ST[EMpower]

PALEONTOLOGY 9: CENOZOIC

VOLUME 9, ISSUE 9, SEPTEMBER 2020

AGE OF MAMMALS

THIS MONTH

POWER WORDS

- **Cenozoic Era**: current and most recent of the 3 geological eras of the Phanerozoic Eon; it follows the Mesozoic Era 66 MYA to present
- **Eocene**: an **Epoch** in the **Cenozoic Era** from 56 to 34 MYA
- **Epoch**: geologic time within a Period

CAREER CONNECTION

- **See separate issue 62.Careers Special Issue**: https://tra.extension.colostate.edu/stem-k12/stem-resources/

This issue on the **Cenozoic Era** is the last in the Paleontology series. The **Cenozoic Era** covers the time from the end of dinosaurs to present day.

Over the course of this series, we have included information and activities on DNA. DNA, the blueprint for all life, is the foundation of biology. A fundamental understanding of DNA helps us to understand how species originate, have a range of existence, and go extinct. This issue will complete the DNA activities with explorations of how DNA mutates, and the consequences of mutations.

My scientific research is on the mammal group xenarthrans (ground and tree sloths, anteaters, armadillos, glyptodonts, and pampatheres). Ground sloths appear in the fossil record during the **Eocene Epoch** (35 million years ago) in Patagonia (Argentina and Chili). All ground sloths are extinct, but the tree sloths (no fossil record) are still here and doing well in the tropics of South and Central America!

Megatherium americanum is the largest ground sloth. It was 30 feet, and lived from 400,000 to 8,000 years ago in Argentina, Bolivia, and Uruguay.

The **Cenozoic Era** is the Age of Mammals. North America was home to many species of saber-toothed cats, dire wolves, short-faced bears, terror birds, elephants, American cheetahs (not true cheetahs), and other wonderful megafauna.

PBS Digital's Eon Series is phenomenal. Check it out! https://www.youtube.com/channel/

The Cenozoic started at ~66 **MYA**, when the fossil record has an abrupt loss of dinosaur fossils, and the slow rise of mammal fossils. It is called the K-Pg boundary, the transition between the Mesozoic and the Cenozoic. K-Pg stands for K = Kreide, a German word for chalk and Pg = Paleogene. It may also be called K-T. The T stands for Tertiary, an **obsolete** term for the Paleogene and Neogene.

The finger is pointing to the white chalky layer that divides the Mesozoic from the Cenozoic

The Cenozoic contains three Periods:

- Paleogene from ~66 **MYA** to ~23 **MYA**
- Neogene from ~23 **MYA** to ~2.6 **MYA**
- Quaternary from ~2.6 **MYA** to today

Epochs are divisions within a Period. Epochs are very useful for scientists studying organisms. You will see the Cenozoic commonly divided by Epochs, for example, the Pleistocene Ice Ages. The seven Cenozoic Epochs are:

- Paleocene
- Eocene
- Oligocene
- Miocene
- Pliocene
- Pleistocene
- Holocene

Paleocene, Eocene, Oligocene: Paleogene
Miocene, Pliocene: Neogene
Pleistocene, Holocene: Quaternary

Paleogene Period
This Period demarks the extinction of non-avian dinosaurs at 65.8 **MYA**. It ends the transition from warm, tropical Eocene to the cooler Miocene. The tropical forests retreated to the equator, and grasslands expanded in the mid-latitudes as the climate cooled around 50 MYA.

The Cenozoic is called the Age of Mammals. Once dinosaurs went extinct, mammals began to speciate, increased in body size starting around 40 **MYA**, and dominated the landscape. They thrived until the Pleistocene and began disappearing from the Australian Continent ~50 **KYA** (K = 1,000), North America Continent ~10 **KYA**, and Madagascar ~2 **KYA**. All these times were shortly after the

appearance of humans. *Ernanodon antelios* (image above) is a fossil found in China. It lived during the Paleocene. It was originally placed with the Superorder Xenarthra (sloths, anteaters, armadillos, and their extinct cousins, ground sloths, glyptodonts, and pampatheres). It is now thought to be in an extinct Order Palaeanodonta.

The "dawn horse" fossil, *Hyracotherium angustidens*, originated in the early Eocene. This early horse stood 12" at the shoulders, had three toes, and rooted teeth. This small, forest-

POWER WORDS

- **~**: stands for approximately
- **browse**: feed on leaves, twigs, or other high-growing vegetation
- **delineation**: the action of indicating the exact position of a border or boundary
- **demark**: set the limits of something or to distinguish among things, to divide them up
- **KYA**: thousand years ago
- **MYA**: million years ago
- **obsolete**: no longer used

MATERIALS

- computer with internet
- sturdy shoebox with separate lid
- playdough, plaster of Paris, or papier mâché
- art supplies (**e.g.** tape, scissors, markers, glue, poster paint, tissue paper, etc.)
- craft knife or box cutter (& parent supervision)
- cellophane wrap (party section of store)
- lots of creativity and imagination

dwelling horse **browsed** on leaves and twigs. Horse speciation is a truly wonderful story. You will later explore how horses changed through time when you complete your timeline in the next activity.

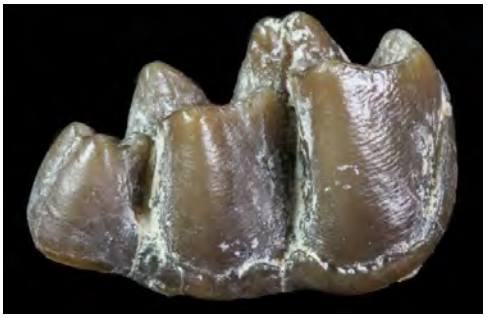
Neogene Period
This Period starts with the continued cooling of the climate. The result of this climate change is our modern ecosystems:

- tropics retreat to the equator
- most deserts are formed around the 30° latitude
- higher latitudes are home to hardwood trees and grasslands between 30° to 50° latitude
- In latitudes 50°—70° ecosystems are dominated by conifer forests
- above the 70° latitude is the tundra
- both the north and south poles of our planet are ice covered

The rise of grasslands are a major cause of horse speciation. Grasses contain a mineral called silica. We make glass from silica. That means, eating grass is like chewing bits of glass. It wears down teeth.

Horses are **grazing** herbivores. Deer and elk are **browsing** herbivores. With the increase in grasslands, horses that inherited teeth better adapted to eating more **abrasive** vegetation thrived. Through time, inheriting beneficial genes, horses speciated into new kinds of horses that were better able to eat grasses.

Miohippus sp. were a genus of 13 species of horses larger than *Hyracotherium* (up to 18 inches at the shoulder). They had three toes, but the ankle and wrist bones were beginning to change. The muzzle elongated. The teeth were better for chewing tough vegetation (tooth image shown below).
The Neogene Period ends with the onset of the first of the

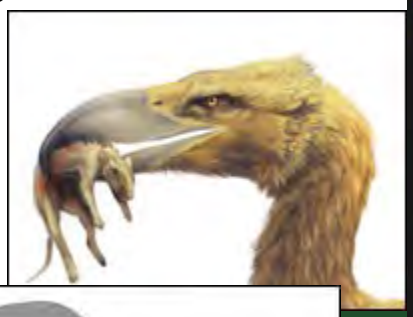


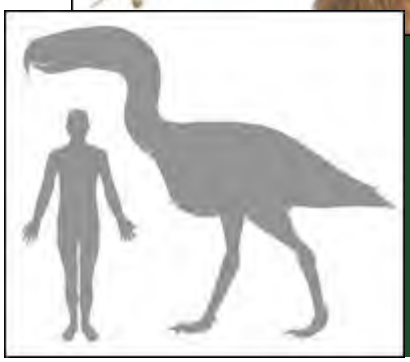
Cenozoic Ice Age.
Many of the species we see today originated in the Neogene. We find fossil dogs, pigs and primates as well as many other familiar animals from this time.

Some, however, are preserved only in their fossils. The terror birds lived through most of the Cenozoic. They originated in South America. With the onset of the first Ice Age, the oceans around the

POWER WORDS

- **abrasive**: causing damage, wear, or removal of surface material by grinding or rubbing
- **graze**: eat grass in a field





Top image is a North American Terror Bird from the American Museum of Natural History in New York City. Image below includes my son standing next to a South American terror bird on display in Museo de La Plata, Argentina.

world lowered as water was stored in the growing ice sheets.

There was volcanic activity that began forming the Isthmus of Panama. The lowering oceans exposed the Isthmus. South America was isolated from all the other land masses for about 95 million years. Wonderful animals speciated in "Splendid Isolation" (the title of a book by paleontologist George Gaylord Simpson about this fascinating story).

Panama slowly emerged from the ocean and became a land bridge between North and South America starting about 9 **MYA**. The **Great American Biotic Interchange** (GABI) refers to South American animals disbursing north, and North American mammals disbursing to South America. The symbol "**†**" (called dagger) means extinct. **†**Ground sloths, **†**glyptodonts, armadillos, **†**terror birds, opossums, and porcupines made their way north.

The North American species were much more successful. Only 5 groups of mammals thrived in South America during its 95 million year isolation:

- xenarthrans (sloths, anteaters, and armadillos)
- ungulates (like deer and cows), but wonderful different species, now all extinct
- marsupials (different than Australia's)
- New World monkeys
- Rodents, like the largest rodent, the capybaras

The massive migration of North American species to South America vastly changed the fauna. It is still home to felids (e.g. jaguars and pumas), canids (amazingly diverse dogs like wolves, foxes, and bush dogs), raccoons, deer, bear, rodents, horses, camels (llamas and alpaca are both in the camel family), and so many more species.

Quaternary Period

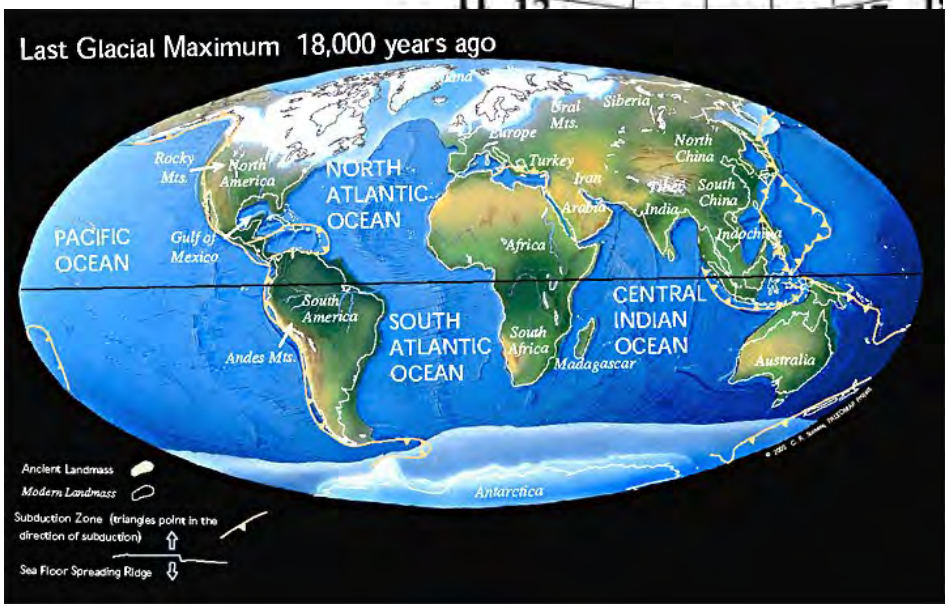
The Quaternary Period starts 2.6 **MYA** with the first of the 5 Ice Sheets expanding then retreating from the Arctic to the USA. If you are interested in learning more about climate change, see the ST[EMpower] issues found here: https://tra.extension.colostate.edu/stem-k12/stem-resources/

- 46. Weather Forecasting
- 47. Here Comes the Sun
- 48. Climate
- 49. Earth in Space
- 50. Oceans Climate
- 51. Greenhouse Gases

The maximum ice sheet reach 37° N.

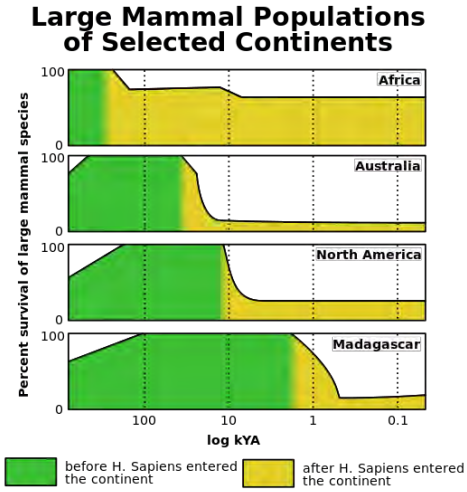
POWER WORDS

- **†**: called dagger and it means extinct
- **cause and effect**: **cause** is the why something happened and **effect** is the what happened
- **Great American Biotic Interchange**: (abbreviated GABI) land and freshwater fauna migrated from North America via Central America to South America and vice versa



The southern border of Colorado is 37° N (orange line on map). There were areas not covered by ice called **refugia**. As the name implies, it was a **refuge** for some species to survive during these times of massive climate change.

Cenozoic megafauna (mega means big and fauna means animal life) thrived on all continents. The graph below show the total percentage of megafauna before the arrival of humans (*Homo sapiens*). Notice that there is very little loss of megafauna on the African Continent, however in Australia, North America, and



Madagascar, there is tremendous loss of these animals.
There is a clear **cause and effect** relationship. The cause is the arrival of humans, and the effect is the loss of large species. The other factors in the loss of megafauna in North America are climate change (the 5 different ice sheets during the Ice Age), and the potential of humans bringing novel diseases that passed to endemic species. Similar to the novel *Coronavirus* jumping from a bat species to humans. This is such a fascinating line of research! North America had wonderful mammals during the Pleistocene. Elephants were very diverse (over 30 known species). Mastodons and

mammoths (pictured above) were widely distributed throughout the **Holarctic**. Saber-toothed cats and dire wolves were two of the top predators during this time, and thousands of their fossils, as well as other species, have been found in La Brea Tar Pits in Los Angeles.

POWER WORDS

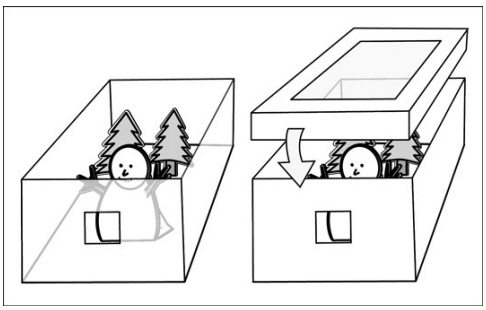
- **Holarctic**: The *Holarctic* is the name for the biogeographic realm that encompasses the majority of habitats found throughout the northern continents of the world
- **refuge**: something providing shelter
- **refugium** (plural refugia): an area in which a population of organisms can survive through a period of unfavorable conditions, especially glaciation

Ground sloths roamed from as far south as Antarctica to as far north as Alaska and Yukon. Glyptodonts, completely encased in a bony skeleton were common.

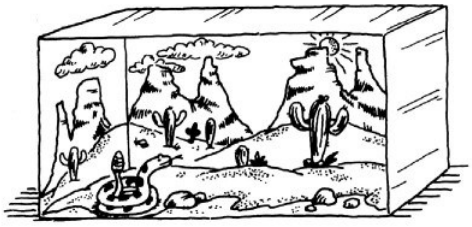
American cheetahs were as fast as modern cheetahs, and looked similar to them. They were, however, cousins of today's puma.

Building **dioramas** are the next best thing to building a time machine! See for yourself what the Paleogene, Neogene, and early Quaternary Epochs looked like. Here's how!

There are two types of **dioramas**, each using a different **orientation** of the box. One is the peephole **diorama**. The advantage is a truly 3D world.



The other type of **diorama** is the open box scene. It provides interest in the full scape. Using everyday materials, like paper, paint, and pebbles, you can create wonderful **dioramas**!



Directions:

- Pick one of the three Periods for your diorama:
  - Paleogene
    - Paleocene Epoch
    - Eocene Epoch
    - Oligocene Epoch
  - Neogene
    - Miocene Epoch
    - Pliocene Epoch
  - Quaternary
    - Pleistocene Epoch
    - Holocene Epoch
- Research information about your Period and the Epochs within it online. The prior pages are very brief summaries of the major features of climate and succession of faunal species during the Cenozoic. Fill in with more specific information. For example, what was happening to Colorado? When did the Rocky Mountains form?
- Verify that your website is from either a university or natural history museum to ensure that your information is authentic. For example, the University of Michigan, the Smithsonian and the American Museum of Natural History have great information.
- The websites in the green boxes below were selected to give you ideas for building each **diorama's** landscape, for example, trees (website 8), horsetails (very similar to bamboo, website 9), mountains (website 3, 4, and 5), or water (website 6 and 7). The first website has complete directions for how to build a **diorama**, including selecting good boxes, and the second website takes you from beginning to end on a Sierra Mountain **diorama**. It has lots of great tips for you.
- The basic steps to building a **diorama**:
  1. select a simple sturdy shoe box with a lid
  2. paint the outside and label what will be inside
  3. Paint the interior of the shoe box with the background
  4. build the topography, the hills, mountains,

POWER WORDS

- **contrast**: strikingly different from something else
- **diorama**: a model representing a scene with three-dimensional figures, either in miniature or as a large-scale museum exhibit; a scenic painting, viewed through a peephole, in which changes in color and direction of illumination simulate changes in the weather, time of day, etc.
- **orientation**: relative position of something

WEBSITES

How to:

1. https://www.youtube.com/results?search_query=Stephanie+Barnett+diorama
2. https://www.youtube.com/watch?v=6ganUXUa0sw

Topography:

3. https://www.youtube.com/watch?v=os1SA2ZpVdE
4. https://www.youtube.com/watch?v=uK0XcoUX9u0
5. https://www.youtube.com/watch?v=pm-wEpu1yBo

streams, etc.
5. add water to streams, lakes, or oceans
6. add vegetation
7. add animals

- When you have gathered enough information about the climate, landscape, plants and animals of the Period you selected, sketch your ideas for your diorama.
- Paint the outside of the shoebox with spray paint, poster (tempera) paint, or wrap with paper, like a present. Allow the paint to dry completely. Using a **contrasting** color marker or poster paint, write the name of the Period (**e.g.** "Neogene").
- The directions are for the open box **diorama**. If you want to make a peephole **diorama**, you need to constantly refer to close and far from the peephole. You don't want something large in front blocking the view.
- Paint the inside of the box with the distant scene. Perhaps you are overlooking a grassland plain. The background would be the grasses, horizon, and sky. If you are looking inland, it could be a distant mountain range.
- Create your **topography** for your scene. For example, website 2 uses plastic cups that are then covered with paper mâché. You can use recycled **corrugated** cardboard boxes cut to give the overall shape (image on left; see https://tra.extension.colostate.edu/stem-k12/stem-resources/ 47.Here Comes the Sun, pages 19-22 for directions), which can then be covered with paper mâché, aluminum foil, or homemade playdough (see https://tra.extension.colostate.edu/stem-k12/stem-resources/ 57.Paleontology 5, page 6 for directions to make playdough). You can carve your terrain from recycled foam (website 11).
- Allow the paper mâché or playdough to dry.
- Paint your **terrain**. Websites 3, 6, and 10 have ideas. If you would like to use rock pigments for a natural look, see the

POWER WORDS

- **corrugated** : material, surface, or structure shaped into alternate ridges and grooves
- **terrain**: a stretch of land, especially with regard to its physical features
- **topography**: the arrangement of the natural and artificial physical features of an area

Water:

6. https://www.youtube.com/watch?v=NwXBvc-FmhU
7. https://www.youtube.com/watch?v=MbjF4oaZ6hQ

Vegetation:

8. https://www.youtube.com/watch?v=UdvwhJoYqAM
9. https://www.youtube.com/watch?v=Jw-CaMe6ltE

Paper Mâché Clay

10. https://www.youtube.com/watch?v=1YQ6eUqcEh8

ST[EMpower] issue https://tra.extension.colostate.edu/stem-k12/stem-resources/ 42.Pigments. It contains ideas for making your own paint pigments from natural sources, like our red rock mountains. There is also a Munsell color chart that you can use to get more realistic soil colors.

- Add vegetation to your diorama. The plants of the Cenozoic are more and more like the plants of today.
- Add animals that were found during that time, sculped from homemade playdough or paper mâché covered aluminum foil shaped like these organisms. The websites below will get you started with fauna and flora.

The diorama to the right is the ground sloth "Rusty" from Macbride Hall University of Iowa, Iowa City, IA . It depicts Rusty in the **foreground**. Rusty is a *Megalonyx jeffersonii* ground sloth from 12,000 years ago that lived during the Wisconsin Glacial Episode (one of the 5 major ice sheets grinding to the USA). The *specific* name, *jeffersonii*, is named after Thomas Jefferson. He found one of the enormous claws from this extinct species.

Teddy Roosevelt, our 26th president of the United States, loved nature. He traveled to South America, collecting fauna and fossils for the American Museum of Natural History (AMNH). He found the remains of a ground sloth, including rusty red fur and feces (poop). That is so absolutely cool!

Have fun! Learn lots!
Science is awesome!

POWER WORDS

- **binomial name**: two part naming system to identify species; the first part is the genus and the second part is the species.
- **foreground**: the part of a view that is nearest to the observer
- **specific**: refers to "species" part of a **binominal name** (genus species)
- **teem**: be full of or swarming with

WEBSITES OF CENOZOIC FAUNA

Paleogene

- https://en.wikipedia.org/wiki/Category:Paleogene_animals

Neogene

- https://en.wikipedia.org/wiki/Category:Neogene_animals

Quaternary

- https://en.wikipedia.org/wiki/Category:Quaternary_animals

This is our final issue in the series Paleontology. In this activity, you will complete the Cenozoic section, and with that, finish the entire Phanerozoic timeline. It is chockful of information about the history of Earth, including continent locations moved by plate tectonics, climate, and the origin, speciation, and extinction of some major groups of organisms.

Saber tooth cat *Smilodon fatalis* was found throughout the United States, and moved into South America after the Isthmus of Panama land bridge formed. This fossil is in Museo de La Plata, Argentina.

In this activity, you will explore the internet to locate the oldest record known of various organisms from this time era. You will find basic information about each Period's climate and organisms on pages 12-13 to get you started. You also have the climate and continents' location on your timeline.

Irish elk *Megaloceros giganteus from* Eurasia *was* the largest deer known

The diversity of life is truly wondrous. Every Era has amazing, weird and wonderful (even terrifying) animals. The Cenozoic Era has fauna that is much more familiar to us that the preceding eras of the Paleozoic and Mesozoic. They are ancestors of our modern species.

The largest known terrestrial animal were sauropod dinosaurs. *Argentinosaurus*, the 130 feet sauropod dinosaur currently is the longest known animal. Another dinosaur, also found in Argentina, may be even bigger, but only a few bones have been found.

The largest terrestrial mammal, although much smaller, was really big. It was 17 feet tall, 30 feet long, and weighed 44,000 pounds. *Paraceratherium transouralicum* in the image below shows the skull and the

Paraceratherium transouralicum was as tall as a three story building!

POWER WORDS

Review Geologic Time: time is divided according to the fossil record

- Eon: The Earth's history is divided in four Eons from formation to today. The current Eon is Phanerozoic
- **Era**: the Phanerozoic is divided into three Eras—Paleozoic, Mesozoic, and Cenozoic
- **Period**: Each Era is subdivided into a different number of periods. For example, the Cenozoic has three Periods: Paleogene, Neogene, and Quaternary
- **Epoch**: Each Period is subdivided into Epochs, for example, the Neogene is divided into Miocene and Pliocene

See geologic timeline on page 11

body outlined with a metal sculpture. The fossils in front and below are bear-sized animals. It is a member of the rhinoceros Family (in the same Order as horses and tapirs) that lived in **Eurasia**. We find the fossils in Oligocene **strata** (35-20 **MYA**).

The most massive animal known to ever live is the blue whale, *Balaenoptera musculus*. The record blue whale was a bit over 108 feet and weighed 440,000 pounds! It was a female caught by whalers in the 1800s. The image below is a full size model of a blue whale in the Hall of Mammals, American Museum of Natural History in New York.

The list does not include bacteria, archaea, protists (organisms with eukaryote cells, but they are mostly single celled organisms), or fungi. These organisms were certainly present in abundance. There are some plants in the table, but most of the organisms are animals.

Get ready for wonder!

Directions:

- The list of organisms is not comprehensive by any means, but it includes a variety of animals and plants.
- The table on pages 13-14

POWER WORDS

- **Eurasia**: Europe and Asia considered together as one continent
- **geologic timeline** (also known as geologic time scale):
- **stratum** (plural strata): a layer or a series of layers of rock in the ground

You do not need to find every organism on this list, but you may...just may...get pulled into this incredible time! It is, after all, the closest thing we do have to a time machine.

MATERIALS

- your Phanerozoic Eon timeline
- sharpies or markers in a variety of colors
- pencil
- yardstick or meterstick
- computer with internet
- printer (color optional)
- glue stick or tape
- print pages 13—18 double-sided
- art supplies (optional)

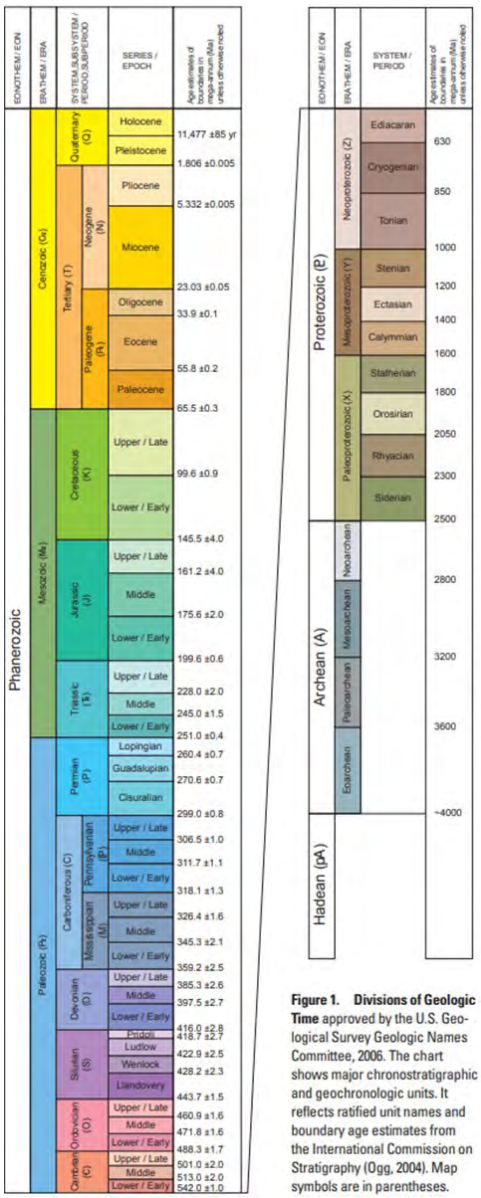


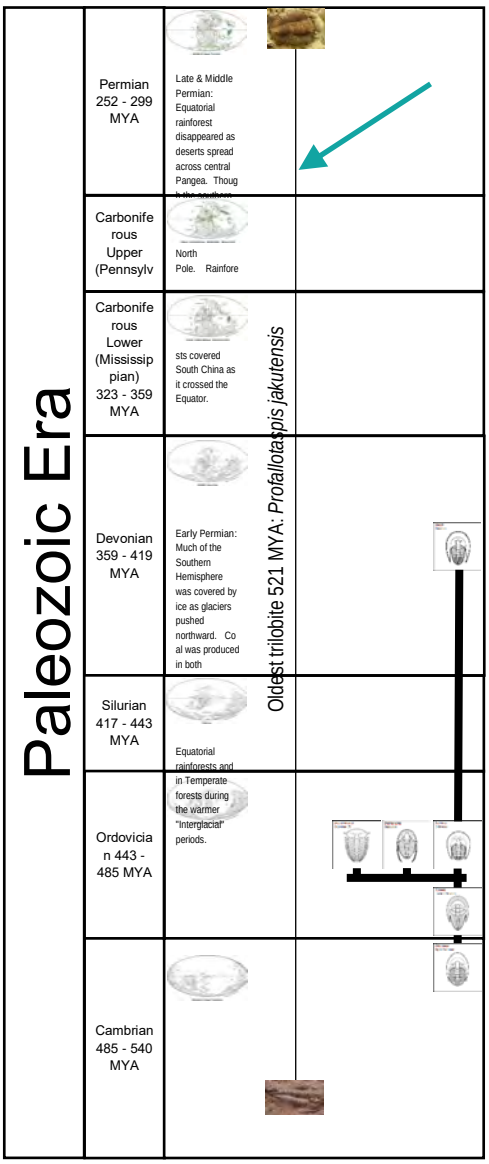
Figure 1. Divisions of Geologic Time approved by the U.S. Geological Survey Geologic Names Committee, 2006. The chart shows major chronostratigraphic and geochronologic units. It reflects ratified unit names and boundary age estimates from the International Commission on Stratigraphy (Ogg, 2004). Map symbols are in parentheses.

Geologic Timeline:
U.S. Geological Survey Geologic Names Committee, 2007, Divisions of geologic time—Major chronostratigraphic and geochronologic units: U.S. Geological Survey Fact Sheet 2007-3015, 2 p.

has one of the first fossils found for representatives of the vertebrate groups and some invertebrate groups. Include each of those on your timeline.

- The tables on pages 15—16 includes horse species. Include all these species on your timeline. Complete the table.

- Find your own fossils to finish your Cenozoic timeline. Be sure that these species lived in the Cenozoic. Hint, if you are interested in predators, search "Cenozoic fossil predators." Add at least 3 to 11 different species. Complete the table on pages 17-18.
- Search the internet to locate images and information.
- Copy and paste the image to a word document, and resize it to fit on your timeline. For example, you could make your images each 3" x 3" (or so). Since that does not convey the proper scale, note the size next to the image. Examples:
  - *Paraceratherium transouralicum* (the enormous rhino) 30 feet long, and stood 17 feet high; Oligocene; from **Eurasia**
- As you collect images of each organism, be sure to identify it on your word document.
- When you have found all the animals and plants you want to include on your timeline, cut out them with scissors.
- Do not tape or glue down anything yet. Wait until you have completed your table and images of all the organisms you are adding to your timeline.
- Once you are done, place all the images in the correct Period. Arrange them until you like how it looks. Tape or glue all your images.
- Include information (like size) by each image.

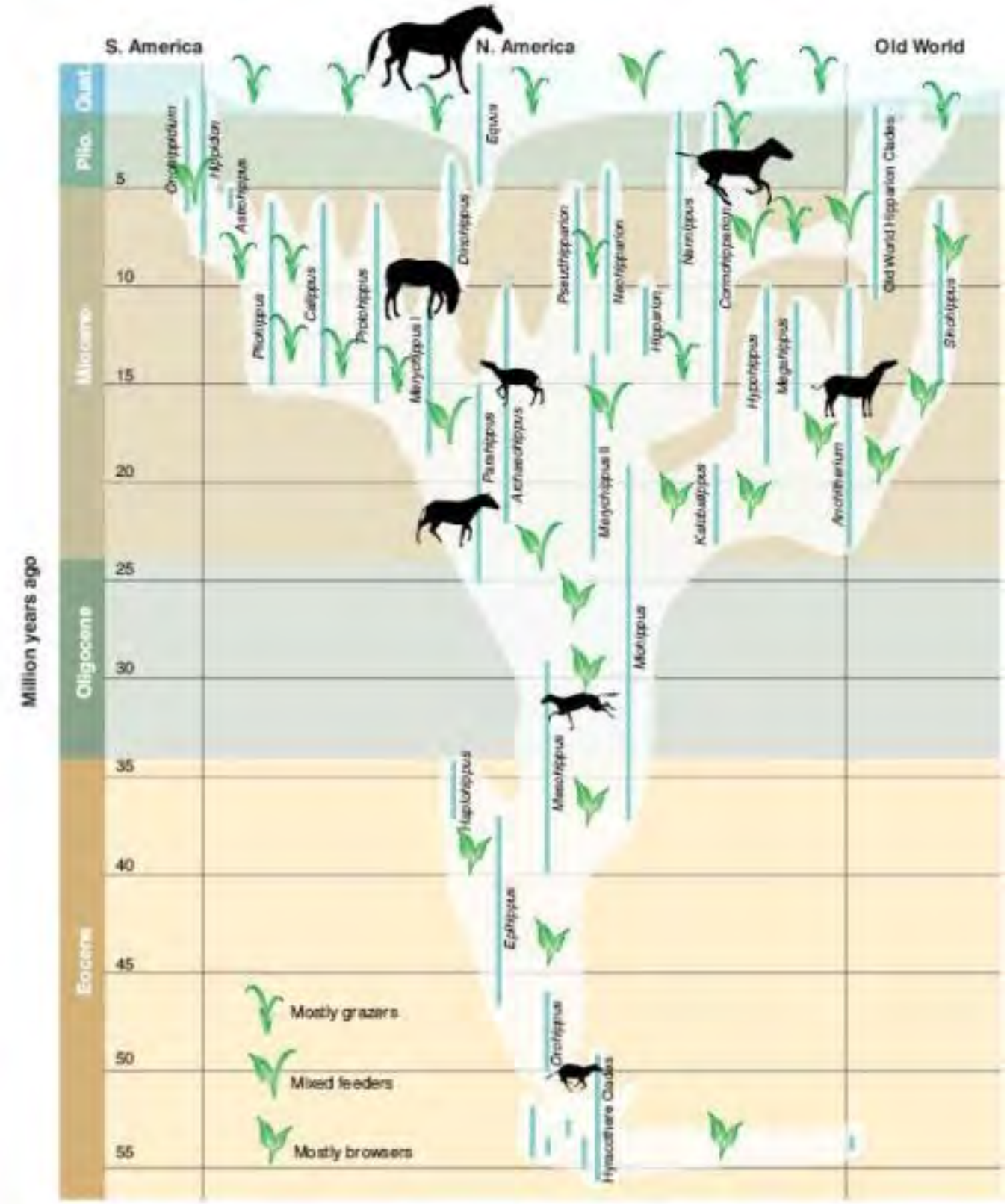


- If you found the range the species fossils lived, you can indicate that with a **vertical** line that starts at their first (origin) fossil occurrence, and their last (extinction) fossil occurrence. See the example above from the Paleozoic Era trilobites.

YOUR TIMELINE IS DONE!

Have fun.
Learn lots.
Science is AWESOME!

Horse speciation is a complex story. Dr. McFadden developed the graph below. Can you describe what this graph means?



From McFadden, Bruce. 2005. "Fossil Horses – Evidence of Evolution." *Science* Vol. 307. no. 5716, pp. 1728 – 1730

- Include all of the organisms in this table on your timeline. They represent some of the oldest fossils in the major **phyla** (plural of phylum). Search for as much information as you can find to complete your table. You may not be able to find everything. Leave that cell blank.
- On the back of your table, include interesting information about each species; e.g. *Nyasasurus parringtoni* was found 100 years before it was studied.

Power Words:

- **Class**: classification of organisms, it falls below Domain, Kingdom, and Phylum
- **Phylum**: a principal taxonomic category that ranks above class and below kingdom (botanists use the word "division" instead)

First Fossil Evidence in the Cenozoic Era					
Organism	Period	Time Range	Phylum	Class	Size
Example: *Megalonyx jeffersonii*	Quaternary	1.8 MYA to 10,000 years ago	Chordata	Mammalia	8—10 feet
Marsupialia (opossum) *Mimoperadectes houdei*					
Cingulata, (armadillo) *Utaetus* sp.					
Pilosa, (sloth) *Thinobadistes segnis*					
Chiroptera (bat) *Onychonycteris finneyi*					
Rodentia (rodent) *Alagomys russelli*					
Carnivora (carnivore) Hesperocyon gregarius					
Lagomorph (rabbit) *Palaeolagus haydeni*					
Artiodactyla (whale) Basilosaurus cetoides					
Artiodactyla (ungulate) Diacodexis sp.					
Proboscidea (elephant) Mammut americanum					

First Fossil Evidence in the Cenozoic Era	
Organism	Interesting Facts
Example: *Megalonyx jeffersonii*	Thomas Jefferson recorded the fossil bones of this animal found in a cave in West Virginia. He thought it belonged to a giant cat with enormous claws. (Megalonyx means giant claw.) He later realized it was related to South American ground sloths.
Marsupialia (opossum) *Mimoperadectes houdei*	
Cingulata, (armadillo) *Utaetus* sp.	
Pilosa, (sloth) *Thinobadistes segnis*	
Chiroptera (bat) *Onychonycteris finneyi*	
Rodentia (rodent) *Alagomys russelli*	
Carnivora (carnivore) Hesperocyon gregarius	
Lagomorph (rabbit) *Palaeolagus haydeni*	
Artiodactyla (whale) *Basilosaurus cetoides*	
Artiodactyla (ungulate) Diacodexis sp.	
Proboscidea (elephant) *Mammut americanum*	

Horse Fossil Evidence in the Cenozoic Era					
Organism	Period	Time Range	Phylum	Class	Size
Epihippus sp.					
Equus sp.					
Hipparion sp.					
Hyracotherium sp.					
Kalobatippus sp.					
Merychippus sp.					
Mesohippus sp.					
Miohippus sp.					
Neohipparion sp.					
Orohippus sp.					
Pliohippus sp.					

Horse Fossil Evidence in the Cenozoic Era	
Organism	Interesting Facts
Epihippus sp.	
Equus sp.	
Hipparion sp.	
Hyracotherium sp.	
Kalobatippus sp.	
Merychippus sp.	
Mesohippus sp.	
Miohippus sp.	
Neohipparion sp.	
Orohippus sp.	
Pliohippus sp.	

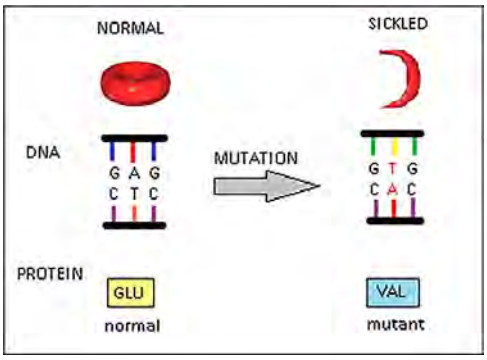
Find Your Own Fossils from the Cenozoic Era

Organism	Period	Time Range	Phylum	Class	Size

Find Your Own Fossils from the Cenozoic Era												
	Interesting Facts											
	Organism											

The Paleontology series has covered concepts of DNA **replication**, RNA **translation**, and protein **synthesis**. To do this final activity on **mutations**, you will need to complete the earlier activities (or review them to refresh your memory). Please visit https://tra.extension.colostate.edu/stem-k12/stem-resources/

- 55. Paleontology 3 page 18
- 57. Paleontology 5 pages 16-18
- 58. Paleontology 6 pages 7-21
- 59. Paleontology 7 pages 2-10



mRNA Codon/Amino Acid Chart

First Base	Second Base: U	C	A	G	Third Base
U	UUU, UUC – Phenylalanine (Phe)	UCU, UCC, UCA, UCG – Serine (Ser)	UAU, UAC – Tyrosine (Tyr)	UGU, UGC – Cysteine (Cys)	U
	UUA, UUG – Leucine (Leu)		UAA, UAG – Stop	UGA – Stop	C
				UGG – Tryptophan (Trp)	A
					G
C	CUU, CUC, CUA, CUG – Leucine (Leu)	CCU, CCC, CCA, CCG – Proline (Pro)	CAU, CAC – Histidine (His)	CGU, CGC, CGA, CGG – Arginine (Arg)	U
			CAA, CAG – Glutamine (Glu)		C
					A
					G
A	AUU, AUC, AUA – Isoleucine (Ile)	ACU, ACC, ACA, ACG – Threonine (Thr)	AAU, AAC – Asparagine (Asn)	AGU, AGC – Serine (Ser)	U
					C
	AUG – Start Methionine (Met)		AAA, AAG – Lysine (Lys)	AGA, AGG – Arginine (Arg)	A
					G
G	GUU, GUC, GUA, GUG – Valine (Val)	GCU, GCC, GCA, GCG – Alanine (Ala)	GAU, GAC – Aspartic Acid (Asp)	GGU, GGC, GGA, GGG – Glycine (Gly)	U
					C
			GAA, GAG – Glutamic Acid (Glu)		A
					G

The activity in 59.Paleontology 7 included an introduction to the **amino acid** wobble. If DNA **mutates**, it may have no impact whatsoever to the protein.

Mutations, however, may have devastating consequences. For example, sickle cell anemia was caused by a single **mutation**. If a child inherits the **mutated gene** from one parent, it can protect them from malaria, the most deadly disease in human history. If a child inherits a mutated gene from both parents, the condition is often fatal.

If a mutation occurs in junk DNA, it will have no impact. If a mutation is within the wobble, it may have no impact. If the mutation occurs in coding a protein, it usually is **debilitating** or **fatal**. Most **mutations** on active genes are **fatal**. Not all, though. Like sickle cell anemia, the **mutation**, can provide protection.

There are four activities to explore some of the

POWER WORDS

- **base pair**: a pair of complementary bases in a double-stranded nucleic acid molecule; Adenine always pairs with Thymine in DNA and Uracil in RNA, and Guanine always pairs with Cytosine
- **characteristic**: a feature or quality belonging to a species serving to identify it
- **codon**: a sequence of three nucleotides which together form a unit of genetic code in a DNA or RNA molecule
- **complementary**: in a gene sequence, the rules of base pairing:
  - Adenine - Thymine or Adenine - Uracil
  - Guanine - Cytosine

continued on page 20…

MATERIALS

- color mini marshmallows
- white mini marshmallows
- licorice sticks (red and black)
- toothpicks
- print pages 24-25 single sided
- scissors
- tape
- pencil or pen
- scrap of paper or sticky label

mutations in DNA and their consequences:

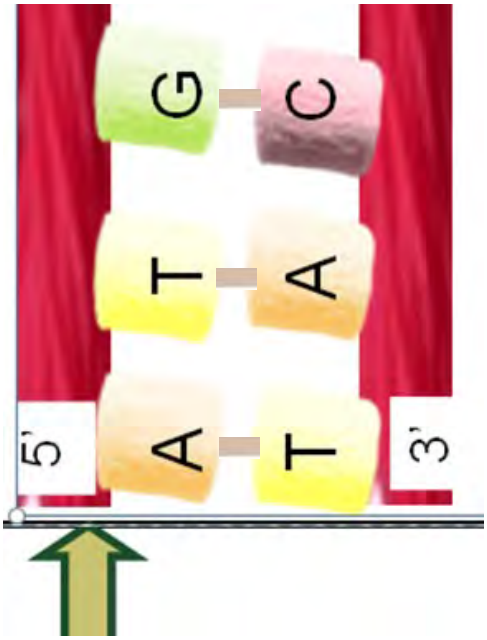
- DNA and the mRNA gene synthesizing the **wildtype** protein (no mutations)
- Examining the RNA / amino acid wobble
- Examining a **mutation** that is usually fatal
- Examining a mutation that is not **fatal** with different consequences

Directions:

- The Paleontology series has covered the DNA concepts:
  - replication (preparing the cell for division)
  - transcription (constructing **complimentary** RNA from DNA)
  - translation (using RNA's code to produce proteins)
- You need to review these concepts before proceeding. See page 19 for the website, the issues and pages that cover DNA, RNA, and protein **synthesis**.
- These activities are designed to continue using the marshmallow / licorice stick models. You can also opt to only use the paper pictures on pages 24-25. If you use the marshmallow models, red licorice represents DNA, and black licorice represents mRNA. The tRNA is represented by red licorice, and the paper model is on page 24.
- Connect the marshmallows to the licorice sticks, and connect the licorice sticks end to end with toothpicks.
- The gene is 42 base pairs (**complementary** pairing):
  - DNA: adenine (A)—thymine (T)
  - DNA and RNA: guanine (G)—cytosine (C)

- The image below shows three base pairs. A pairs with T and G pairs with C:

A	T	G
T	A	C



Build the Marshmallow Model:

- Cut out your DNA paper template on page 24 between the dashed lines. Keep the double strands together (the licorice sticks with the two marshmallows rows between them). There are 3 sections.
- Tape the strands end to end making one double strand DNA. The gene is on the "ATGGT" strand, indicated by the gold arrow. The other strand is not expressed.

POWER WORDS
continued from page 19...

- **debilitate**: make weak and infirm
- **express:** cause an inherited **characteristic** or gene to appear in a phenotype
- **fatal**: causing death
- **gene**: unit of heredity transferred from a parent to offspring; determines offspring's **characteristic**
- **mutation**: changing the structure of a gene, to produce a different form
- **nitrogen base**: Adenine, Thymine, Uracil, Guanine, and Cytosine
- **nitrogenous base**: Adenine, Thymine, Uracil, Guanine, and Cytosine

continued on page 21…

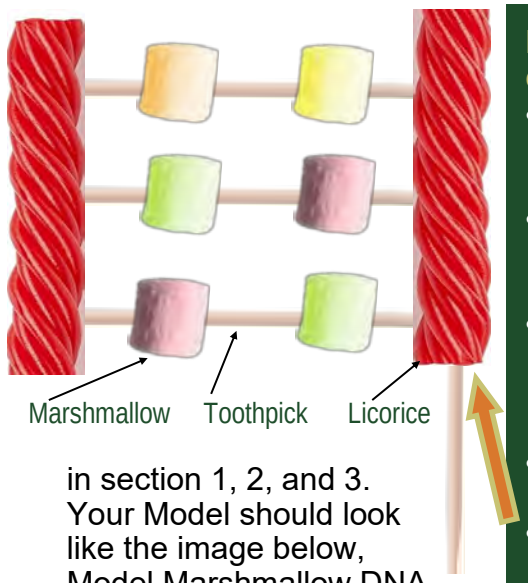
- Build the marshmallow strands using the paper model as your template.
- You need 45 toothpicks. Evenly space 15 toothpicks on one licorice twist, and push them into the twist.
- Space 15 more toothpicks on the second licorice twist; push them into the twist.
- Repeat one more time

FUN FACT:

- Your **DNA** could stretch from the earth to the sun and back ~600 times.
- We're all 99.9 percent alike.
- Genes make up only about 3 percent of your **DNA**.
- The human genome contains 3 billion base pairs of **DNA**.

with the third licorice twist.

- Use the paper template on page 24 for the color marshmallow sequence. Each color marshmallow represents a different **nitrogen base** (Adenine is orange, Thymine is yellow, Guanine is green, and Cytosine is pink—below).
- Use the DNA paper template, push the matching color marshmallow ⅔ on the toothpick.
- When you complete the third licorice twist, you will have three toothpicks without marshmallows at the end. Remove those toothpicks. You needed them to space the marshmallows.
- Add the **complementary nucleobase** (marshmallow) on each of the toothpicks. Leave a gap between the marshmallows as shown in the image above right.
  - A-T (orange -yellow)
  - G-C (green- pink)
- Push your second licorice twist onto the open ends of the toothpicks to complete the ladder. Take care you do not get poked!
- Join the three licorice / marshmallow ladders together. Push the toothpick into the end of one twist (image above indicated by the orange arrow). Use a toothpick to join the twist together end to end. Be sure that you keep the correct sequence of marshmallows in section 1, 2, and 3. Your Model should look like the image below, Model Marshmallow DNA.



- Label the 5' and 3' end of DNA (read 5' as "five prime" and 3' as "three prime"). The image of the licorice / marshmallow model below identifies the top as the 5' to 3' strand, and the lower as the 3' to 5' strand. The bottom strand's direction is opposite to the upper strand, and the 3' is on the left and the 5' is on the right. Use a paper strip and a piece of tape to attach to the licorice twist as depicted.
- The gene starts at the 5' ends and moves down the strand (licorice stick) towards the 3' end.

POWER WORDS
continued from page 20...

- **nucleobase** Adenine, Thymine, Uracil, Guanine, and Cytosine
- **nucleoside**: The nitrogen base plus a sugar molecule
- **nucleotide**: the nitrogen base plus the sugar molecule plus phosphate
- **replication**: copying or reproducing
- **synthesis**: production of chemical compounds by reaction from simpler materials (e.g. mRNA to amino acid protein strand)
- **trait**: distinguishing quality or characteristic; a genetically determined characteristic

continued on page 22…

Wild Messenger RNA (mRNA)

- The DNA unzips between the two strands. To "unzip your DNA, you cut the toothpicks between the two base pair marshmallows.
  Cut out your paper mRNA

5' →

Model Marshmallow DNA

3'

3'

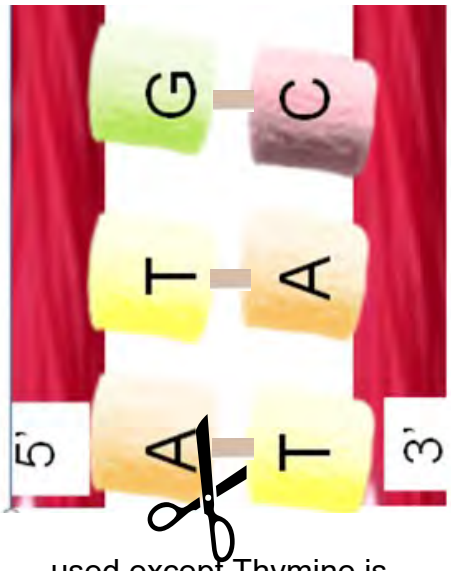
← 5'

DNA Marshmallow Color Code

Adenine (A) = orange (O) pairs with Thymine (T) = yellow (Y) in DNA
Thymine (T) = yellow (Y) pairs with Adenine (A) = orange (O) in DNA
Guanine (G) = green (G) pairs with Cytosine (C) = pink (P) in DNA & RNA
Cytosine (C) = pink (P) pairs with Guanine (G) = green (G) in DNA & RNA

RNA Marshmallow Color Code on page 22 (also repeated on page 23)

model on page 24. Tape your three sections together to make one long strand, as imaged below. Compare the paper model of DNA to the paper model of mRNA. What do you notice? The RNA strand is the same as the strand of DNA that is not

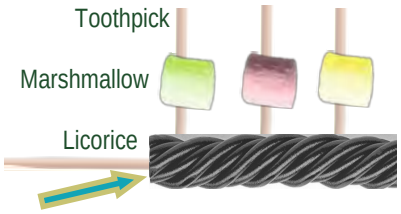


used except Thymine is replaced by Uracil!

- Build your mRNA model from marshmallows and black licorice. This is the "**wildtype**" mRNA, **transcribed** from unmutated DNA. Use the paper RNA model as the template.
- You need 23 toothpicks and 3 black licorice twists. Cut the toothpicks in half.
- Evenly space 15 half toothpicks on the black licorice twist, and push them into the twist.
- Space 15 more half toothpicks on the second licorice twist; push them into the twist.
- Repeat one more time with the third black licorice twist.
- Use the paper RNA template for the color marshmallow sequence. Each color marshmallow represents a different **nitrogen base** (Adenine is orange, Thymine is yellow, Guanine is green, and Uracil is white—see green box below).
- When you complete the third licorice twist, you will have three toothpicks without marshmallows at the end. Remove those toothpicks. You needed them for correct spacing.
- Join the three licorice/ marshmallow sections together. Push the toothpick into the end of one twist (image on the right indicated by the arrow). Use a toothpick to join the twist together end to end. Be sure that you keep the correct marshmallow sequence in sections 1, 2, and 3.

POWER WORDS
continued from page 21...

- **transcription**: the information in a strand of DNA is copied into a new molecule of messenger RNA (mRNA)
- **translation**: sequence of **nucleotide** triplets in a messenger RNA; gives rise to a specific sequence of amino acids during synthesis of a protein
- **wildtype**: a gene that functions normally



DNA (modeled with red licorice) "unzipped" for transcribing mRNA (modeled with black licorice).

mRNA transcribed from the above DNA sequence.

DNA "unzipped" strand not being transcribed. After transcription, it will hydrogen bond with the complementary DNA strand again.

RNA Marshmallow Color Code

Adenine (A) = orange (O) pairs with Uracil (U) = white (W) in RNA
Uracil (U) = white (W) pairs with Adenine (A) = orange (O) in RNA
Guanine (G) = green (G) pairs with Cytosine (C) = pink (P) in DNA & RNA
Cytosine (C) = pink (P) pairs with Guanine (G) = green (G) in DNA & RNA

DNA Marshmallow Color Code on page 4

Your model should look like the image below "Model Marshmallow mRNA."

Synthesizing a Protein

- On your paper model of the mRNA (black licorice), group the **nitrogen bases** in threes, called **codons**, with a pen or pencil. For example: UAC | CAC | GUG | GAC...
- Print page 25 and cut apart each of the 14 Transfer RNA (tRNA) boxes. Each tRNA **codons** (three **nitrogen bases**) holds one amino acid. The different sequence of the three **nitrogen bases** is specific for the amino acid.
- You need 21 toothpicks and 3 red licorice twists. Cut the toothpicks in half. Cut each licorice twist into 5 equal pieces. You will have 15 licorice twist pieces. You only need 14 pieces. Set one licorice piece aside (or you could eat it…)

- Evenly space 3 half toothpicks on each of the red licorice twist pieces, and push them into the twist.
- Use the paper tRNA template for the color marshmallow sequence. Each color marshmallow represents a different **nitrogen base** (Adenine is orange, Thymine is yellow, Guanine is green, and Uracil is white—see green box to the right). Place the marshmallow / licorice model tRNA on the paper tRNA and set aside.
- **Complementary** pair tRNA's three **nitrogen bases** with the mRNA's **codon** (three **nitrogen bases**). See #2 image below for the **complementary** pairs between tRNA and mRNA.
- Tape the 14 tRNA boxes together in the correct sequence. You will need them for the next activity.

Note: The final protein will not include the "start" and "stop" **codons**.

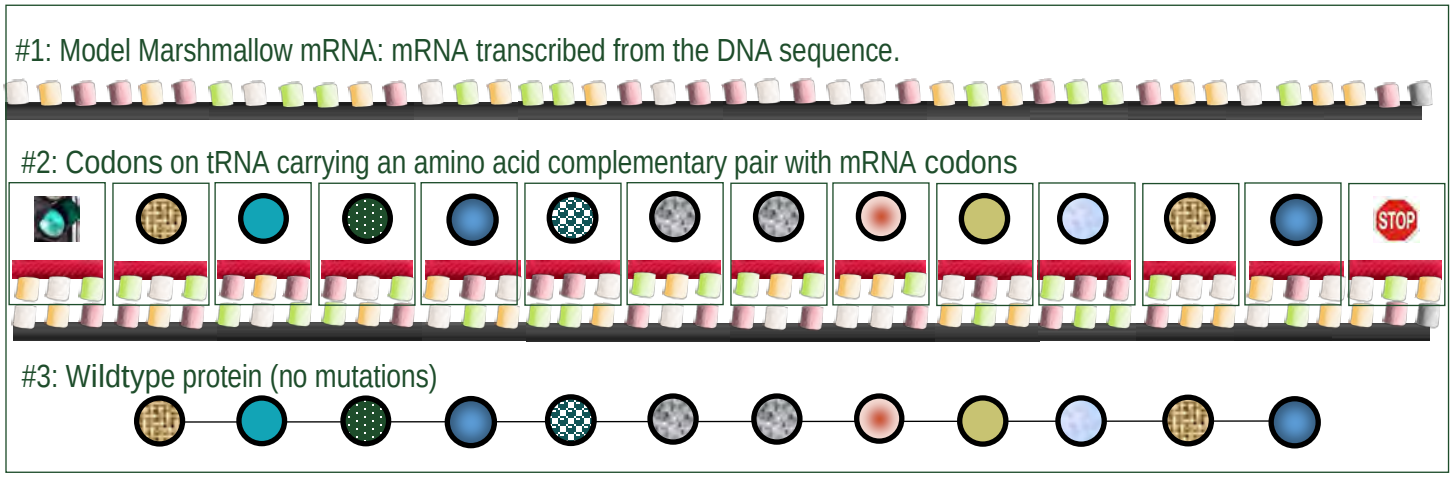
POWER WORDS

Science vocabulary is confusing. Molecular biology (DNA and RNA) is hard to grasp. Some interchangeable terms:

- **nitrogen base**
- **nitrogenous base**
- **nucleobase**

They all are terms for the molecules Adenine, Thymine, Uracil, Guanine and Cytosine. Each of these molecules contain a nitrogen atom.

Each molecule bonds with a sugar molecule and a phosphate chain. The nucleobase with their sugar molecule are called **nucleosides**. When the phosphate chain is added, they are called **nucleotides**. Wow!

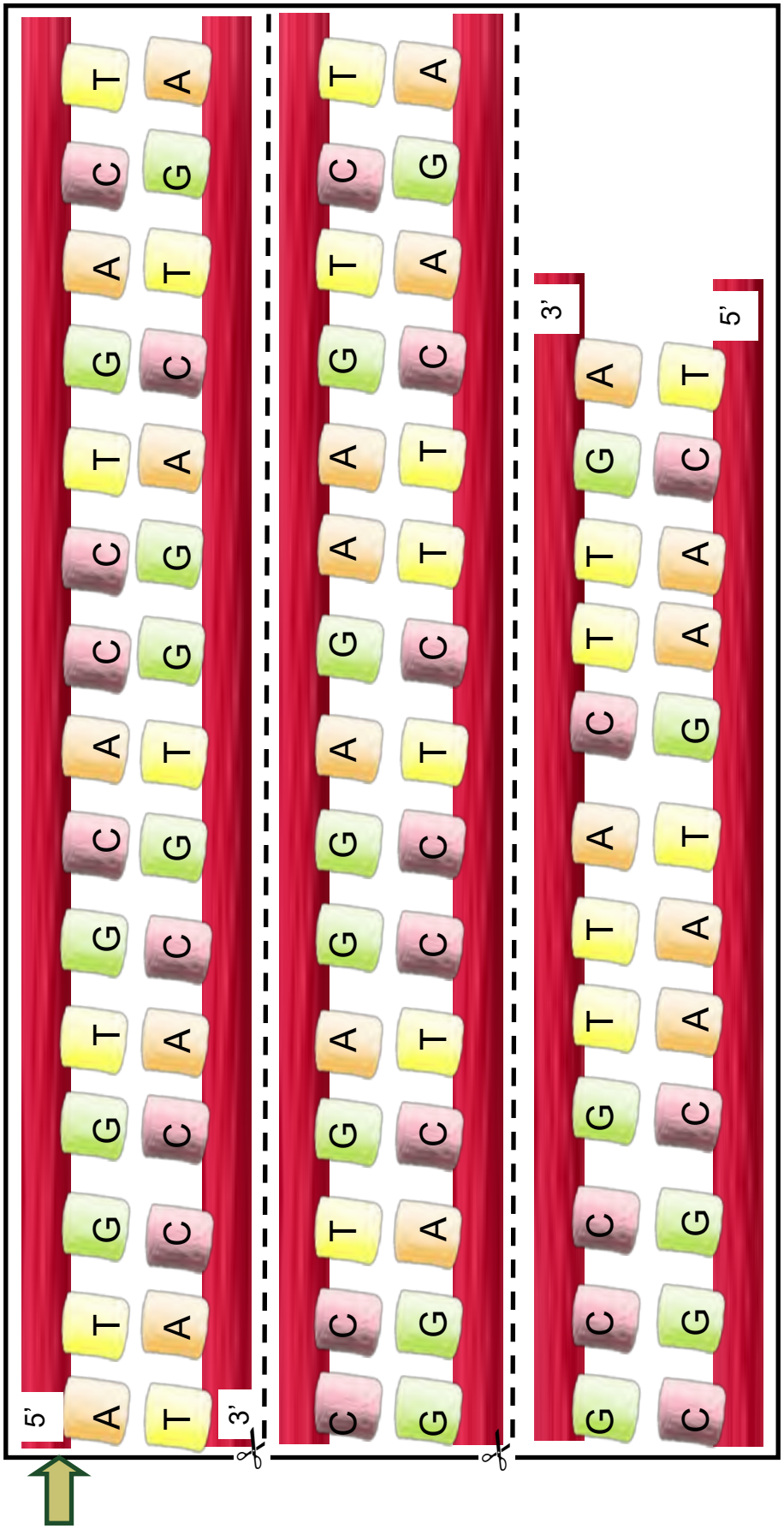


RNA Marshmallow Color Code

Adenine (A) = orange (O) pairs with Uracil (U) = white (W) in RNA
Uracil (U) = white (W) pairs with Adenine (A) = orange (O) in RNA
Guanine (G) = green (G) pairs with Cytosine (C) = pink (P) in DNA & RNA
Cytosine (C) = pink (P) pairs with Guanine (G) = green (G) in DNA & RNA

DNA Marshmallow Color Code on page 4

DNA



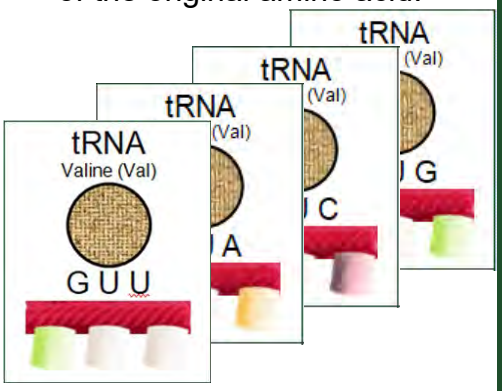
mRNA original sequence

tRNA Start—Methionine (Met)  A U G	tRNA Valine (Val) G U G	tRNA Histidine (His) C A C	tRNA Leucine (Leu) C U G
tRNA Threonine (Thr) A C U	tRNA Proline (Pro) C C U	tRNA Glutamic Acid (Glu) G A G	tRNA Glutamic Acid (Glu) G A G
tRNA Lysine (Lys) A A G	tRNA Serine (Ser) U C U	tRNA Alanine (Ala) G C C	tRNA Valine (Val) G U U
tRNA Threonine (Thr) A C U	tRNA STOP  U G A		

There are a total of 64 **codon** combinations of **nitrogen bases**. There are 4 nitrogen bases available for tRNA (Adenine, Uracil, Guanine, and Cytosine). **Codons** are in groups of 3. That means, 64 different combinations (see pages 27-30 for all 64). There are a total of 22 amino acids. Two amino acids are incorporated with special translation mechanisms. They are not included in this activity. This activity focuses on the 20 common amino acids in humans.

Directions:

- Lay out your tRNA sequence with amino acids for the wild-type protein you built in the last activity (image #1).
- Print pages 27-30, and cut out the 64 different combinations of **codons**.
- Find all the matching amino acids for each tRNA in the **Wildtype** protein. Stack the matching tRNA boxes on top of the original amino acid.

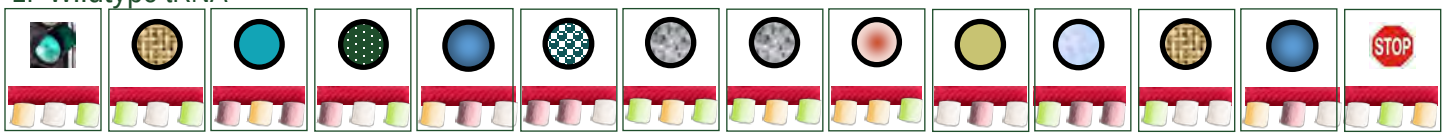


- You will <u>not</u> use all the 64 tRNA boxes.
- When you have found all the matching amino acids, complete the datasheet.
- Examine your datasheet. (pages 31-32), and analyze the results by answering questions on page 32.

POWER WORDS

- **allele**: different form of the same gene; for example, red blood cells have 4 **alleles**: A, B, AB, and O (the red blood cells function the same, carrying oxygen to the cells in the body)
- **reproductive cells**: eggs and sperm; each mature **reproductive cell** contains half the usual DNA amount

1. Wildtype tRNA



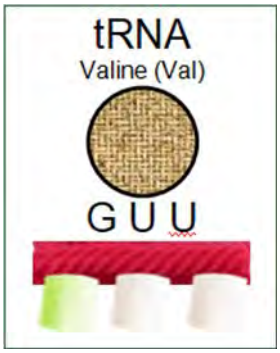
2. Wildtype mRNA

3. Wildtype DNA

5' 3'

3' 5'

- Each tRNA includes the name of the amino acid (e.g. Valine), the abbreviation (Val), a symbol for that amino acid ( ), the **codon** (GUU), and the marshmallow model of the **codon**.



MATERIALS

- print pages 27-30 single sided
- print pages 31-32 double sided
- scissors
- pencil

tRNA Phenylalanine (Phe) U U U	tRNA Phenylalanine (Phe) U U C	tRNA Leucine (Leu) U U A	tRNA Leucine (Leu) U U G
tRNA Serine (Ser) U C U	tRNA Serine (Ser) U C C	tRNA Serine (Ser) U C A	tRNA Serine (Ser) U C G
tRNA Tyrosine (Tyr) U A U	tRNA Tyrosine (Tyr) U A C	tRNA STOP U A A	tRNA STOP U A G
tRNA Cysteine (Cys) U G U	tRNA Cysteine (Cys) U G C	tRNA STOP U G A	tRNA Tryptophan (Trp) U G G

tRNA Leucine (Leu) C U U	tRNA Leucine (Leu) C U C	tRNA Leucine (Leu) C U A	tRNA Leucine (Leu) C U G
tRNA Proline (Pro) C C U	tRNA Proline (Pro) C C C	tRNA Proline (Pro) C C A	tRNA Proline (Pro) C C G
tRNA Histidine (His) C A U	tRNA Histidine (His) C A C	tRNA Glutamine (Glu) C A A	tRNA Glutamine (Glu) C A G
tRNA Arginine (Arg) C G U	tRNA Arginine (Arg) C G C	tRNA Arginine (Arg) C G A	tRNA Arginine (Arg) C G G

tRNA Isoleucine (Ile) A U U	tRNA Isoleucine (Ile) A U C	tRNA Isoleucine (Ile) A U A	tRNA Start—Methionine (Met)  A U G
tRNA Threonine (Thr) A C U	tRNA Threonine (Thr) A C C	tRNA Threonine (Thr) A C A	tRNA Threonine (Thr) A C G
tRNA Asparagine (Asn) A A U	tRNA Asparagine (Asn) A A C	tRNA Lysine (Lys) A A A	tRNA Lysine (Lys) A A G
tRNA Serine (Ser) A G U	tRNA Serine (Ser) A G C	tRNA Arginine (Arg) A G A	tRNA Arginine (Arg) A G G

tRNA Valine (Val) G U U	tRNA Valine (Val) G U C	tRNA Valine (Val) G U A	tRNA Valine (Val) G U G
tRNA Alanine (Ala) G C U	tRNA Alanine (Ala) G C C	tRNA Alanine (Ala) G C A	tRNA Alanine (Ala) G C G
tRNA Aspartic Acid (Asp) G A U	tRNA Aspartic Acid (Asp) G A C	tRNA Glutamic Acid (Glu) G A A	tRNA Glutamic Acid (Glu) G A G
tRNA Glycine (Gly) G G U	tRNA Glycine (Gly) G G C	tRNA Glycine (Gly) G G A	tRNA Glycine (Gly) G G G

How many combinations are there to code for the amino acid:

Wildtype tRNA	Wildtype Codon	Codon / Position	Codon / Position	Codon / Position	# in 1st position	# in 2nd position	# in 3rd position
start example	**AUG (start)**	X / X	X / X	X / X	X	X	X
valine example	**GUG**	GUU / 3rd	GUA / 3rd	GUC / 3rd	0	0	3
histidine	**CAC**						
leucine	**CUG**						
threonine	**ACU**						
proline	**CCU**						
glutamic acid	**GAG**						
glutamic acid	**GAG**						
lysine	**AAG**						
serine	**UCU**						
alanine	**GCC**						
valine	**GUU**						
threonine	**ACU**						
stop	**UGA (stop)**						

Analyze your results:

- How many different **nitrogen bases** are different in the first position of the **codon**?
- How many different **nitrogen bases** are different in the second position of the **codon**?
- How many nitrogen **bases** are different in the third position?
- Which is the most common position change in the amino acid wobble?

Think about this: A mutation occurs on the DNA. It is an error if the mistake occurs during either transcription (making the mRNA) or translation (building the protein). The mistake is expressed in the protein, but it is not a permanent mistake. It becomes permanent only if the error occurs on the DNA.

Think about this: Almost all the cells in your body cannot pass a mutation to the next generation. Offspring (the next generation) can only inherit the mutation if the mistake happens in the **reproductive cells**.

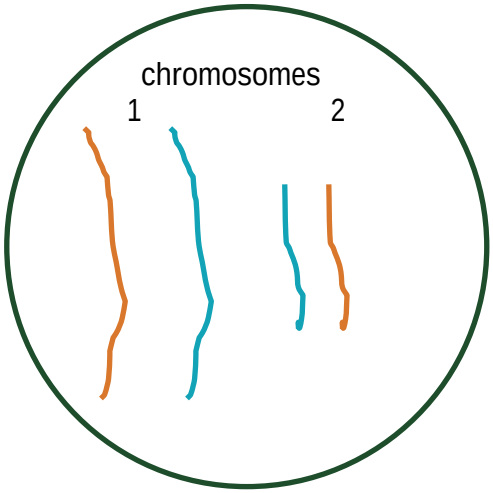
- Looking at the first protein (after "Start"), Valine can have four mistakes in the third position, and the mutation still codes for the same amino acid.
- We have been using a portion of the DNA gene for red blood cells. This section contains the mutation that produces sickle cell anemia. It is a recessive gene. If a child inherits the **wildtype** gene from both parents, there is no change in the blood cells. If a child inherits one sickle cell anemia **allele** (different form of a gene), that child has an advantage in areas where malaria is common. In the presence of the plasmodium (the parasite that causes malaria), the cell will form a sickle shape, and the plasmodium is killed. If the child inherits the sickle cell **allele** from both parents, it is usually fatal.
- Below is the **Wildtype** DNA, mRNA, and tRNA in green. Sickle Cell Anemia has a single **nucleobase** mutation. It changes the amino acid. Small mutation with huge consequences!
- Find and identify the change that occurred in the Mutant DNA, and how that changes the mRNA and tRNA. Record the amino acids that produce sickle cell anemia.

Wildtype DNA	ATG	GTG	CAC	CTG	ACT	CCT	GAG	GAG	AAG	TCT	GCC	GTT	ACT	TGA
Wildtype mRNA	UAC	CAC	GUG	GAC	UGA	GGA	CUC	CUC	UUC	AGA	CGG	CAA	UGA	ACU
Wildtype tRNA	AUG	GUG	CAC	CUG	ACU	CCU	GAG	GAG	AAG	UCU	GCC	GUU	ACU	UGA
Amino Acid	start	Val	His	Leu	Thr	Pro	Glu	Glu	Lys	Ser	Ala	Val	Thr	stop
Mutant DNA	ATG	GTG	CAC	CTG	ACT	CCT	GTG	GAG	AAG	TCT	GCC	GTT	ACT	TGA
Mutant mRNA	UAC	CAC	GUG	GAC	UGA	GGA	CAC	CUC	UUC	AGA	CGG	CAA	UGA	ACU
Mutant tRNA	AUG	GUG	CAC	CUG	ACU	CCU	GUG	GAG	AAG	UCU	GCC	GUU	ACU	UGA
Mutant Amino Acid	start													stop

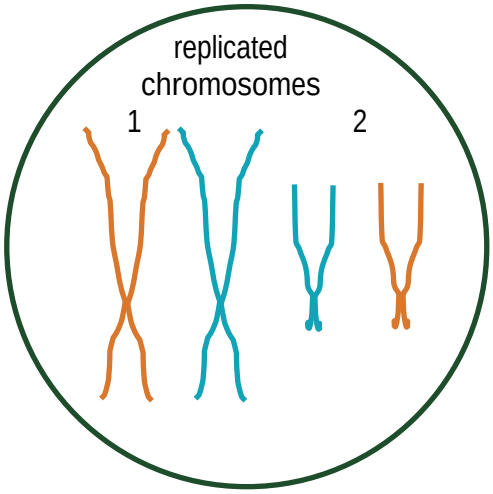
In your own words, explain the Amino Acid Wobble. How is the wobble different than the mutation in Sickle Cell Anemia?

Before doing this next activity, review 58.Paleontology 6: Paleozoic Mitosis https://tra.extension.colostate.edu/stem-k12/stem-resources/

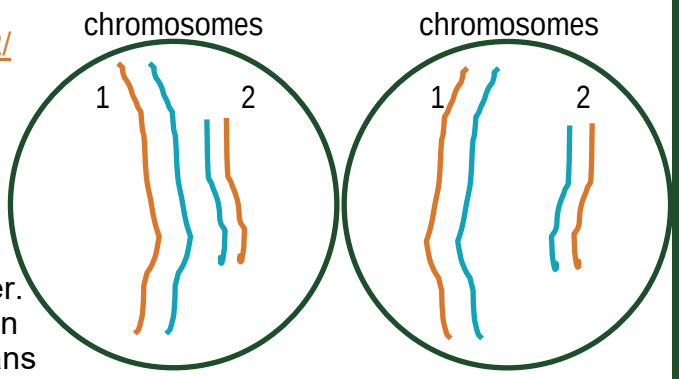
Almost every cell in our body has two pairs of DNA; one set from our mother and the other set from our father. The DNA is organized in **chromosomes**. Humans have a total of 23 pairs of **chromosomes**. These cells are **diploid** cells.



- Orange is the mother's chromosomes
- Blue is the father's chromosomes
- There are two pairs of chromosomes



Mitosis is how our cells divide. The two pairs of **chromosomes** replicate. The cell organizes the



DNA so that the dividing cell each gets the pair of **chromosomes** from each parent.

That is every cell <u>except</u> for **gametes**, the reproductive cells (egg and sperm). They only have one set of **chromosomes** called **haploid** cells. Some of those **chromosomes** are from the mom, and some are from the dad. Which cell gets which **chromosome** is random.

Instead of dividing one time, it divides into two cells, and those two cells divide into four cells.

Directions:

- Watch at least one of these videos on meiosis:
  - https://www.youtube.com/watch?v=7EvtgLLuJpo
  - https://www.youtube.com/watch?v=MNq015d03MU
  - https://www.youtube.com/watch?v=zrKdz93WIVk
  - https://www.youtube.com/watch?v=VzDMG7ke69g
  - https://www.youtube.com/watch?v=nMEyeKQClqI

POWER WORDS

- **chromatid**: one of two threads of DNA containing the double helix of DNA
- **chromosome**: threadlike structure of nucleic acids and protein found in the nucleus of cells, carrying genetic information in of genes
- **crossover**: exchange of genetic material between homologous chromatids
- **diploid**: containing two complete sets of **chromosomes**, one from each parent.
- **gamete**: egg or sperm
- **haploid**: having a single set of unpaired **chromosomes**

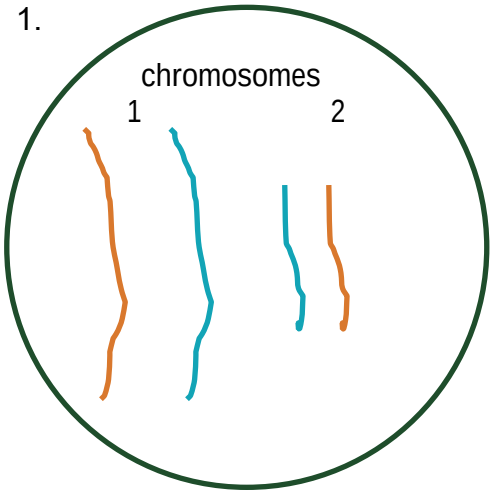
continued on page 34...

MATERIALS

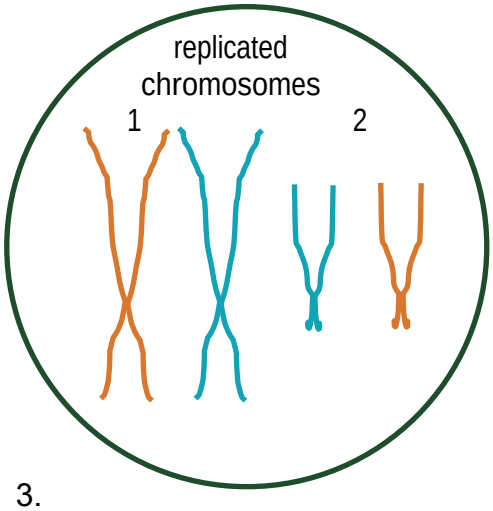
- computer with internet
- parent permission

Meiosis

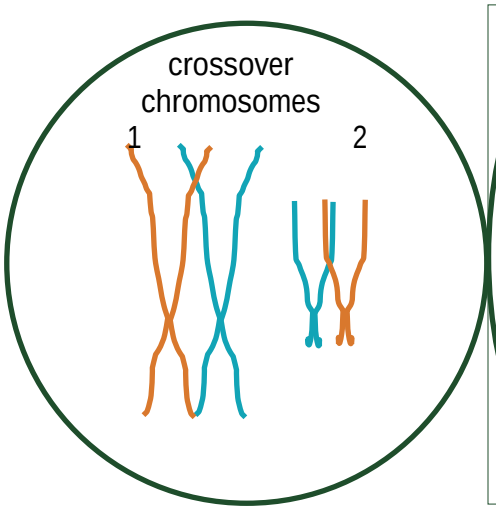
1.



2.
Chromosomes replicate—DNA duplicates an exact copy

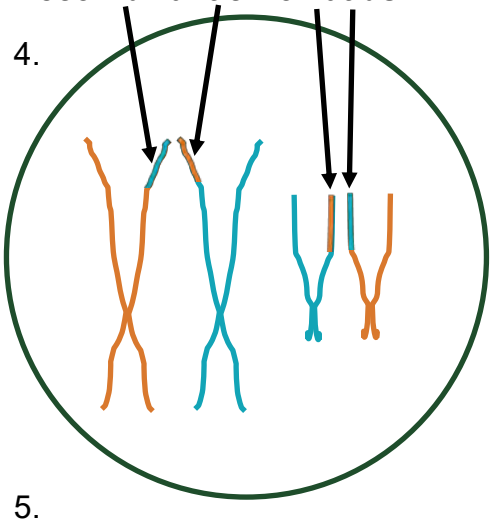


3.
Chromosome crossover—the **homologous chromosomes** randomly swap some genes

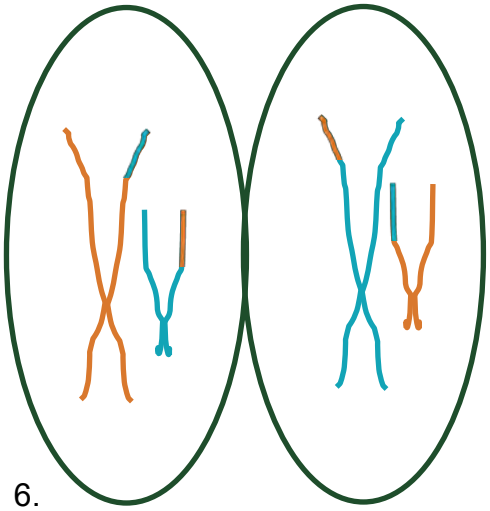


Recombinant chromatids

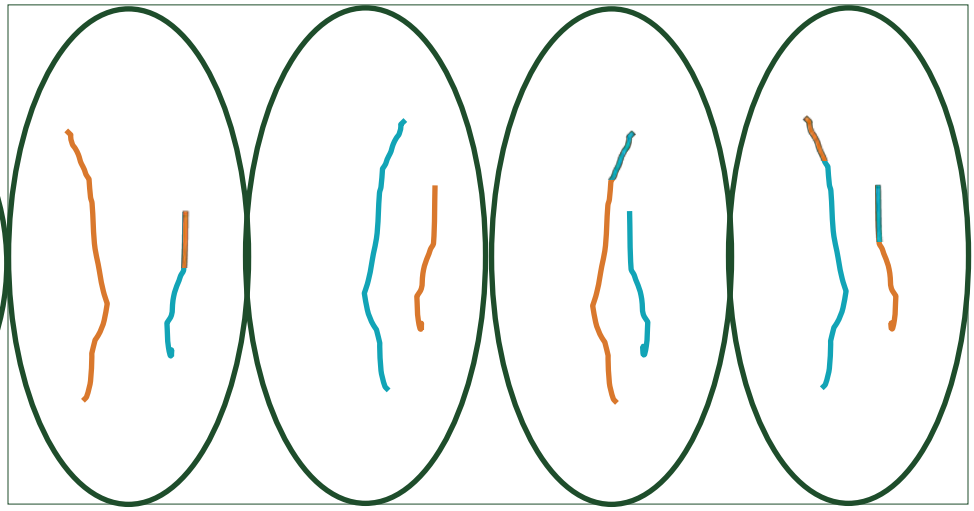
4.



5.
First division randomly separates mom's and dad's **chromosomes** into two cells



6.
Second division—the **replicated** (with **recombinant chromatics**) separate randomly into 4 cells



POWER WORDS
continued from page 33...

- **homologous**: same structural features and pattern of genes
- **meiosis**: **gamete** cell division that results in four daughter cells each with half the number of **chromosomes** of the parent cell, as in the production of **gametes** and plant spores
- **mitosis**: a type of cell division that results in two daughter cells each having the same number and kind of **chromosomes** as the parent nucleus
- **recombinant**: DNA united differently
- **replicate**: make an exact copy of; reproduce

- Crossover: bits of DNA are <u>randomly</u> exchanged between the two homologous chromosomes
- First division: homologous chromosomes <u>randomly</u> separates
- Second division: replicated DNA <u>randomly</u> separates

Sickle Cell Anemia is beneficial when inherited from only one parent, but fatal if inherited from both parents. The benefits (protection from malaria) outweigh the **detriments** (fatal if inherited from both parents).

Mutations are usually **lethal** or **debilitating**. This activity examines a **fatal** gene found in Angus cattle called Neuropathic hydrocephalus, abbreviated as NH. It is a recessive gene. That means the offspring need to inherit the **allele** from both parents for the gene to be **fatal**.

Before you do this activity, review the inheritance activities in 57.Paleontology 5: Speciation, pages 16-20 found here: https://tra.extension.colostate.edu/stem-k12/stem-resources/.

Genes follow certain patterns:

- dominant or recessive (dominant **allele** is **expressed** and recessive **allele** is hidden, like AO blood type, only A is **expressed**, and O is hidden)
- codominant (both **alleles** are **expressed**, like people with blood type AB inherited A from one parent and B from the other parent)
- incomplete dominance (**alleles** blend together, like curly hair and straight hair parents will have a child with wavy hair)
- multiple **genes** influence the **trait** (like the 378 genes that modify skin color in humans!)

Introduction to Punnett Squares: My beloved beagles!

- Molly is a tricolor beagle (dominant—black in coat).
- Sam is a lemon beagle (recessive—no black).

- Molly and Sam are from the same litter of seven puppies. Only two of the puppies are lemon beagles.
- The capital letter represents the dominant **allele**, and the little letter represents the recessive **allele**.
  - T = tricolored with white, red, and black
  - t = white and red only—no black
- Their mother was from a litter of a lemon mother and tri-colored father. Their father's parents were both lemon beagles.
- Inheritance is random. A Punnett square helps to determine the probability of a **Mendelian traits** like a lemon puppy.

POWER WORDS

- **detriment**: a cause of harm or damage
- **gene expression**: the observable effect or **characteristic** attributed to a particular gene
- **genotype**: the total genetic composition of an individual organism
- **lethal**: sufficient to cause death
- **Mendelian trait**: passed down by dominant and recessive **alleles** of one gene
- **phenotype**: the set of observable characteristics of an individual resulting from the interaction of its genotype with the environment

continued from page 36...

Genetics Punnett Square

- What are the chances of a lemon puppy?

		Mom (T/ t)	
		T	t
Dad (t/t)	t	T / t tri-color	t / t lemon
	t	T / t tri-color	t / t lemon

MATERIALS

- lunch-size paper bags
- red and black tempera paint (or markers)
- wite out correction fluid or tape
- paint brushes
- print pages 38-42 single sided
- scissors
- tape
- coin (like a quarter)
- google eyes

- The chances are that two out of every four puppies will be lemon colored. In Molly and Sam's case, it was 2 out of 7 (2 are lemon colored, and 5 are tri-colored). We would actually expect 3 or 4 lemon colored beagles from a litter of seven.

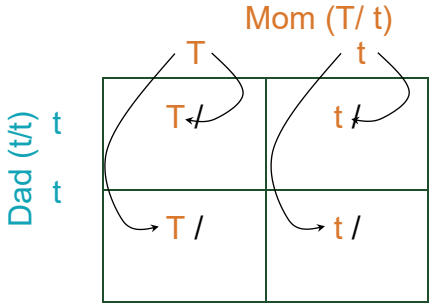
Directions:

- To better understand how inheritance is random, flip a coin 10 times. Record the number of heads and the number of tails on the datasheet (page 38).
- Repeat 10 more times and record.
- Repeat 10 more times and record.
- Repeat 10 more times and record.
- Repeat 10 more times and record.
- Repeat 10 more times and record.
- Repeat 10 more times and record.
- Repeat 10 more times and record.
- Repeat 10 more times and record.
- Repeat 10 more times and record.
- You have flipped the coin a total of 100 times. The more you flip the coin, the closer to half heads and half tails. Each group of ten flips, however, may have very different results. You may get 5 heads and 5 tails, or 2 heads and 8 tails, or just about any other combination in any set of 10.

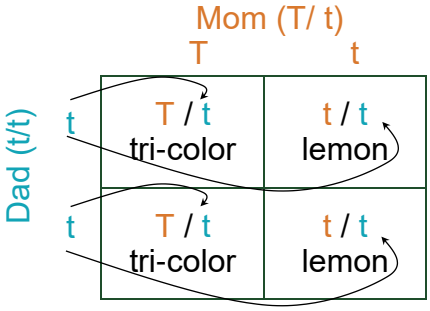
Thanks Brandon Creamer! He is the 4-H Agent in Montrose County. When he was in 4-H, he raised Black Angus for his livestock projects. He reviewed this entire activity to ensure the Black Angus genetics is correct.

Directions:
Punnett Squares

- Geneticists use Punnett squares as a tool to evaluate the probability of a specific **phenotype** (a **characteristic** expressed) based on the **genotype** (the genes inherited from the mother and the father that may carry different **alleles**).
- They are simple to complete. Let's look closer at Molly and Sam, the beagles. Remember the capital letter represents the dominant **allele**, and the little letter represents the recessive **allele**.
  - T = tricolored with white, red, and black
  - t = white and red only—no black



- To complete the Punnett square, simply fill in each parents **genotype**.



- Then determine the phenotype (tri-color or lemon).

POWER WORDS
continued from page 35...

- **probability**: the likelihood that some random event will occur before the actual event occurs
- **random**: made, done, happening, or chosen without method or conscious decision

Consider This:

- Most **characteristics** are not this simple. Our traits are often influenced with many factors, including:
  - more than two **alleles** for a single gene (for example A, B, AB and O blood types)
  - more than a single gene (skin color is influenced by more than 100 genes)
  - environment (for example hydrangeas are blue if soil is basic and pink if acidic)

- Coat Color and NH are both single gene dominant / recessive **alleles**. Remember than an allele is just a different form of the gene (like our red blood cells are A, B, AB, or O—different forms for the same red blood gene). For the purposes of this activity, the **characteristics** are all considered dominant / recessive in simple **Mendelian Inheritance**.
- Offspring can inherit **homozygous** or **heterozygous alleles** from their parents for each set of genes. Wow, those are big science words.
  - homo means same; **homozygous alleles** means that the pair of genes are the same form of the gene (i.e. O type blood and O type blood)
  - hetero means different; **heterozygous alleles** mean that the pair of genes have different forms of the gene (i.e. A type blood and B type blood)
- The parents also randomly inherited alleles from their parents. To simulate that **random assortment**, you will flip the coin. If you flip a heads, that indicates a dominant **allele**. Place a capital letter in the parent's **genotype**. If you flip a tails, that indicates a recessive **trait**. Place a small letter in the parent's genotype.

	Mom (c / C) Genotype	
Dad (c / c) Genotype	c / c red	C / c black
	c / c red	C / c black

- Example for above Punnett square:
  - This coat color gene is identified with the letter "C." If you flip heads, dominant (black), use a capital C. If you flip tails, use a small letter "c" for recessive (red). Start with mom, and fill her **genotype** with the first two flips. The next two flips determine the father's **genotype**.
    - tails—small letter
    - heads—capital letter
    - tails—small letter
    - tails—small letter
- Fill in the 4 squares with all the possible combinations the offspring can inherit.
- Determine the **phenotype**, the expressed coat color.
- Build your four Angus calves using the **traits** in the highlighted box. Each individual has a different highlight color: yellow, blue, pink, and green. At the end, you will have 4 different calves with randomly selected **traits** (yellow **traits** calf, blue **traits** calf, pink **traits** calf, and green **traits** calf). Add google eyes.
- A trait may not appear because selection is random.
- What would happen to a calf with parents "h/h" **homozygous** for NH recessive **allele**?

POWER WORDS

- **heterozygous**: having two different alleles of a particular gene
- **homozygous**: having two identical alleles of a particular gene
- **random assortment**: refers to the way **chromosomes** get organized into **daughter cells** during **gamete** (sperm and egg) formation; each sperm and each egg will have different combinations of **chromosomes**, some of which will have come from the person's mother and others from the father
- **trait**: distinguishing quality or characteristic; genetically determined **characteristic**

	Mom (letter / letter) Genotype	
Dad (letter/letter) Genotype	/	/
	/	/

If you have a calf with the **homozygous genotype** for NH (Neuropathic Hydrocephalus)

"h" "h"

blow up your bag, and smack it with your hand to pop it!

Coin Flips:
Coin flips are random events. The probability each flip is equal for heads or tails. The more flips, the closer to 50% heads and 50% tails. It is the same randomness in inheritance.

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10	Total
Heads											
Tails											

Characteristics: heads, dominant, capital letter … tails, recessive, small letter

Coat Color: C (heads) c (tails)
Heads—Dominant—black
Tails—Recessive—red
Paint the bag with tempera paint. Allow the paint to dry. (If you don't have paint, you can use a black or red marker.

Coat Color

Dad (____/____) Genotype	Mom (____/____) Genotype	
	/	/
	/	/

Nose Pad: N (heads) n (tails)
Heads—Dominant—oval
Tails—Recessive—round
Page 41 has the nose pad template. Cut out the "oval" or "round" nose pad and tape on the face of your calf

Nose Pad

Dad (____/____) Genotype	Mom (____/____) Genotype	
	/	/
	/	/

Ears: E (heads) e (tails)
Heads—Dominant—round
Tails—Recessive—tapered
Pages 39-40 has the ear template. Cut out the "round" or "tapered" ears to add to your calf.

Ears

Dad (____/____) Genotype	Mom (____/____) Genotype	
	/	/
	/	/

Tail Tuff: T (heads) t (tails)
Heads—Dominant—big tuft
Tails—Recessive—small tuft
Page 42 has the tail template. Cut out the "big tuff" or "small tuff and add to your calf on the back of your bag.

Tail Tuff

Dad (____/____) Genotype	Mom (____/____) Genotype	
	/	/
	/	/

White Spots: S (heads) s (tails)
Heads—Dominant—no spots
Tails—Recessive—white spots
Use the wite-out correcting fluid or tape to make 3 or 4 white dots on the belly of your calf below the belly button.

White Spots
(behind belly button)

Dad (____/____) Genotype	Mom (____/____) Genotype	
	/	/
	/	/

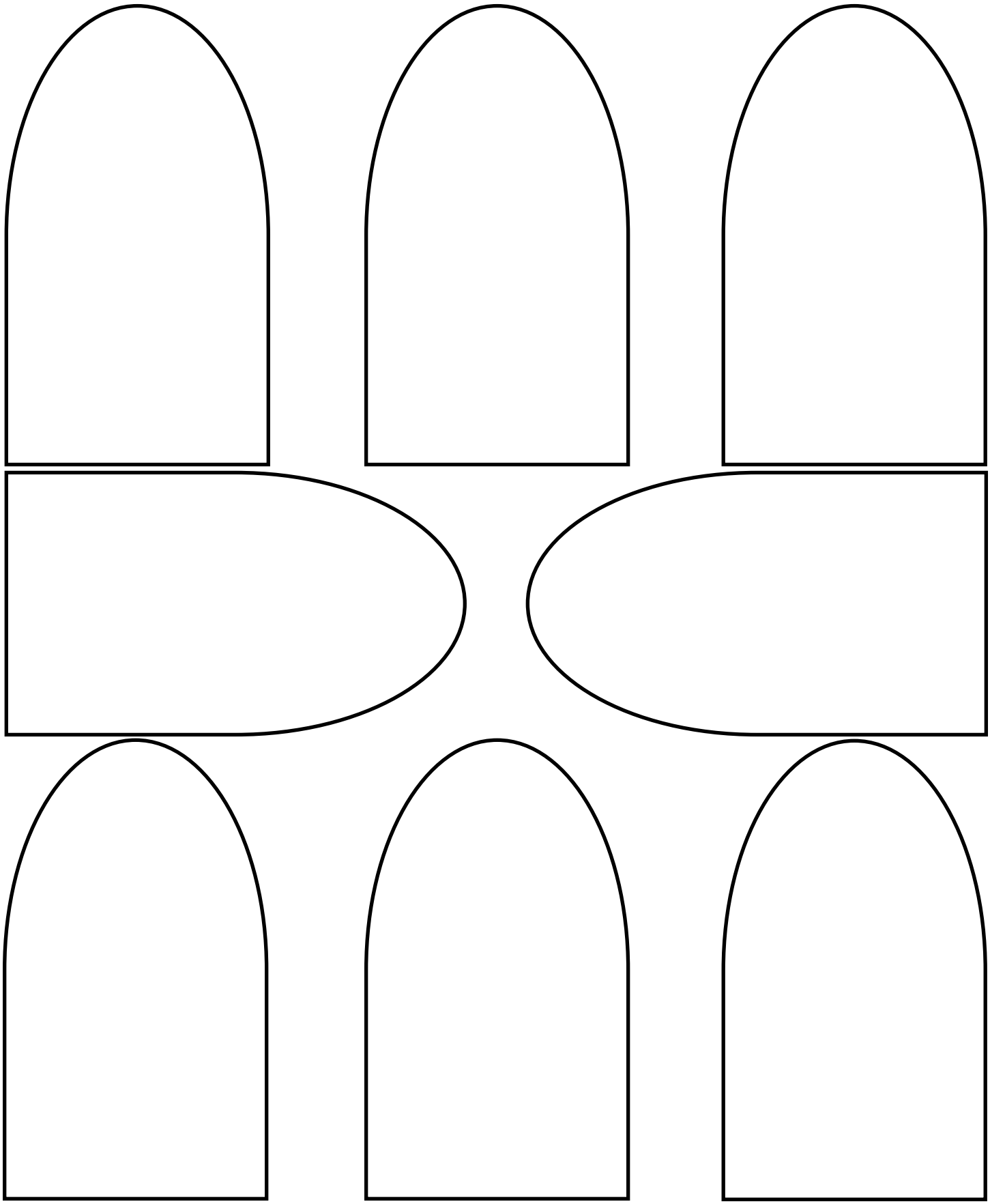
NH: H (heads) h (tails)
Heads—Dominant—not lethal
Tails—Recessive—lethal
If dominant, you have completed your calf!
If recessive, blow up your bag and smack the bag to pop it.

Neuropathic Hydrocephalus (NH)

Dad (____/____) Genotype	Mom (____/____) Genotype	
	/	/
	/	/

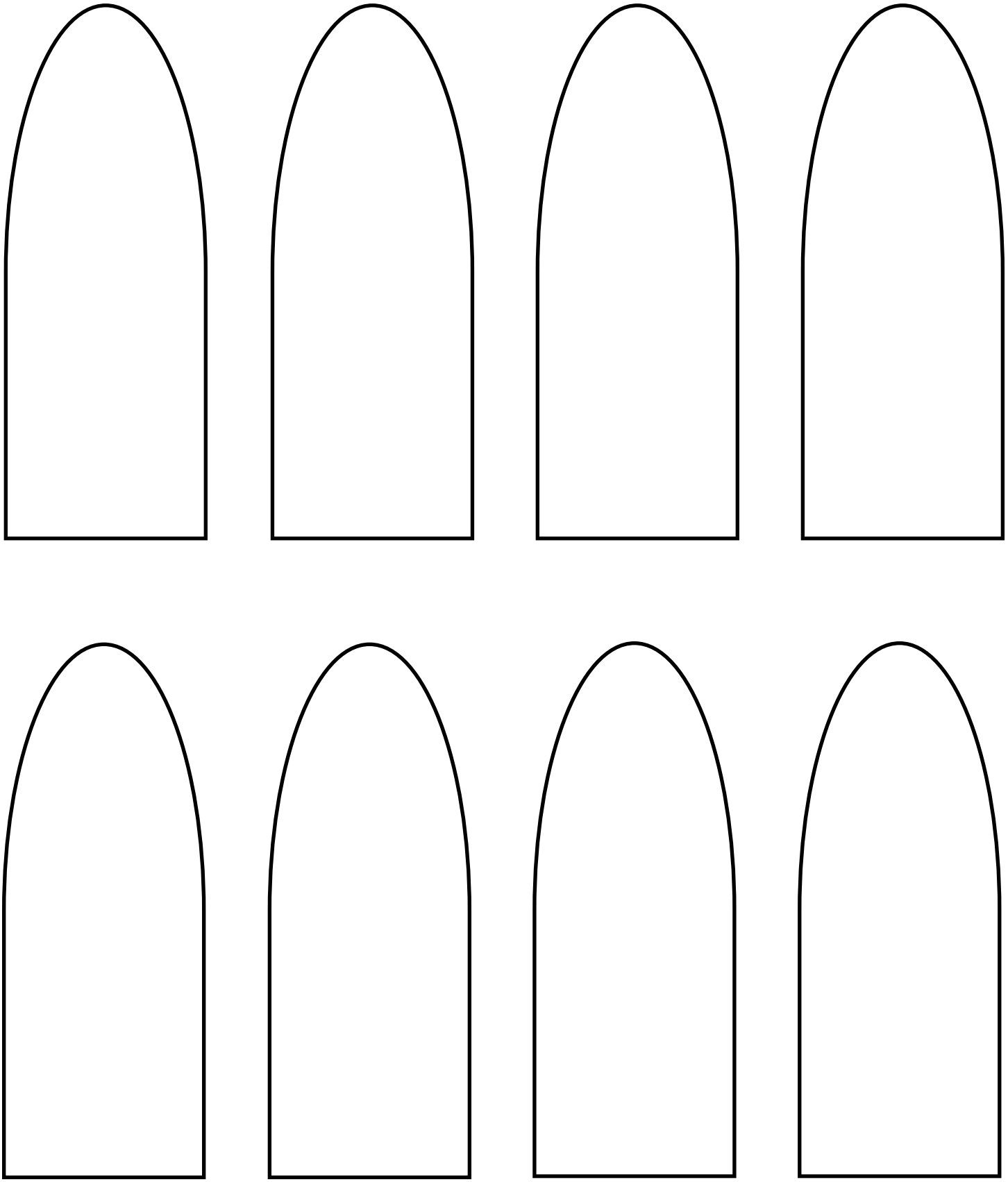
Rounded Ears (Dominant) “E”

Paint your ears the same color as your calf coat color

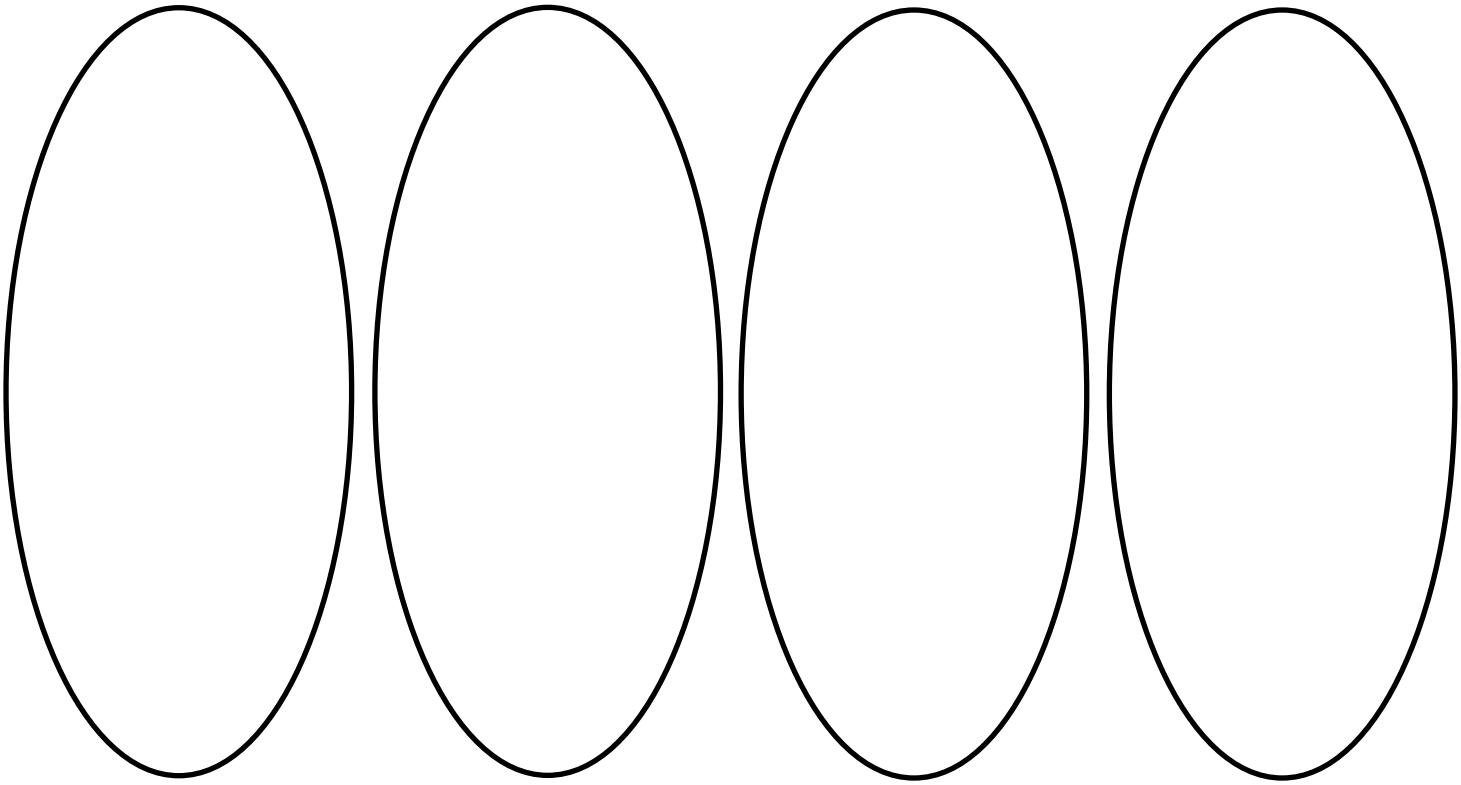


Tapered Ears (recessive) “e”

Paint your ears the same color as your calf coat color

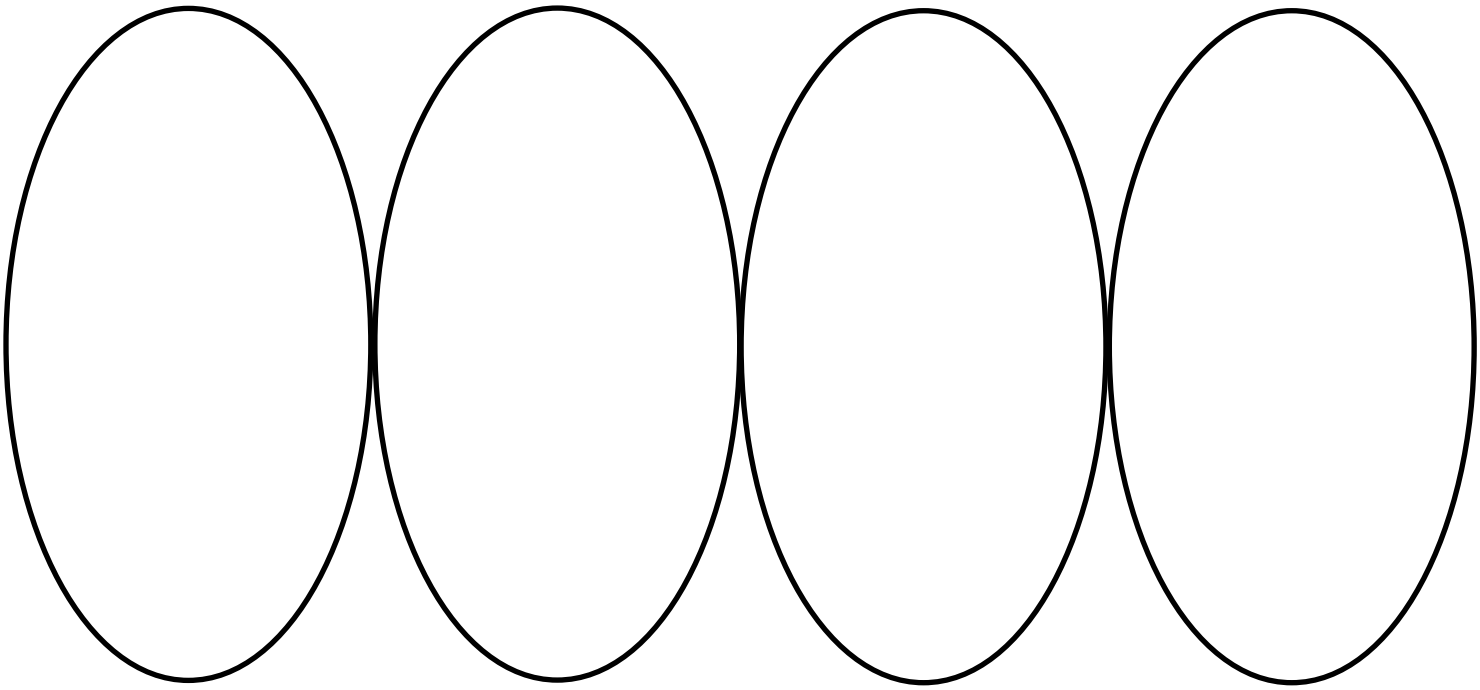


Oval Nose Pad (Dominant) “N”

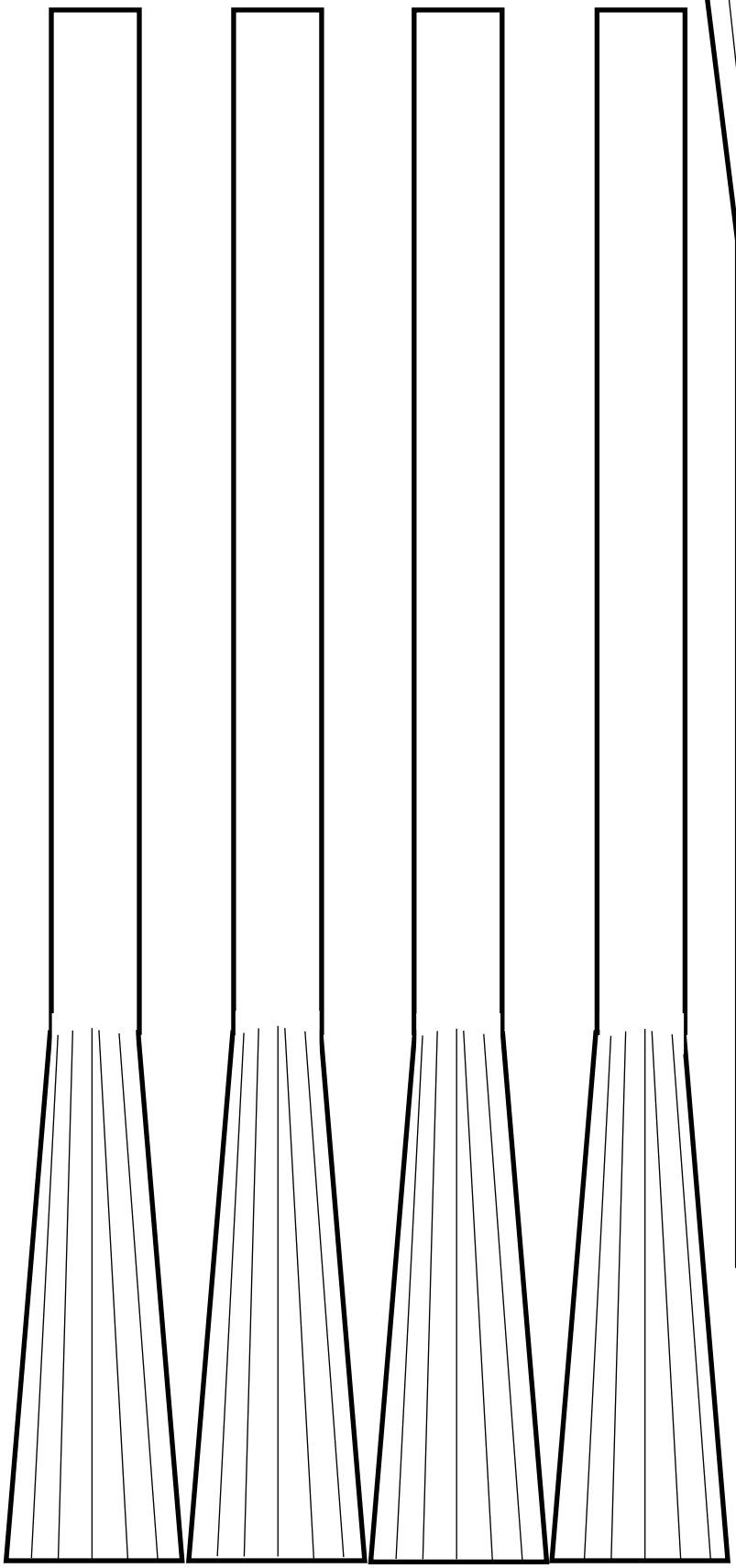


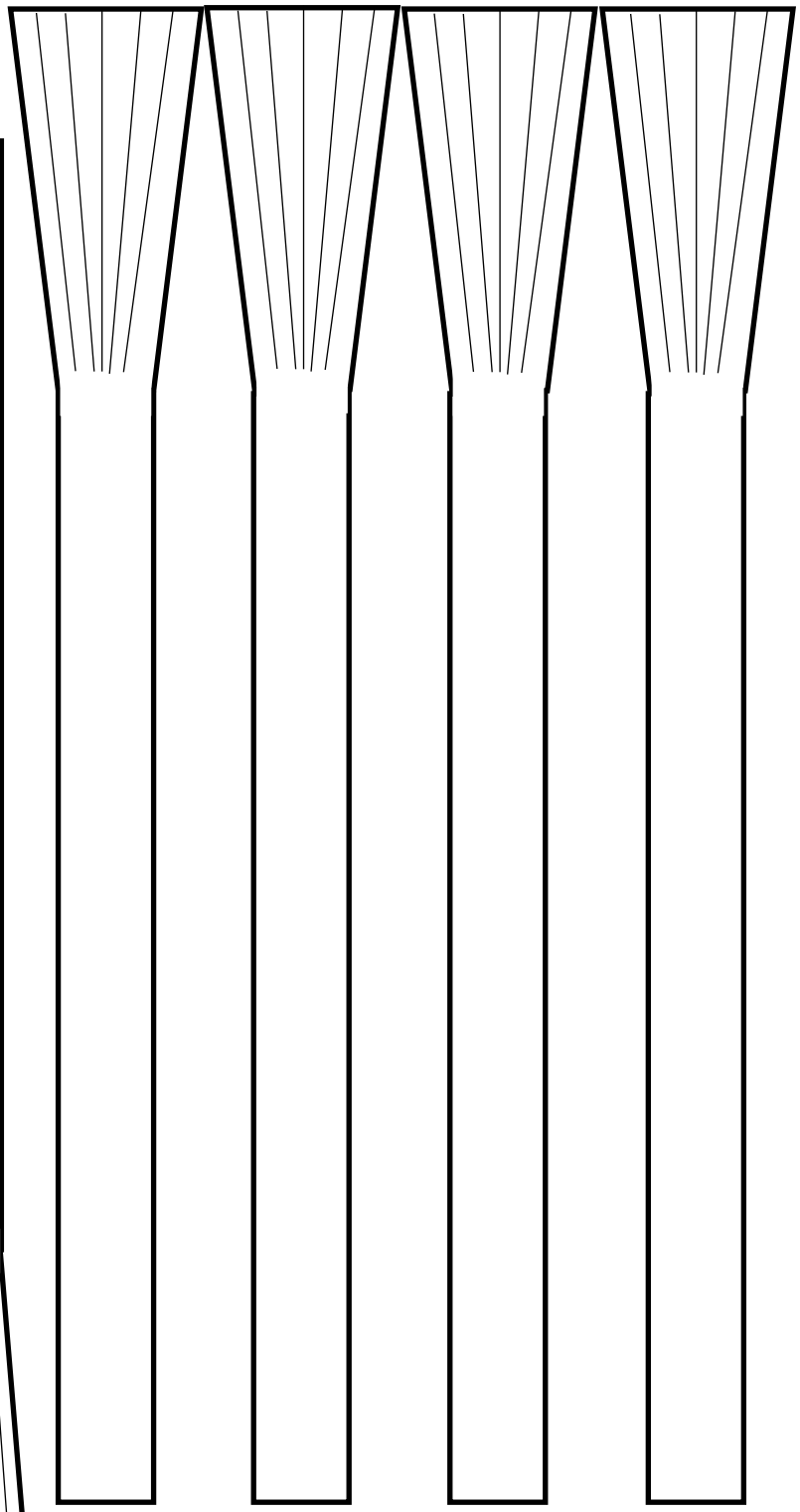
Paint your nose pad the same color as your calf coat color

Round Nose Pad (recessive) “n”



Big Tail Tuff (Dominant) “T”





Small Tail Tuff (recessive) “t”

Paint your tails the same color as your calf coat color

A mutation can have no effect, detrimental effect, or beneficial effect. As we discussed earlier, a mutation will have no effect if it occurs:

- in a section of **junk DNA**
- part of the wobble

Mutations that occur in a section of DNA of an active gene is usually **deleterious** or **fatal**. Occasionally, however, it will be neutral or even provide a benefit. If these neutral or beneficial mutations occur in the **gametes**, they will be passed on to the next generation, and eventually spread through the population.

Remember that speciation happens over a vast amount of time. Review the first issue of this series, 53.Paleontology 1—Introduction, Big Numbers activity on page 2 https://tra.extension.colostate.edu/stem-k12/stem-resources/.

Sickle cell anemia is a **substitution** mutation. The seventh codon in the section we have been using was changed from GAG to GTG. That **substitution** in the second position of the **codon** translates into a different amino acid.

Other types of mutations are:

- **insertion**—when one or more **nucleobases** are added into the DNA, causing the sequence to change
- **deletion**—when one or more **nucleobases** are removed from the DNA, causing the sequence to change

In this activity, you will build a **wildtype** bumblebee from pipe cleaners based on the **wildtype** DNA. You will then build three more bumblebees with a mutation in their DNA. You will then determine which of the three mutations is beneficial, which is neutral, and which is **fatal**.

This is a model of codons using three-letter words:

- **Wildtype**
  The red dog ran
- **Substitution**
  The rod dog ran
- **Insertion**
  The reg ddo gra n
- **Deletion**
  The rdd ogr an

Directions:

- The next six pages contain the instructions to build your pipe cleaner bumblebees.

POWER WORDS

- **deletion**: the loss or excision of a section of genetic code, or its product, from a nucleic acid or protein sequence
- **insertion**: the addition of extra DNA or RNA into a section of genetic material
- **junk DNA**: non-coding DNA; DNA that does not encode proteins, and whose function, if it has one, is not well understood
- **substitution**: the action of replacing nucleobase or section of genetic code with another nucleobase or section of genetic code

Complete the:

- **wildtype** bumblebee
- **substitution** bumblebee
- **insertion** bumblebee
- **deletion** bumblebee

- Then, determine which mutation could be:
  - neutral
  - detrimental
  - beneficial
- Describe what happened.

MATERIALS

- 4 black pipe cleaners
- 5 brown or orange pipe cleaners
- 3 yellow pipe cleaners
- 1 red pipe cleaner
- pencil
- white tissue paper
- school glue
- 8 google eyes
- scissors
- print pages 46-49 (optional)

This activity is adapted from Genome British Columbia Geneskool Lost in Translation

Pictorial Directions for Wildtype Bumblebees:

Twist the black and yellow pipe cleaners at one end—just a bit so they don't fall apart.

Use a pencil. Hold the twisted end against pencil and wrap the pipe cleaners around it.

Wrap the pipe cleaners to the end.

Push the coils together from both ends.

At the end that wasn't twisted, pull the black end out to make a stinger.

On the other end, stick the twisted end into the bee's body.

Pictorial Directions for Wildtype Bumblebees (continued):

Fold the brown pipe cleaner in half, and then in half one more time. Cut at each bend for 4 small pieces. Bend each of the 4 pieces into a “V” shape. Attach 3 of the pipe cleaners about 1/3 from the head for legs

Take a small piece of tissue paper, and twist in the center for the wings.

Attach the wings at the same section as the legs.

Use the remaining two brown pipe cleaners to make antenna. Attach them in front of the wings and legs.

Add the google eyes.

This is the wildtype bumblebee. Each mutation will modify the results of this bee.

Codon	Wildtype Bumblebee Instructions
ATG start	Gather these supplies: 1 black pipe cleaner, 1 brown pipe cleaner, 1 yellow pipe cleaner, tissue paper, pencil, goggle eyes, school glue
GTG	Twist the black and yellow pipe cleaners at one end—just a bit so they don't fall apart.
CAC	Use a pencil. Hold the twisted end against pencil and wrap the pipe cleaners around it.
CTG	Continue to wrap the pipe cleaners to the end.
ACT	Push the coils together from both ends and remove from the pencil.
CCT	At the end that wasn't twisted, pull the black end out to make a stinger.
GAG	On the other end, stick the twisted end into the bee's body to make the face.
GAG	Cut the brown pipe cleaner into 4 equal pieces. Bend each of the 4 pieces into a "V" shape.
AAG	Attach 3 of the pipe cleaners about 1/3 from the head for legs.
TCT	Take a small piece of tissue paper (~4" x 2"), and twist in the center for the wings.
GCC	Attach the wings at the same section as the legs.
CTT	Use the remaining brown pipe cleaner piece to make antennae. Attach it in front of the wings and legs.
ACT	Add the google eyes with the white school glue.
TGA stop	Your completed wildtype bumblebee.

Codon	Substitution Bumblebee Instructions
ATG start	Gather these supplies: 1 black pipe cleaner, 1 brown pipe cleaner, 1 red pipe cleaner, tissue paper, pencil, goggle eyes, school glue
CTG	Twist the black and red pipe cleaners at one end—just a bit so they don't fall apart.
CAC	Use a pencil. Hold the twisted end against pencil and wrap the pipe cleaners around it.
CTG	Continue to wrap the pipe cleaners to the end.
ACT	Push the coils together from both ends and remove from the pencil.
GCT	At the end that wasn't twisted, pull the black end out to make a stinger.
GAG	On the other end, stick the twisted end into the bee's body to make the face.
GAG	Cut the brown pipe cleaner into 4 equal pieces. Bend each of the 4 pieces into a "V" shape.
AAG	Attach 3 of the pipe cleaners about 1/3 from the head for legs
TCT	Take a small piece of tissue paper (~4" x 2"), and twist in the center for the wings.
GCC	Attach the wings at the same section as the legs.
CTT	Use the remaining brown pipe cleaner piece to make antennae. Attach it in front of the wings and legs.
ACT	Add the google eyes.
TGA stop	Your completed substitution bumblebee.

Codon	Insertion Bumblebee Instructions
ATG start	Gather these supplies: 1 black pipe cleaner, 2 brown pipe cleaner, 1 yellow pipe cleaner, tissue paper, pencil, goggle eyes, school glue
GTG	Twist the black and yellow pipe cleaners at one end—just a bit so they don't fall apart.
CAC	Use a pencil. Hold the twisted end against pencil and wrap the pipe cleaners around it.
CTG	Continue to wrap the pipe cleaners to the end.
ACT	Push the coils together from both ends and remove from the pencil.
CCT	At the end that wasn't twisted, pull the black end out to make a stinger.
GAG	On the other end, stick the twisted end into the bee's body to make the face.
GAG	Cut both the brown pipe cleaner into 4 equal pieces (for a total of 8 pieces). Bend 5 of the pieces into a "V" shape.
AAG	Attach 3 of the pipe cleaners about 1/3 from the head for legs.
TCT	Take a small piece of tissue paper (~4" x 2"), and twist in the center for the wings.
GCC	Attach the wings at the same section as the legs.
CTT **CTT**	Use the remaining two brown pipe cleaner pieces. Attach two of the pipe cleaners in front of the wings and legs. (Your bee has 4 antennae.)
ACT	Add the google eyes.
TGA stop	Your completed Insertion bumblebee.

Codon	Deletion Bumblebee Instructions
ATG start	Gather these supplies: 1 black pipe cleaner, 1 brown pipe cleaner, 1 yellow pipe cleaner, tissue paper, pencil, goggle eyes, school glue
GTG	Twist the black and yellow pipe cleaners at one end—just a bit so they don't fall apart.
CAC	Use a pencil. Hold the twisted end against pencil and wrap the pipe cleaners around it.
CTG	Continue to wrap the pipe cleaners to the end.
ACT	Push the coils together from both ends and remove from the pencil.
CCT	At the end that wasn't twisted, pull the black end out to make a stinger.
GAG	On the other end, stick the twisted end into the bee's body to make the face.
GAG	Cut the brown pipe cleaner into 4 equal pieces. Bend each of the 4 pieces into a "V" shape.
AAG	Attach 3 of the pipe cleaners about 1/3 from the head for legs
TCT	Take a small piece of tissue paper (~4" x 2"), and twist in the center for the wings.
- - -	Since this codon was deleted, your bumblebee is wingless (NO WINGS)
CTT	Use the remaining brown pipe cleaner piece to make antennae. Attach it in front of the wings and legs.
ACT	Add the google eyes.
TGA stop	Your completed deletion bumblebee.

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CITATIONS

Information:

- Cenozoic: https://www.nationalgeographic.com/science/prehistoric-world/paleogene/; megafauna public domain https://commons.wikimedia.org/wiki/File:Large_Mammals_Africa_Australia_NAmerica_Madagascar.svg; Geologic Timeline U.S. Geological Survey Geologic Names Committee, 2007, Divisions of geologic time—Major chronostratigraphic and geochronologic units: U.S. Geological Survey Fact Sheet 2007-3015, 2 p. captured on 7/31/2020 https://pubs.usgs.gov/fs/2007/3015/
- Horse Speciation: From McFadden, Bruce. 2005. "Fossil Horses – Evidence of Evolution." *Science* Vol. 307. no. 5716, pp. 1728 – 1730
- Sickle Cell Anemia: https://www.nature.com/scitable/topicpage/genetic-mutation-441/
- DNA / mRNA / tRNA / protein synthesis: https://oerpub.github.io/epubjs-demo-book/content/m46032.xhtml
- Lethal Gene: http://www.angus.org/pub/nh/nhfactsheet.pdf; Dixon, C. (2012) Maaaaastering Genetics. Colorado State University Extension.
- Mutations: Lost in Translation—Bees. Genome British Columbia Geneskool retrieved 4/20/2020 from website https://knowgenetics.org/dna-mutations-2/; https://www.youtube.com/watch?v=FbZBH3-mF90:

Images:

- Maps: Last Ice Age—http://scotese.com/lastice.htm; Latitude / Longitude USA map— https://www.fgdc.gov/usng/educational-resources/USNGInstruct_No1v4_No2_r.pdf
- Terror Birds: Barbara J. Shaw specimen articulated in American Museum of Natural History, New York, NY; Barbara J. Shaw specimen articulated in Museo de La Plata, La Plata, Argentina; https://www.npr.org/templates/story/story.php?storyId=6381194
- Cenozoic dioramas: https://en.wikipedia.org/wiki/Cretaceous%E2%80%93Paleogene_boundary
- Making dioramas: https://www.dummies.com/crafts/holiday-crafts/christmas-crafts-for-kids-shoebox-diorama-with-peephole/; https://lifestyle.howstuffworks.com/crafts/nature-crafts/nature-craft-projects-for-kids7.htmK-Pg Boundary: https://en.wikipedia.org/wiki/Cretaceous%E2%80%93Paleogene_boundary
- Ground sloth diorama: Macbride Hall University of Iowa, Iowa City, IA captured 7/24/2020 from https://now.uiowa.edu/2013/04/get-knowrusty-giant-sloth
- Finish the Timeline: Barbara J. Shaw images from AMNH and Museo de La Plata; *Paraceratherium transouralicum painting* https://commons.wikimedia.org/wiki/File:Paraceratherium_transouralicum.jpg; Horse Speciation From McFadden, Bruce. 2005. "Fossil Horses – Evidence of Evolution." *Science* Vol. 307. no. 5716, pp. 1728 – 1730.
- RNA / Amino Acid Chart: https://students.ga.desire2learn.com/d2l/lor/viewer/viewFile.d2lfile/1798/12708/dna-rna13.html
- Sickle Cell mutation: Laurentino, M.R., Parente Filho, S.L.A., Parente, L.L.C. *et al.* Non-invasive urinary biomarkers of renal function in sickle cell disease: an overview. *Ann Hematol* 98, 2653–2660 (2019).
- Winky Face: https://www.energylivenews.com/2014/06/30/smiley-face-emoticons-save-people-energy/
- Blow up a paper bag: https://vk.am/wp-content/uploads/2018/04/21533060-39114060-3-0-1522418468-1522418489-1500-1-1522418489-650-6f9081b3ae-1522945909.jpg
- Bumblebees: https://www.youtube.com/watch?v=FbZBH3-mF90 ; https://klaraluna.wordpress.com/tag/pipe-cleaner-bee/