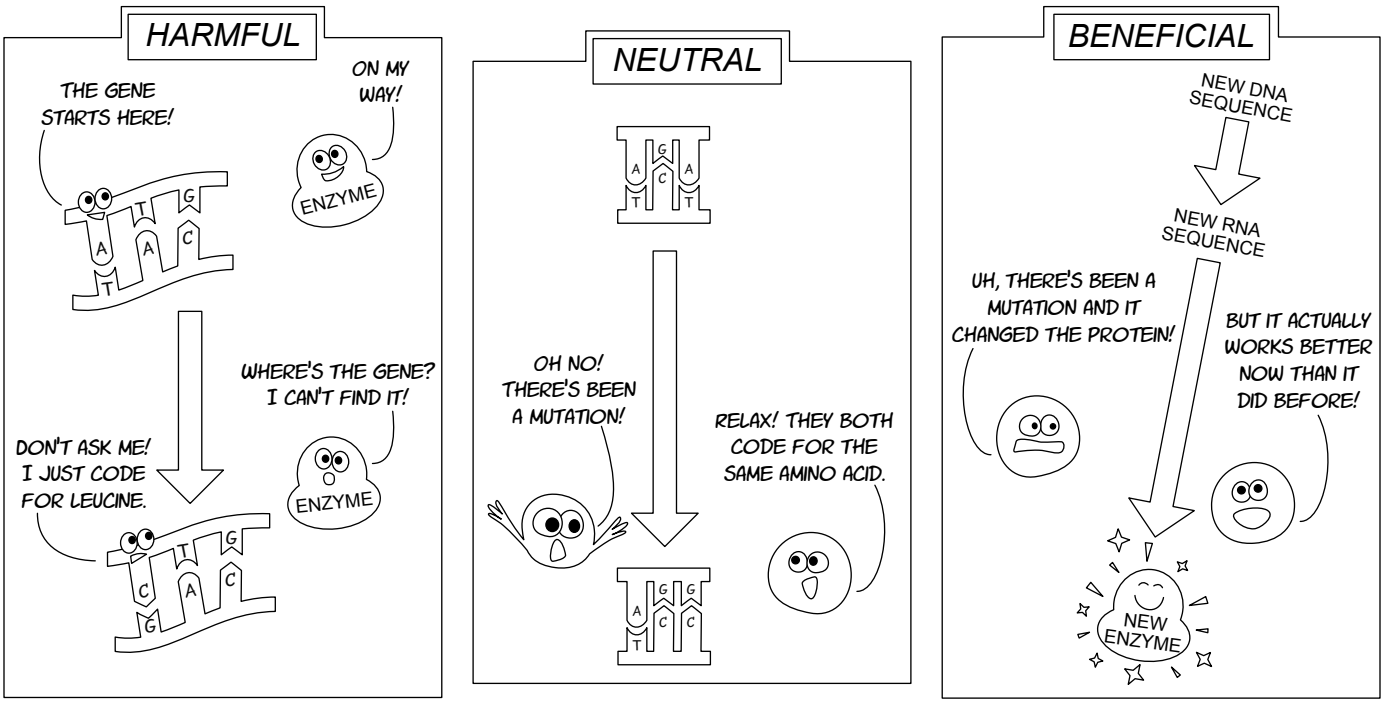
Something goes wrong in the copying process without getting corrected.



Viruses

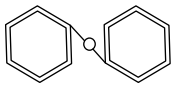
Some viruses insert their own DNA into the genome of host cell. (This DNA then becomes part of the host DNA and is passed on to the next generation.)

EFFECTS OF MUTATIONS

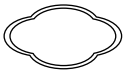


Is the mutation that causes lactase persistence harmful, neutral, or beneficial? Support your answer with an example.

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.



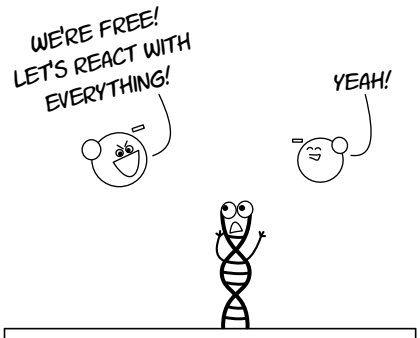
Lactose - the sugar in milk! (galactose + glucose)



Lactase - the enzyme that can cut lactose in half

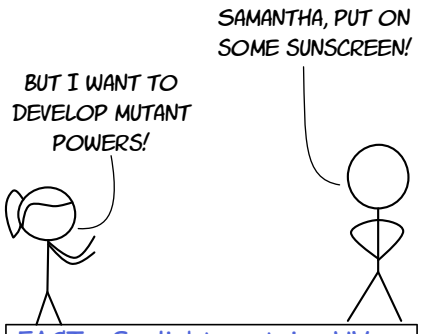
Are these FACT or FICTION? *Write your verdict below each statement:*

Hydrogen peroxide produces molecules called free radicals that damage DNA.



FACT

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



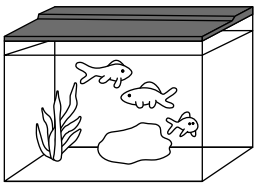
FACT - Sunlight contains UV-radiation that can harm skin cells and DNA.

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

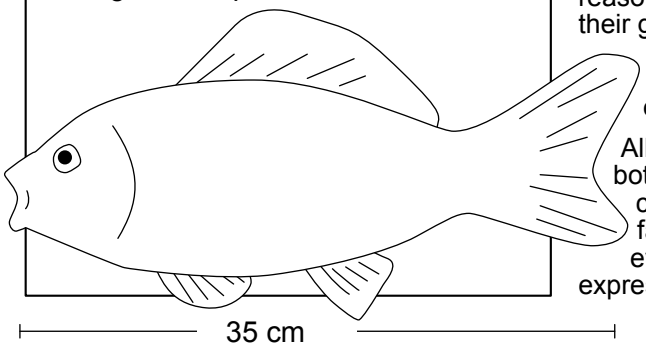
Nature & Nurture

Goldfish in a tank



3-5 cm long

Same goldfish species in Lake Tahoe



35 cm

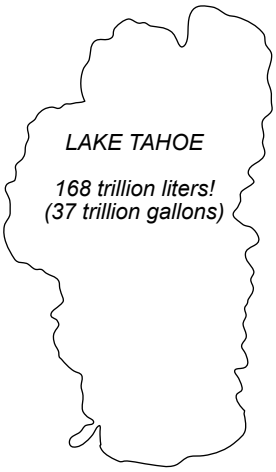
Several years ago, someone dumped a tank of goldfish into Lake Tahoe. They probably thought the goldfish would become food for another fish. But instead, the goldfish became an invasive species!

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.

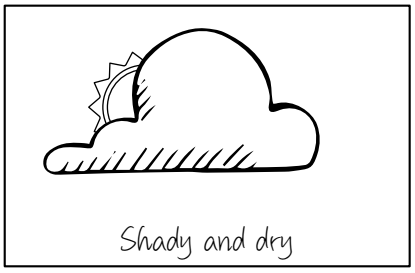
All living organisms are affected by both their genetics and the conditions in their environment. In fact, environmental factors can even influence how genes are expressed!

STANDARD FISH TANK

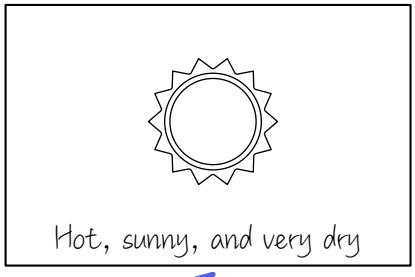
37 liters (10 gallons)



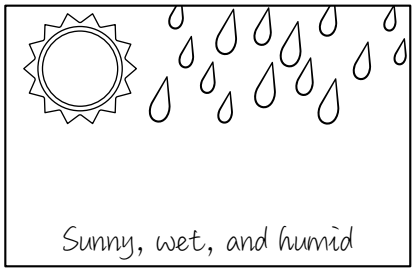
Three genetically identical dandelion seeds landed in three different environments. Match each plant to its environment. Then note one or two characteristics that gave clues to the match.



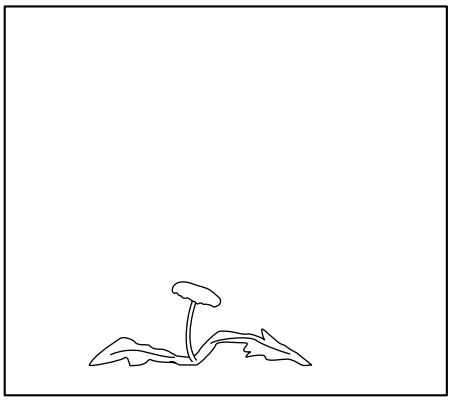
Shady and dry

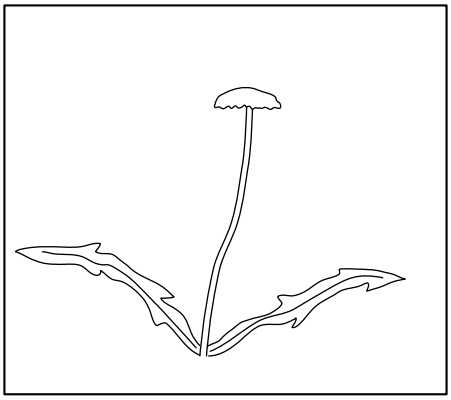


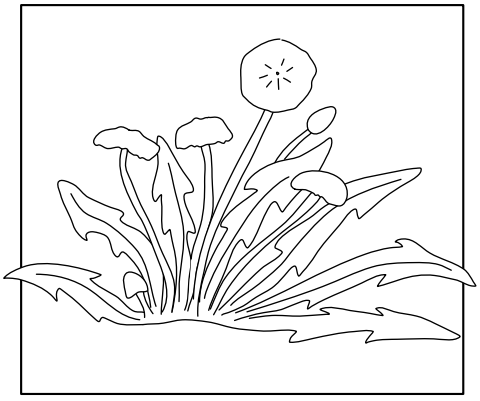
Hot, sunny, and very dry



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.

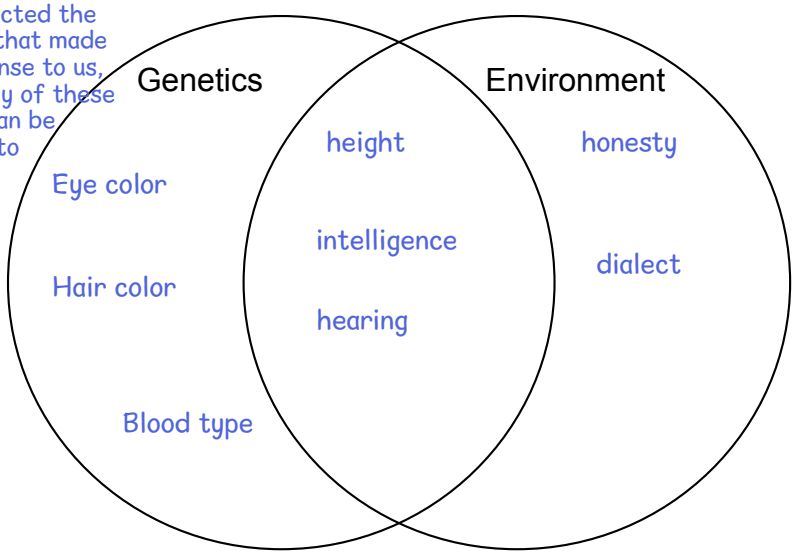
This plant is the largest.

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.

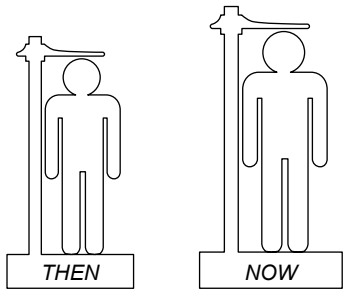
FILL IN THE BLANKS USING THESE WORDS:

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__.

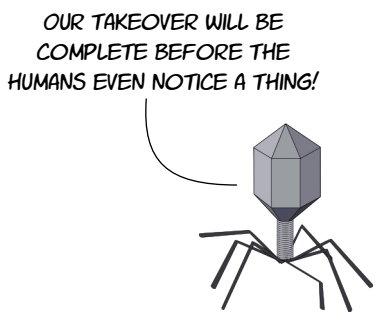
ARE THESE FACT OR FICTION? *Write your verdict below each statement:*

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



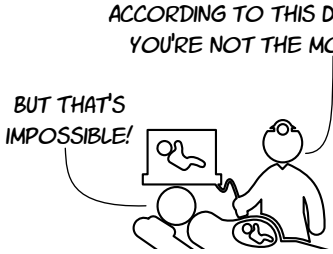
FALSE - but average height has increased by half that amount. For more, see https://ourworldindata.org/human-height

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.

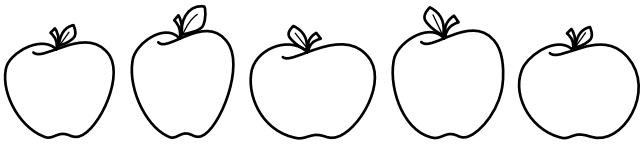


FACT - They're called human chimeras. This rare condition can occur when a dizygotic twin dies in utero and the other embryo absorbs the cells. Recipients of organ transplants are another example of a person who contains two different sets of DNA. For more information see: https://www.sciencedirect.com/science/article/pii/S1769721220302895

Hands-on Science Project

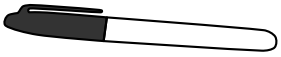
APPLE VARIETY TASTE TEST

MATERIALS:

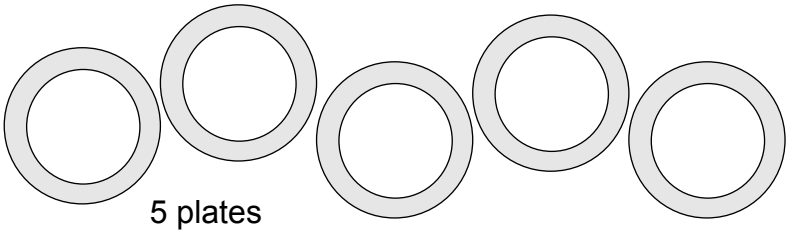


5 apples of different varieties

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.

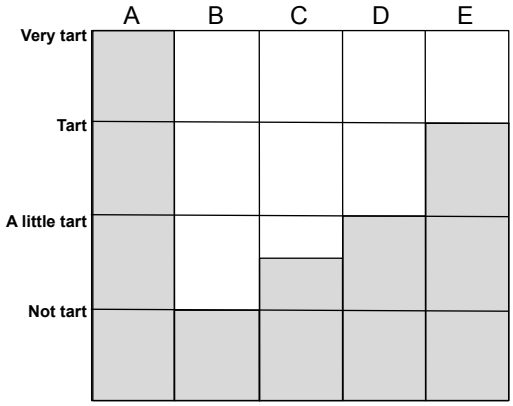
2. At home, use a marker or paper to label each plate with a letter: A,B,C,D,E. Place the sticker from each apple or a label with the name of each apple on the bottom of each plate to help keep track of which apple is which. Be sure the label with the apple variety is not visible to the person taste-testing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

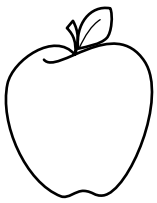
3. For the browning test, cut each apple in half. Place one half face-down on the plate for future taste testing. Cut a piece from the other half and leave it face up and exposed to the air. Then set a timer. Rate each apple variety for browning at 1, 5, 15, and 30 minutes. The taste test can proceed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

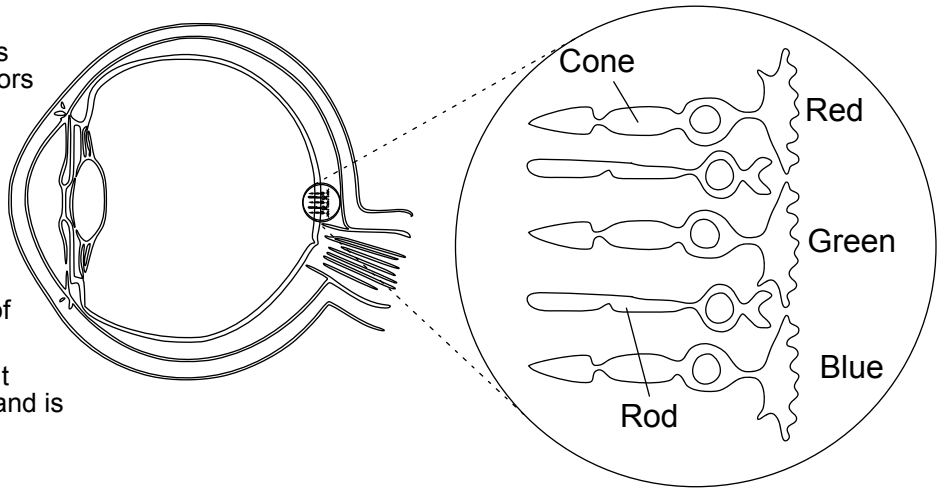
Genes located on different chromosomes are inherited independently. Genes that are further apart on the same chromosome are also inherited independently because of recombination. But if genes are close together on a chromosome, there's a very good chance they'll be inherited together. We call them linked 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

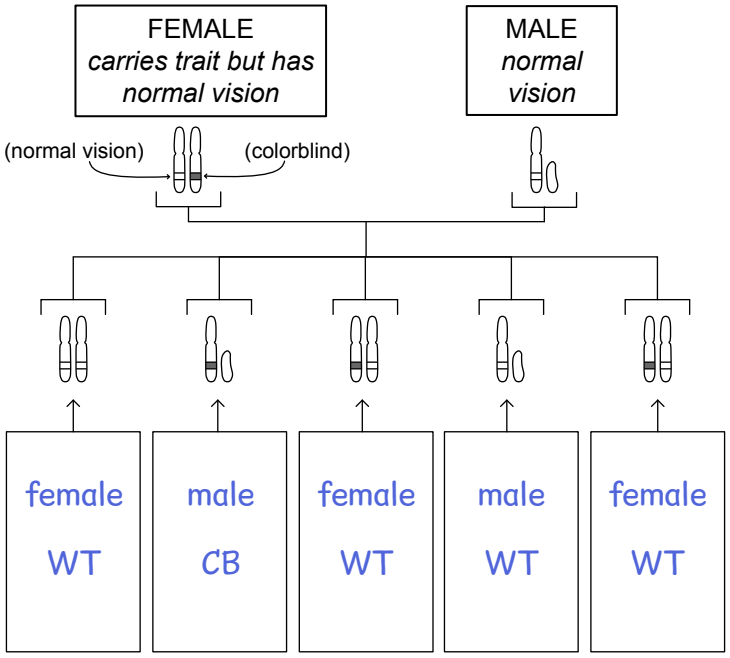
Human vision comes from specialized cells called rods and cones. These photoreceptors work by detecting specific wavelengths of light. The genes with the information to create the color-sensitive red and green cones are located on the X-chromosome.

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.

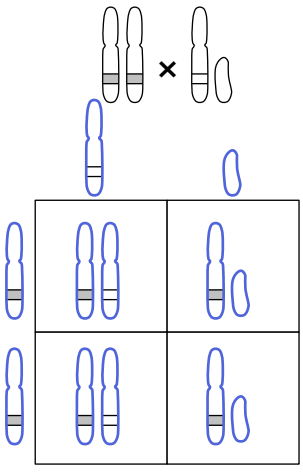
Tritanopia (no blue cones) is not x-linked. It arises from a mutation on chromosome 7 and is much rarer than red-green colorblindness.



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).

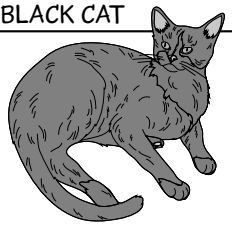
In females with an XX genotype, early in development, one of the X chromosomes is inactivated and supercoiled into a dense structure known as a Barr body. None of its genes will ever be expressed!

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).

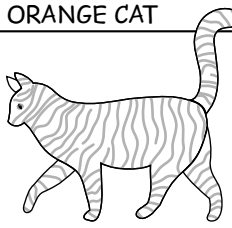
The white fur in a calico cat is caused by the recessive piebald gene, which is located on a different chromosome. It creates unpigmented (white) patches of fur.

BLACK CAT



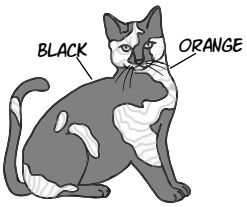
Female X^bX^b
Male X^bY

ORANGE CAT



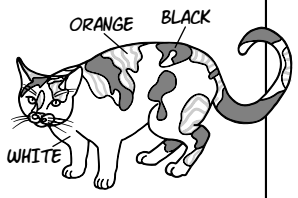
Female X^BX^B
Male X^BY

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

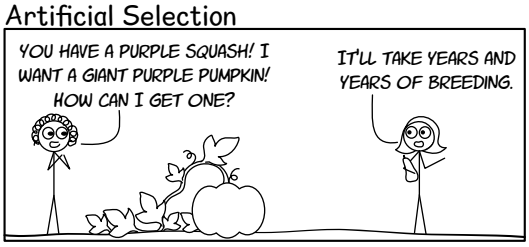
WHAT THEY ARE

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.

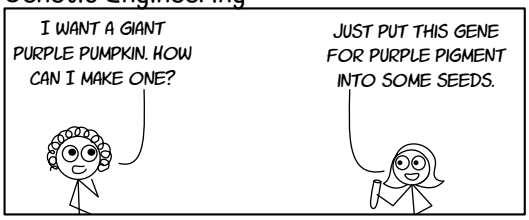
Sometimes this piece of new DNA is from the same species. For example, a pumpkin could be genetically engineered to have another trait by taking the gene from a different breed of squash and inserting it into the pumpkin genome. This would be faster than achieving the same result through artificial selection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

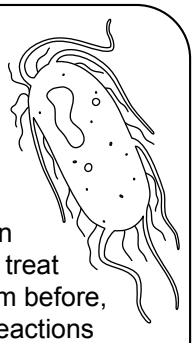
Artificial Selection



Genetic Engineering



EXAMPLE 1: Insulin-producing bacteria



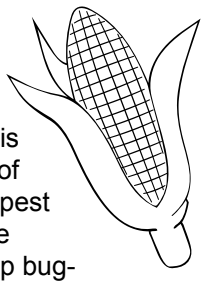
Insulin is a hormone that regulates the amount of glucose in the bloodstream. Someone with diabetes is unable to produce enough insulin. Before 1922, diabetes was a fatal illness. After the discovery of insulin, doctors used insulin from the pancreases of pigs or cattle to treat diabetes. This was an 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.

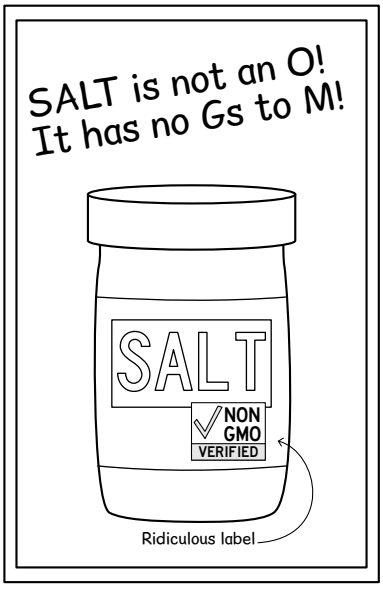
If you could design a genetically modified organism, what would you design and why?

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?



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-.

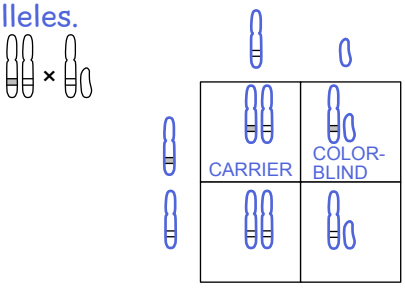
    What genotypes do the parents have for blood type?

    The parents have the genotypes AO+- and BO+- or one parent could be homozygous recessive for Rh factor. (ex: AO+- and BO--)

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

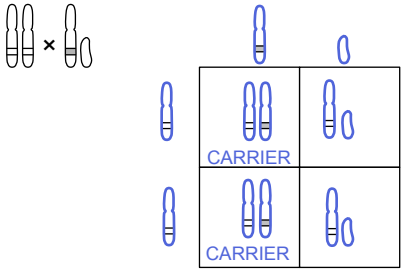
They cannot. Both black and orange alleles are needed for a calico kitten. An orange male cat only carries the orange allele. An orange female cat has two orange alleles.

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-?

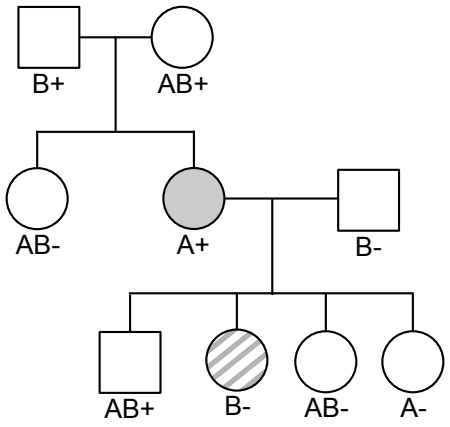
A. 1/2
B. 1/4
C. 1/8
D. 1/16
E. 1/32

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.

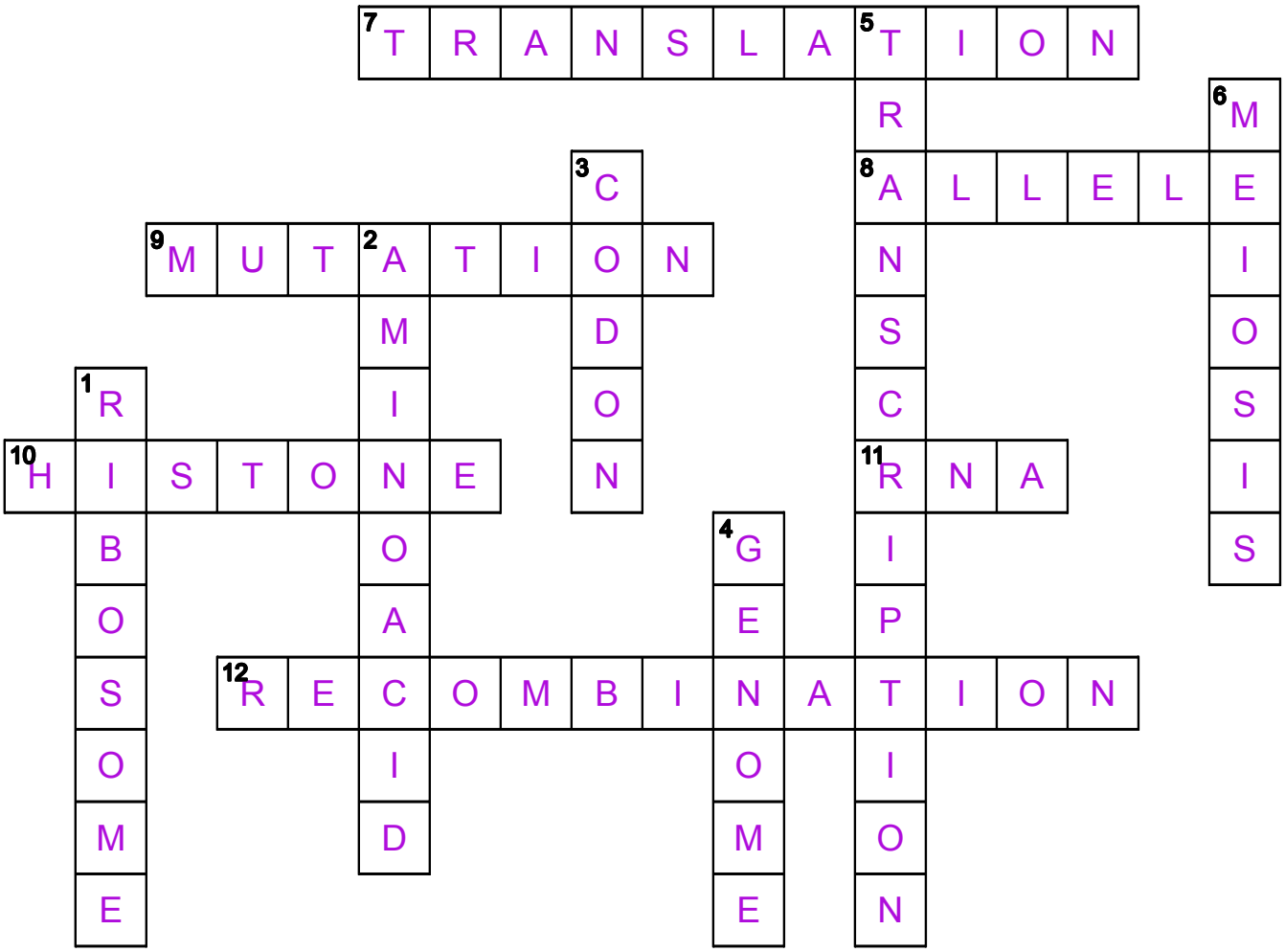


21 What is the genotype of the striped individual in the pedigree?

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.

Genetics Crossword Puzzle



VERTICAL Words

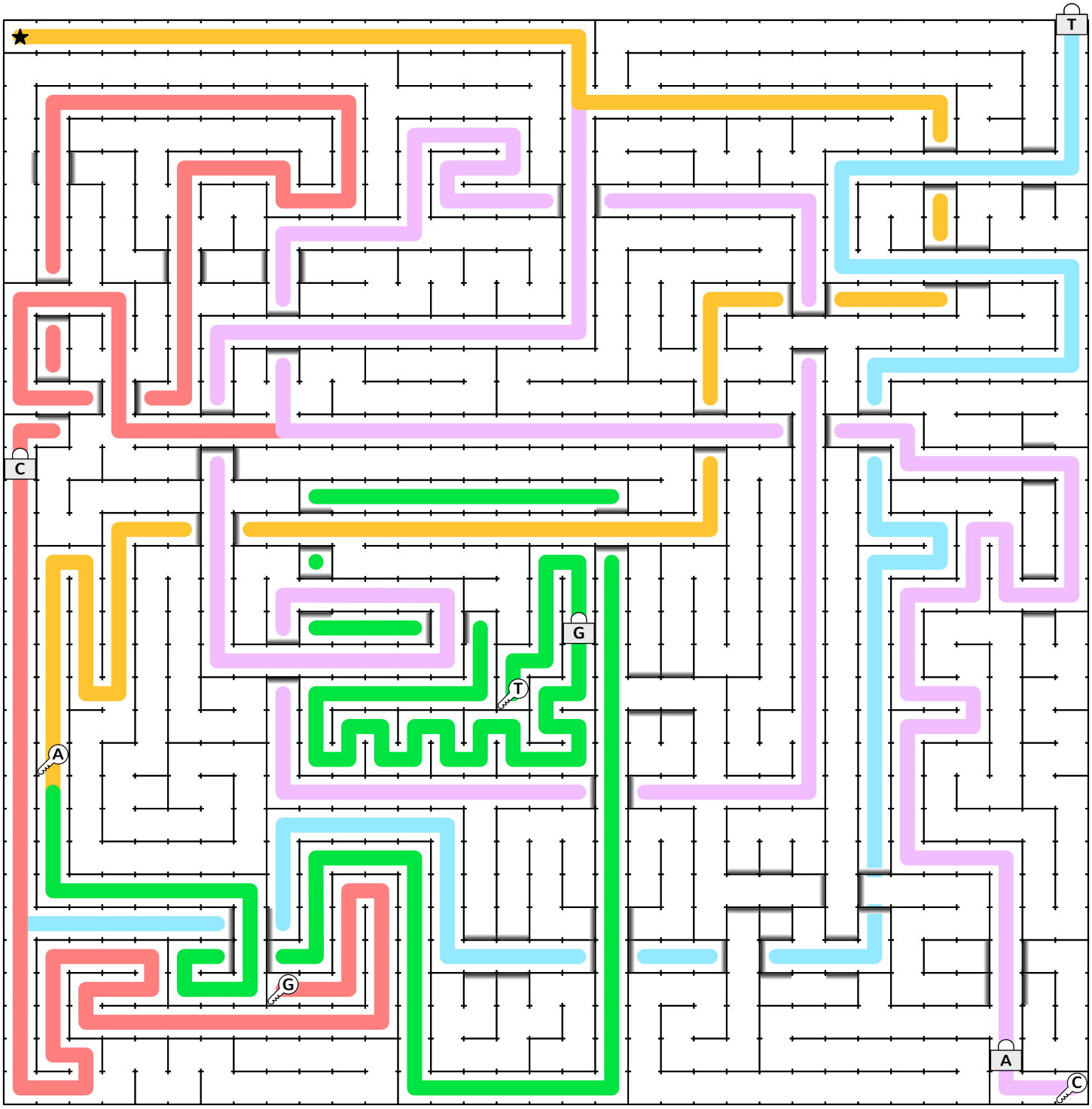
1. A cell organelle where protein synthesis occurs
2. A type of molecule that combines to form proteins
3. A sequence of three nucleotides
4. The complete set of genes or genetic material present in a cell or organism
5. The process of making an RNA copy of a DNA sequence
6. The process of creating haploid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