Virtual SKIES

Aeronautics

teacher guide

Activity I: Evolution of Flight

Well before humans invented flying machines, animals flew through the air. When man dreamed of flying, he dreamed of having wings, feathers, or flaps. Most flying machines are based on natural flying animals. Even today, scientists look to nature to come up with ways to innovate existing flying machines, or invent new ones.

Part A - What do you already know about flight?

1. Name 3 invertebrate flying animals.

____

____

____

2. Name 3 vertebrate flying animals.

____

____

____

3. Do you know of any flying plants?

4. What is flight? Describe flight as clearly as possible, in terms that an average adult could understand. You might mention the kinds of movements in flight, directions of movement, tools or appendages required, etc.

5. How is man-made flight similar and different from natural flight? What do you think scientists used as "model flyers" to design the first flying structures (that were able to fly or not)? You might think about legends, stories, and the history of flight.

NASA

Part B - Vertebrate Flight

Use the information on http://www.ucmp.berkeley.edu/vertebrates/flight/enter.html to answer the following questions about flight.

1. What are the 4 generalized levels of motion?
   a) __parachuting____________________
   b) __gliding_________________________
   c) __flying__________________________
   d) __soaring_________________________

2. a) __Parachuting_____________ is defined by the angle between the ground and the path of descent. How big does this angle have to be? ***AT LEAST*** / LESS THAN __45_______ degrees.

   b) Draw 2 pictures of something descending with some form of p________. The first picture should be "not p__________" and the second should be "p_________" based on the definition above. Be specific by labeling your figure.

   c) What non-human thing uses this level of motion?

   Plants to disperse seeds

   d) What factors affect the falling speed of a p_____________ ? Explain in words and draw 2 pictures to defend your explanation. One picture should be of a fast p_____________, and the second should be of a slow p____________. Label your drawing to show how drag and surface area are related to p____________.

3. a) ___Gliding_______________ is defined by the angle between the ground and the path of descent. This angle has to be AT LEAST / ***LESS THAN*** __45_______ degrees.

   b) Draw 2 pictures to show what "not g___________" and "g_____________" are. Label your pictures.

   c) This level of motion works by having an airfoil design that generates ___lift________. It is very important that this design be __streamlined___ in order to keep drag to a minimum.

4. a) Flight____________ is very explicitly defined at this web site. What is f__________ and why are the 2 other levels above not considered to be f____________?

Flight involves flapping wings; parachuting and gliding do not involve this. Flyers can move horizontally and ascend at a steady speed, which only occurs in parachuters and gliders if wind gusts (pushing up) occur.

b) By this definition, is the movement done by an airplane considered f____________? No

c) Flapping wings provides __thrust__________ which increases speed.

d) This level of motion evolved 3 times in vertebrates. What were the three animals it evolved in?
   a. ___pterosaurs________________
   b. __birds___________________________
   c. ___bats_______________________

5. a) Soaring_______________________ uses wind currents or thermals to keep an animal at a constant altitude.

b) This is considered to be the most advanced level of motion, for a variety of reasons. One of the main reasons is because it is very energy efficient, meaning few calories are used to remain in the air for a period of time or over a period of distance. Explain, using a specific example, why you might consider this to be the "most advanced" in terms of efficiency.

In soaring, you don't have to use muscle groups to flap wings and stay aloft. Gliding, Parachuting, and Soaring all use fewer muscles to stay in air. However, Soaring and Flying are the only means of staying at the same altitude for an extended period of time. Gliding and Parachuting result in the animal descending constantly. Specific examples will vary.

c) Why might you consider this to be the most advanced in terms of evolutionary history. Hint: Think about how this trait would appear in evolutionary history if it was an ancestral trait versus a newly evolved trait.

The web site explains that there are only a few soarers in the evolutionary record - pterosaurs and some modern birds. It also states that only larger creatures have the ability to soar. If the trait were to be ancestral, it would be more likely to be seen throughout birds and other flying creatures, as well as in all sizes.

* One might argue that this trait is ancestral, but was “lost” through the record, because of physical limitations to soaring (size). It is notable that all flying birds have the ability to soar when they reach a certain size, but most do not display this ability, because they are of a smaller size.

6. a) Although air is not water, air is __fluid________, just like water is. The force needed to deform a __fluid________ is dependent upon how fast the __fluid________ is deformed. In other words, the force needed to move the air is dependent on how fast the air is moved.

For instance, think about running in water (like you might do, in a pool). If you were running very slowly (walking) in the pool, you would notice that you would need to use more force to move your legs than you would if you were walking outside the pool. Think also about the kind of effort you must use to run even faster in the pool.

b) As you move faster in the pool, you must use ***MORE*** / LESS force.

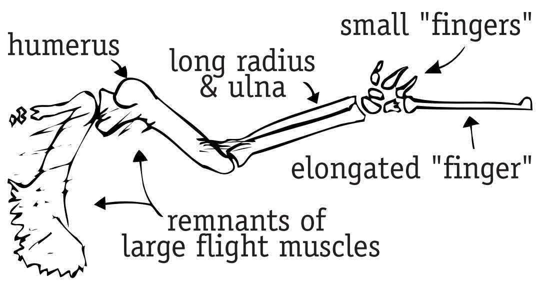
c) Draw a picture of yourself walking or running forward through a pool, to help illustrate the following components of flight. Include labels and arrows to show directions of force. Include the terms : drag, lift, thrust, and weight.

d) When is drag useful? Provide an example.

Students might mention stopping or slowing down.

7. As a paleontologist, you discover parts of five different animal skeletons and would like to know if they are Gliders or Fliers. Use the following pictures to make your decisions.

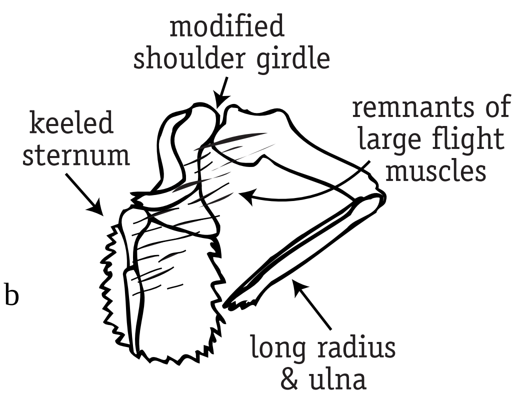
a



DORSAL VIEW

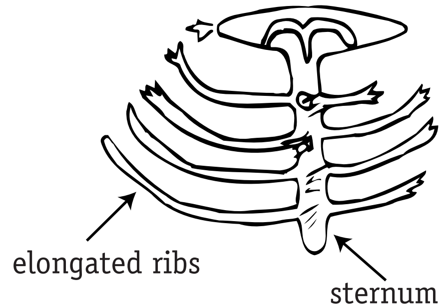
Key: Sample a. Dorsal view showing large flight muscles, elongated distal wing, long forearm, small hands

b



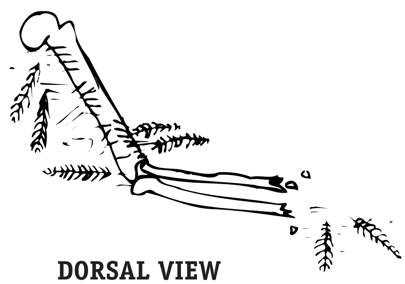
VENTRAL VIEW

Key: Sample b. Ventral view with folded wing showing large flight muscles, keeled sternum, humerus, modified shoulder girdle, longer forearm length c



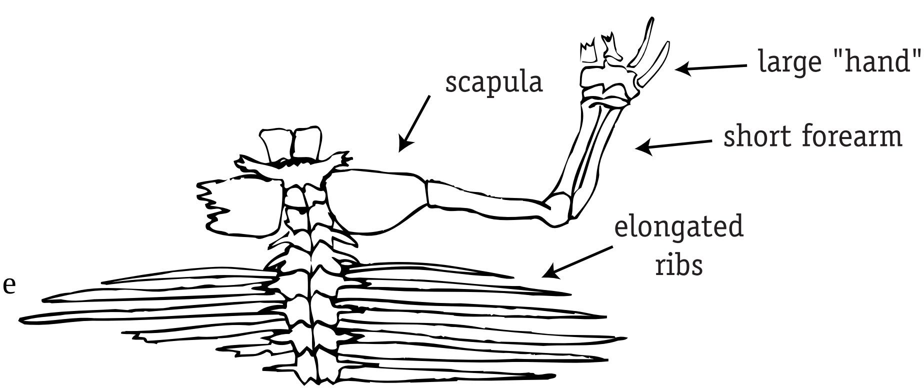
Key: Sample c. Ventral picture with part of wing broken off, elongated ribs

d



Key: Sample d. Dorsal picture with part of wing broken off, feathers

e



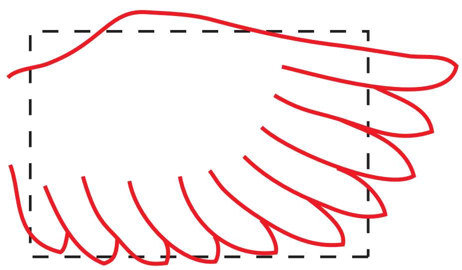
Key: Sample e. Dorsal picture with shorter forearm, larger hands, front appendages AND wings

The following are characteristics of Gliders and Flyers (information to assist in teaching material or grading this question).

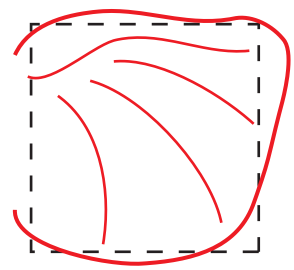
Characteristic	Glider	Flyer
Flight Muscles	small	large
Distal Wing	not elongated	elongated
Keeled sternum		yes
Humerus	yes	
Modified Shoulder Girdle		yes
Forearm Length	shorter	longer
Size of hands exterior to wing	larger	smaller (reduced)
Wing used for…	flight, jumping, climbing	limited to flight use
Structural elements to stiffen wing		yes (feathers, fibers in pterosaurs, fingers in bats)
Elongated ribs	yes (support gliding membrane)	
Aspect ratio	lower	higher
Maneuverability	lower	higher

8. How could one use aspect ratio to determine if the animal is a glider or flier? What would this look like?

Aspect ratio refers to the ratio between wing length and wing breadth. Gliders have lower aspect ratio, while fliers have higher aspect ratio. This means that flyer wings are long or thin, while glider wings are short or fat.



Flier Wing
length = 3 units
width= 2 units
Aspect Ratio = 3/2 = 1.5



Glider Wing
length = 2 units
width= 2 units
Aspect Ratio = 2/2 = 1

9. If you were to observe 2 animals that you knew could move through the air using gliding or flying, but could not watch them doing either action, how might their behaviors on land indicate which type of animal each is?

Gliders often use their wings to jump and climb, while fliers use their wings only for flying.

Activity I: Evolution of Flight

10. Use the web site and any extra information (encyclopedia, other on-line sources, etc.) to a) find a common name, b) categorize into a lay-man's-termed group, c) categorize as a type of mover, d) identify a notable trait associated with its movement type, and e) sketch a picture of the type of animal.

Answers may vary.

Organism	Common Name	Type of Animal	Glider, Parachuter, Soarer, or Flyer?	Trait that defines it as a g./p./s./f.
1. *Draco volans*	flying dragon	lizard	glider	elongated ribs
2.*Cynocephalus volans*	flying lemur	mammal (close to bats; not a lemur)	glider	elongated ribs and forearms
3. *Exocoetidae* family	flying fish	fish	glider	large pectoral fins (low aspect ratio)
4. *Rhacophorus pardalis*	arboreal frog	frog	glider & parachuter	large toe membranes
5. *Thoracocharax* sp.	Hatchet-fish	fish	glider	large pectoral fins
6. *Glaucomys volans*	Flying Squirrel	Mammal (rodent)	glider	span of tissue btwn all appendages
7. *Sturnus vulgaris*	Starling	Bird	flyer	all bird traits
8. Charadriiformes (Order)	Sea Gull	Bird	soarer, flyer	all bird traits

Activity I: Evolution of Flight

11. How did flight evolve? The web site provides a 4-step plan for determining this. Describe each step in your own words.

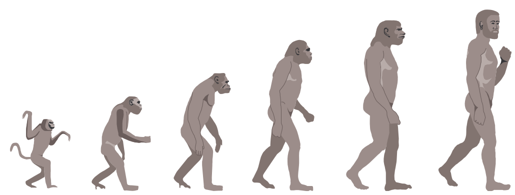
The answers below are verbatim from the source - students should have answers in their own words!
1. Understand the phylogeny of the group; what its origins were
2. Understand the functional morphology relevant to flight, and how that changed from the nonflying ancestor to the earliest flyer
3. Accumulate empirical evidence explaining how flight evolved, using such tools as aerodynamic analysis, ichnology (study of fossilized tracks), and paleoenvironmental assessments
4. Formulate an evolutionary hypothesis proposing why flight evolved in that lineage, supported by and consistent with all of the evidence from the previous 3 steps

12. It is thought that wings must have been exadaptations, or adaptations that are "co-opted from a previous use to a new use." What might have been the previous use for wings? List your best 5 ideas. Hint: Think of animals with large structures that appear like wings (rabbit's large ears, for example). Also think about some of our special gliders and parachutists!

1. ____________________
2. ____________________
3. ____________________
4. ____________________
5. ____________________

Some ideas from the reading include:
1) Wings evolved from arms used to catch prey in (like a catcher's glove or net).
2) Wings evolved from legs or arms used to keep an animal up, when leaping in air (wing is extension of arm or leg).
3) Wings were sexual display structures; bigger wings preferred by potential mates.
4) Wings evolved from gliding structures in gliding ancestors who may have benefitted from flapping them to produce thrust.

13. The scientists cited in this web site prefer 2 theories to explain how flight evolved. Use a series of cartoon frames to illustrate how flight is hypothesized to have evolved. Your cartoon should be like that below, showing gradual change over time. Be sure to include important "props" or environmental features in the background (for instance, trees) if they are important.



First Hypothesis:
Add more frames on another paper if needed.

Answer: Ground-Up Scenario: the ancestor was bipedal and running, with arms free for use as wings. There were no trees around, so to take off, running increased to takeoff speed and flapping wings allowed takeoff to occur.

Second Hypothesis:
Add more frames on another paper if needed.

Answer: Trees-Down Scenario: the ancestor was arboreal and leapt from branch to branch, perhaps first becoming a glider before evolving flapping wings.

14. If flying were to evolve, it would have to not be selected against, but rather be selected for or provide a fecundity advantage.

In your own words, what are the five main hypotheses for how flight was selected for ("Why" it evolved)?

Teacher note: Answers are verbatim from web site.

a. __To help escape from predators__________________________________

b. __To help catch flying or speedy prey______________________________

c. __To help move from place to place (leaping or gliding)_______________

d. __To free the hind legs for use as weapons__________________________

e. __To gain access to new food sources or an unoccupied niche_________

15. It is very common for students to erroneously think that natural selection occurs because an organism wills it to occur. In your own words, provide a scenario, using the ideas about how and why flight evolved, above, in which the organism has willed the evolution of flight.

A popular answer might be that because an animal wanted to better fly or glide, it stretched the skin on its arms (like Rudyard Kipling's Just So Stories) to make wider "wings." Progeny were then born with the stretched skin. An example that students could better relate to would be the non-heritable nature of pierced ears – generation after generation can pierce their ears, but no one is born with them.

16. Now explain, based on what you know about the occurrence of mutation, reproductive rates, and other features of natural selection, why this scenario is erroneous.

This is erroneous because changes in phenotype entirely due to the environment are not heritable. Only if there is a genetic basis to the phenotype, is it heritable.

Share your scenario with a classmate and have him/her describe what is erroneous. Share answers as necessary.

17. a) Why is the evolution of flight called convergent?

Because three different taxa (very unrelated) evolved or converged on the same trait.

b) How is this different from divergent?

The term, divergent, is used for related organisms with diverging or differing traits.

c) How could you use a phylogeny or tree to illustrate convergent and divergent evolution?

Commonness of traits is shown with more proximity of branch tips. Relatedness (on a genetic level) is shown by related members sharing branches.

18. The evolution of flight resulted in sudden adaptive radiation or macroevolution. Describe what this principle is, what it would look like on a phylogeny, and provide some ideas as to why such evolution could occur so quickly.

Macroevolution - once adaptation has occurred it spreads or radiates to diverse environments through reproduction or breeding. It would look like massive webbing at branch tips of the tree. It occurs so quickly because the adaptation confers so much more fecundity or it occurs simultaneously with an extinction / demise of a competing / predatory population (as with several historic macroevolution periods).

19. a) Pterosaurs are thought to have evolved through which of the two hypotheses you illustrated previously?

Ground-up hypothesis (cursorial)

It should be noted that the authors of the web site acknowledge that this is still an area of quite a bit of debate.

b) What evidence supports this?

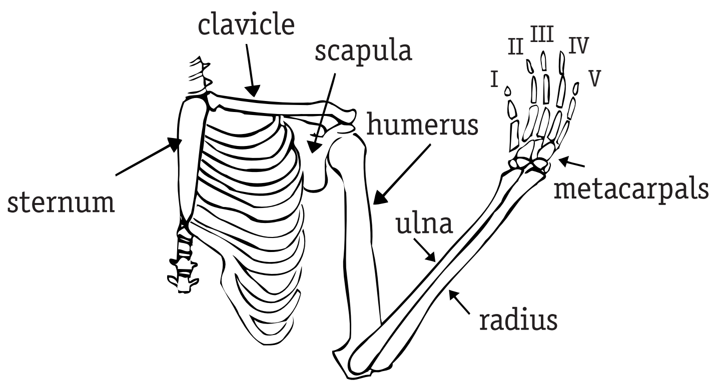
Pterosaurs have no arboreal adaptations and they are thought to have been derived from another cursorial dinosaur (Scleromochlus)

20. Pterosaurs do not have feathers, but have other structures to support the wing. Describe them.

Modified scales served as wing-supporting fibers. These may have formed hairlike structures to provide insulation.

21. The pterosaur wing and torso have several components in common with a human arm, shown below. Draw a pterosaur wing and label each component by drawing arrows to similar structures.

Human arm and torso



22. The pterosaur has a specialized bone that is not known to occur in other animals. What is it and what does it do? Label it on your drawing.

Pteroid bone - points from the wrist towards the shoulder, supporting part of the wing membrane.

23. Why is the occurrence of this bone so noteworthy to scientists.

This bone's occurrence appears suddenly then vanishes (after 140 million years of pterosaurs). This rarely occurs in evolution; usually appearance is gradual and occurs over a larger group of organisms. In addition, usually the structure will have moved gradually - in function and perhaps position.

24. The avian wing and torso are also very similar to the human arm and torso. Continue your drawing from #21 by drawing an avian torso and wing. Be sure to label your parts.

Teacher note: a very clear picture (for a key) occurs at http://www.ucmp.berkeley.edu/vertebrates/flight/aves.html

25. The earliest known bird is ___Archaeopteryx_____________________.

26. There are 2 other lines of animals linked to the earliest known bird, which are useful to study in order to understand the evolution of birds. What are these two and how are they linked to the earliest known bird?

Dromaeosaurs = transitional stage (before birds)

Sinornis = transitional stage (the Archaeopteryx of "modern" birds)

27. a) By what hypothesis previously mentioned are birds thought to have evolved flight?

Ground-up (cursorial) hypothesis

b) What evidence is there?

Dromaeosaurs were bipedal, terrestrial, and fairly cursorial, no evidence for an arboreal lifestyle. Archaeopteryx shows approximately the same characteristics as Dromaeosaurs, so it is assumed they lived equivalently. Similarly, there is no evidence of large trees in areas where some Archaeopteryx fossils were found.

28. Why is the fact that a majority of modern birds live arboreally, poor evidence for the Tree-Down hypothesis as a means of flight evolution?

That most modern birds live in trees does not indicate that ancestral birds lived in trees, especially when fossils of ancestral birds occur very much in the absence of trees.

29. The clavicle is fused in birds, forming the furcula. What function does this bone have?

The furcula acts as a brace during the flight stroke.

30. The furcula is first seen in Dromaeosaurs. What did it serve as, and why does this supply evidence of exadaptation?

It served as reinforcement for the shoulder girdle while the Dromaeosaur was holding prey. As it had one purpose before another which eventually became the main purpose, this is a perfect example of exadaptation. Students might also mention that wing use here provides an example of exadaptation - wings used to hold and capture prey, to wings used to fly.

31. The phalanges of the wing evolve, as well. Sketch the three "stages" of phalanges and label notable changes.

There is reduction and fusion of hand structures, in the following order.:
1. Dromaeosaurs have large clawed hands
2. Archaeopteryx has clawed fingers and a longer wing
3. Modern birds have only 2nd digit of hand present at end of wing

32. a) The evolution of flight in bats seems to have occurred according to which of the illustrated hypotheses?

Arboreal / gliding hypothesis

b) What evidence is there for this?

The hypothetical ancestor is thought to have been nocturnal, insectivorous, arboreal, and a glider. (Like the "flying lemur," which is a closely related modern-day glider.)

33. Continue your torso and arm drawings with that of a bat. Label appropriate features.

Teacher note: A clear image occurs at

http://www.ucmp.berkeley.edu/vertebrates/flight/bats.html

34. a) The bat does not have a tail like birds, but instead has a uropatagium. What is this and what is its function?

This is a membrane stretched between the hind limbs. It serves to help balance during flight as well as capture prey (like a net).

b) Why does this serve as defense to the bat's evolution of flight according to the hypothesis named in question #32?

Because many gliders have or a use a similar structure.

35. a) There is a bone in bats that may be analogous to a famous bone in pterosaurs. What is it and why might it be deemed analogous?

The bat has a calcar, which is a bone that supports the uropatagium at the heel, much like the pteroid supports the membrane at the wrist in Pterosaurs. Morphologically and functionally it is similar, and it occurs in similar regions of the body (at distal appendage joints).

b) What further information should we obtain before we determine its analogy or homology with another bone?

Developmental information, both temporally and genetically.

36. Using the drawings you have produced of torso and arm/wing morphology, create a list, chart, or essay pointing out the main changes that must have occurred between organisms. You can place your list on a tree or juxtapose this information with that of a phylogeny, to get a sense of how much time passed between organisms, for such changes to take place. Add some of the transitional groups to your tree to see if you can pinpoint what morphological changes must have taken place first (assuming each feature will evolve only once).

Teacher note: Question 36 may require more time and resources. Encourage students to use current information/findings in completing their projects.

You could group students by function (behavior), morphology (anatomy), development, and heredity (genetics) groups. You could also create a group to look into Linnean organization (this should be simple), then research what traits were used to establish this method of classification.

Part C - Insect Flight

It may seem abnormal to include this section after vertebrate evolution has been discussed, because invertebrates came first, but the web resources for invertebrates are much less prevalent.

Use the web site
http://parallel.park.org/Canada/Museum/insects/evolution/evolution.html
to help you answer the following questions.

1. Insect evolution of flight probably occurred as an exadaptation. What is an exadaptation? Hint: see text in part B if you have forgotten.

   Part B #12 shows the answer: "adaptations that are co-opted from a previous use to a new use.

2. What are wings thought to be derived from?

   gill-like structures (flaps)

3. What might these flaps have initially been used for, before they were wings?

   To assist in jumping (then later in evolution: diving, gliding, flapping)

Wings may have been used as sails or floats in the water, prior to their being used for flight. Today, stoneflies use wings as sails and other insects flap their wings in order to be propelled across the surface of the water (like a wind-powered boat).

4. The responses in questions #2 and #3 may cause you to think about another animal - a vertebrate without legs - that has "wings" which evolved in the same way and provide the same function.

   a) Which animal might this be, and how are its wings similar to the wings of invertebrates?

   Flying fish or Ratchetfish; pectoral fins are derived from gills. They use them to assist in swimming, diving, and gliding.

   b) Why is this of evolutionary significance?

   This is of evolutionary significance because we have an example of two very divergent lines of animals evolving in a similar way to produce an adaptation with very similar functions. This may be a case of convergent evolution. This also lends some support to Saint Hillaire's hypothesis.

5. What is the principal criterion for distinguishing insects at all hierarchical levels?

wing morphology

6. How does a bee's vision differ from a human's in terms of speed? Explain by using a specific example.

A bee's compound eye sees much more quickly than the human eye. (It has a greater flicker fusion rate.) A Hollywood Movie looks very fluid to us, but to a bee, it would look like a series of still photos (it can see each frame).

7. Why is this change in vision important for flying insects?

Insects fly at very high speeds through complicated environments (like woods, marshes, etc.). They need to be able to spot obstacles, predators, and prey while they fly quickly. They also need to be able to detect slight changes when at rest (so they can see the fly swatter well before it becomes a threat).

8. If the compound eye had not been so useful for finding food (thus eating and remaining healthy) and avoiding predators, it may not have lasted as a new mutation. (This is especially true if previous eyes were capable of seeing very well for large distances.) Why not? Hint: Consider the requirements for traits to be passed on from one generation to the other.

It is difficult for a flying insect to spot a potential mate using its eyes. Therefore, the first mutant flies may not have been able to reproduce to pass on this adaptation.

9. Insects are fragile creatures, and almost anyone who has held a moth or butterfly knows that the wings are extremely fragile and without them the insect may die. What major adaptation has helped insects protect their wings?

ability to fold wings, often inside of or underneath a hardened shell

10. Vertebrate wings have several structures to make them harder and less fragile. While birds have feathers, what do insects like Lepidoptera have?

Scales

11. What other adaptations involving wing appearance have insects evolved to help protect themselves?

Scales may be colored or reflect the light to produce a "scary" large face (for butterflies) or to produce a shine that is distracting and can be disturbing.

Students might also mention mimicry, which several animals have used in body and appendage (wing) coloration. Great examples are (a) the Monarch and Viceroy (the mimicker) Butterflies, and (b) sweat bees (mimicker) and yellowjacket wasps or other bees.

12. The ancestral flying insect had how many wings?

four

13. Diptera uses its front wings to flap, but its hind wings are used for something else. What is it?

The hind wings are stumps that work like gyroscopes to stabilize flight and allow for quick direction changes.

This is a great opportunity to explain to kids how gyroscopes work. You can do a demonstration involving a spinning chair or swing (make sure the kids are firmly seated) and a wheel on a sturdy axis. For the wheel and the spinning chair, it is desirable to have the least amount of friction possible.

Students sit in the chair, then are handed the wheel which has been made to spin rapidly (you can get a circular spinner or sander to get it going). Students will notice that if the wheel is held exactly perpendicular to their bodies, the chair remains still. But as soon as the wheel is turned to the left or right of perpendicular, the chair will spin to the right or left. It spins more and more rapidly as the wheel is turned more and more.

14. Print the Flapping Flight pages from the web site and make a flip book so you can better understand this method of flight! Glue the printout to some stiff paper, then cut out each step in the dragonfly flight pattern, being careful to make each card the same size and orientation. Attach the cards together by sewing a binding or stapling your book. Books can be colored to emphasize specific wings and positions. Do the same for the locust, butterfly, and beetle illustrations.

15. Most insects do not fold their wings during flight, like a bird can. Knowing this, if the insects were to flap up and down using only two wings, fully extended, without folding, significant drag would be produced in the upstroke, and the flight would require a lot of energy in tilting and down strokes to remain in the air.

a) However, insects like dragonflies have 4 wings and flap them in a way so drag is not the only force occurring in an up-down direction during an upstroke of one pair of wings. What is this way of flapping and how is it advantageous?

They beat their pairs of wings in opposite phase, so during one down stroke, an up stroke is occurring. This cancels out drag, keeping the dragonfly in the air longer.

b) Other insects may have 4 wings, but beat them very differently than a dragonfly does. Explain how the locust, butterfly, and beetle flap their wings differently that each other and a dragonfly.

A locust beats its wings out of phase like a dragonfly does, but this is not as dramatic. It seems like a transitional animal with respect to the dragonfly and butterfly. The butterfly holds its wings together like a single wing.

The beetle doesn't use its aft wings (front wings) at all in flight, but uses them as shields. Thus, it only uses two wings during flight, which is different from all insects. The butterfly and beetle are similar in their use of single airfoils for flight.

c) Why are these different methods advantages for each animal? Think about how each animal lives and what amount of their days are spent in the air.

This would make a great research prompt for students. The following includes some preliminary ideas to prompt discussion if the teacher does not wish to have students do additional research.

The locust does not spend nearly as much time in the air as a dragonfly. It also has a significantly larger body and shorter wingspan than the dragonfly. Perhaps this has something to do with their less exaggerated out-of-phase flying ability (relative to dragonfly).

The butterfly spends a great deal of time in the air, and has larger wings to facilitate this. Their aspect ratio is clearly lower, which should facilitate gliding through the air.

The beetle does not spend much time in the air (in fact they prefer to run), and they tend to live on the ground, where a shell is needed for defense. Flying may have been conserved in many beetle species for finding food and mates (as with the ladybug), but they do not typically fly for very long distances (like butterflies and dragonflies).

Questions 16 to 21 refer to DIRECT MUSCULATURE.

16. Why is the Direct muscle system called "direct"?

Because muscles are directly attached to the wings.

17. The muscle system in insects is very similar to that in birds. Draw the rostral cross-sectional view of the wings and muscles involved in flight for a bird, next to a copy or sketch of the drawings provided for insects. Label the drawing with important bones we have studied. Include important muscles or muscle groups if you know them.

Clear pictures are shown at:
http://parallel.park.org/Canada/Museum/insects/evolution/muscles.html#muscles

18. What are the tergum and what are analogous structures in birds?

The tergum are the hinges or joints where wings attach to the top of the thorax. Analogous structures would be tendons where the Scapula, Coracoid and Humerus meet. These are called the Supracoracoideus tendons.

19. There are two groups of muscles associated with flight. What are they and where are they?

Muscles to raise wings (medial) and muscles to lower wings (more lateral).

20. Draw a series of cartoons illustrating the job of each muscle by showing the length of the muscle (include a label) during different parts of flight. The muscle should extend or contract. (Extending is considered a resting phase or a passive process.)

1. Rest (no flight, or end of Down Stroke)	2. Upstroke	3. Transition (Upstroke finished)	4. Down Stroke

1. Should show both muscles extended.
2. Should show medial muscles contracted, lateral muscles extended.
3. Should show both muscles extended.
4. Should show medial muscles extended, lateral muscles contracted.

21. Why is this type of musculature disadvantageous?

The insect's brain must instruct each muscle independently to contract or relax each muscle and do it in a relatively synchronous way. If these signals are to be synchronized or coordinated, the authors suggest that a low wing beat frequency is necessary. In general, this type of flight is clumsy.

Questions 22 through 26 refer to INDIRECT MUSCULATURE

22. Why is this system called "indirect"?

Because muscles are not attached to the wings.

Activity I: Evolution of Flight

23. The tergum in this system is slightly different, in terms of what it attaches. Explain.

The tergum attaches the top of the thorax to another hinge that then attaches to the wing. (This is the displacement that makes this an indirect system.)

24. What are the two kinds of muscles in this system? Draw a picture and label it, like you did for the direct muscles. Be sure to show or explain the muscles' different roles.

Dorsoventral muscles (more lateral) contract to raise the wings and longitudinal muscles (more medial) contract to lower the wings. A clear picture is at
http://parallel.park.org/Canada/Museum/insects/evolution/indirect.html#indirect

You might suggest that the students draw a picture from a different perspective to show that the dorsoventral muscles run "vertically" and the longitudinal muscles run "horizontally" or make a 3-D model. If you don't have them do this, they may still make this connection when they try the tennis ball demo (#25).

25. The reading on the web site suggests a hands-on demonstration with a tennis ball and pins, to help explain how this muscle system works. Use pictures and a paragraph or list to explain how the ball models this muscle system.

The ball models movement of wings under indirect musculature. Pins represent wings. When the ball is pressed vertically (dorso-ventral muscles contracting), the pins move up. When the ball is pressed from front-to-back (longitudinal muscles contracting), the pins rotate down.

26. How is the indirect system better than the direct one?

It allows for faster wing beating. While the brain still has to send out different signals for different muscles, both muscles are attached to the tergum and it moves constantly, so wings are immediately synchronized and a new contraction immediately follows a contraction by another muscle. You could think of the tergum as the hinge on a pendulum, to some degree. The brain basically only has to tell the muscles to start, stop, or modify strokes.

27. Most insects don't fold their wings during flight like a bird can, but they can twist and contort them. How does this work?

There are several muscles attached to the wing that can be contracted or extended differently, thus curving and tilting the wing.

28. What do the authors say the bee and other insects use traditionally for navigation?

The sun and moon

29. To orient using these objects and fly in a straight line, a moth does what?

It maintains a relatively constant angle between its flight path (direction in which eyes are pointed) and the sun or moon (a source of light).

30. Why has this caused a problem for insects using the same navigational system, at night?

People use lights at night, and often these lights are brighter than the moon. The insects often mistakenly navigate using these lights. Because the lights are very close to them, in order to maintain a constant angle between the path and the light source, the insect will end up circling the source in a logarithmic spiral. If the angle between the insect's path and the light is acute, the insect will spiral nearer to the light source. Eventually, the insect will come so close to the source so as to be killed by it (burned by a flame or zapped by a bug lamp, for instance).

31. What are the environmental implications for this?

Some insects will die, migrate inappropriately, or be lured to populated communities where they can do a lot of damage. The Luna moth is nearly extinct due to this problem. If insect populations become extinct, the ecosystem will be imbalanced and populations of other animals will alter. For instance, their prey, perhaps a very destructive aphid or weed, may cause a great deal of damage due to decreased predation pressure.

Activity I: Evolution of Flight

Part D - Genetics and Evolution

The method described in Part B (question 11) is a traditional way of approaching evolution. However, with more genetic data available, and a clear link between development and genetics, evolutionary biologists are using more contemporary tools, linking modern-day mutants to archetypal mutants from long ago.

Well before genetics was understood, scientists worked with different groups of cells, understanding that certain groups of cells were precursors to certain structures (muscle and bone, for example). More specifically, scientists knew that cells from certain parts of the body were precursors for specific body parts. Observations of situations where cells were removed, transplanted, or marked indicated if cells were required for the formation of a specific structure.

1. Describe three kinds of tests you could do to see if a group of cells was solely responsible for limb formation. Draw cartoons for each test, below. (Hint: all three tests are mentioned in the last sentence of the paragraph above.)

Cartoon 1 describes: Removing cells to see if limb forms or not.

Add more frames on another paper if needed.

Cartoon 2 describes: Cells are transplanted to a new location to see if they form a limb there.

Add more frames on another paper if needed.

Cartoon 3 describes: Cells are marked with dyes or radioactive precursors, so descendents of cells can be tracked and localized to specific limb regions.

Add more frames on another paper if needed.

Using all of these methods, scientists were able to isolate the region where wings and legs form and identify some of the key cell groups involved.

One of the most important cell groups in limb development is the AER (apical ectodermal ridge). The AER forms in birds and mammals. It begins forming through "communication" between the underlying mesoderm.

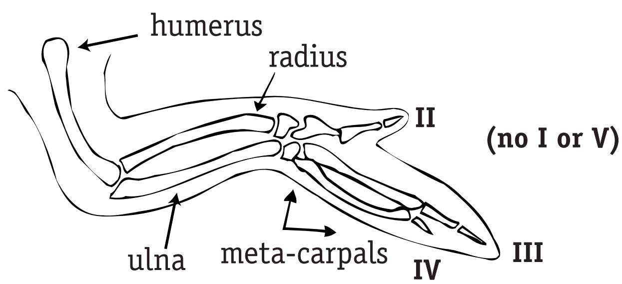
This lesson serves as a great precursor to motivate interest in the importance of chemical signals involved in development.

2. How might this communication take place? Are words exchanged?

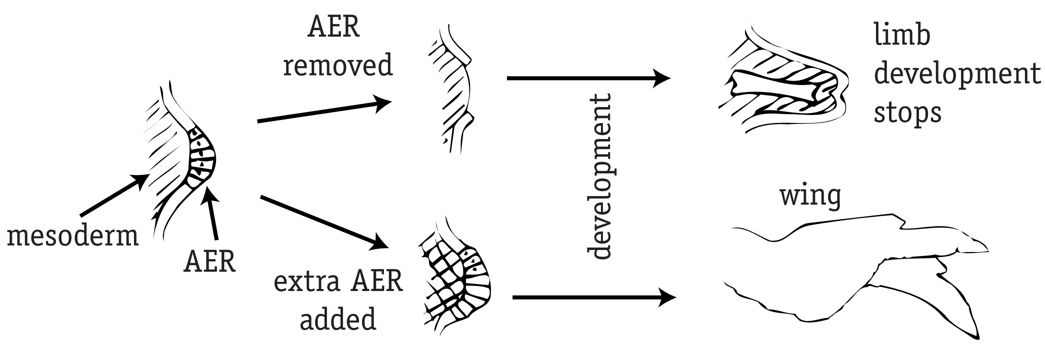
This is a great opportunity to discuss how cell-to-cell communication takes place; there may be proteins expressed, blocked, or protein amount may change (it may occur in a gradient). Ions or other products may also pass from cell to cell.

3. Use the following pictures to write a short sentence describing each situation and elucidating AER's role in wing formation.

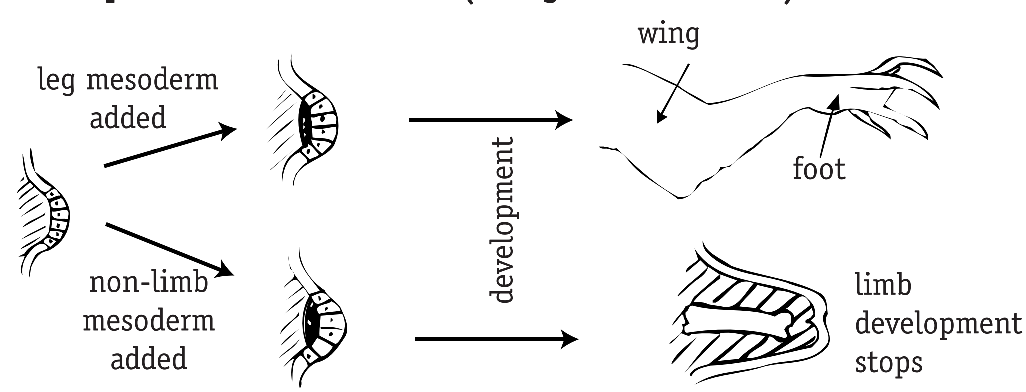
wild-type chick wing



AER experimental observations (changes in ectoderm)



AER experimental observations (changes in mesoderm)



a. When AER is removed, limb development stops (this occurs at any stage in limb development).
b. When extra AER is grafted onto pre-existing AER, extra wing is formed at the distal end.
c. When leg mesenchyme is grafted directly below the AER, toes develop at the distal end of the limb (the remainder of the wing looks normal).
d. When nonlimb mesoderm is grafted directly below the AER, limb development stops.

4. Use your pictures from Part B to compare the flying animals and their wings. You will notice that in evolution of wings, the proximo-distal structures change. The "hand" that occurs in pterosaurs and avian precursors has been reduced and fused in modern bats and birds. It is easy to think of an ancestor as a tetrapod with 4 "legs" of similar appearance. Then, by the fascinating process of evolution, legs became winglike.

In a similar fashion to asking ourselves, "How does my body know to make a pinkie finger on one side of my hand and thumb on the other side?" We can also ask, "How does a chicken make a wing for one appendage and a leg for another?"

The previous problem provides a hint. Which situation and result from question #3 gives you an idea about how the developing limb's AER region for a pterosaur or Dromaeosaur was different from that of a normal chicken?

The developing limb's AER region had a combination of leg mesenchyme and wing mesenchyme in the Pterosaur and Dromaeosaur. This is like result c from question #3.

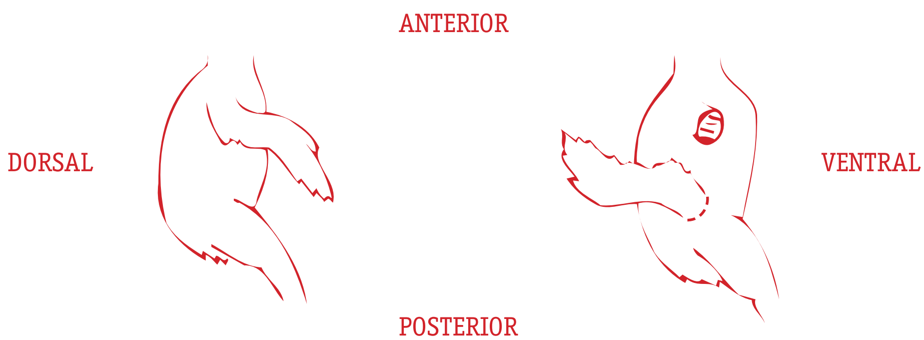
Students might also mention result b (from question #3) and suggest that it provides a means for wings to enlarge or perhaps provides redundancy so extra structures can evolve to gain new functions.

5. Why does the AER do what it does?

The AER provides positional information through a series of chemical cues. A special region within the AER is the polarizing zone. From its name, it should be clear that the polarizing zone provides information about an axis with respect to how limb parts will develop.

If you were to cut out a developing organism's polarizing zone and turn it 180 degrees, then reattach it, how would the resulting limb differ from a wild-type limb?

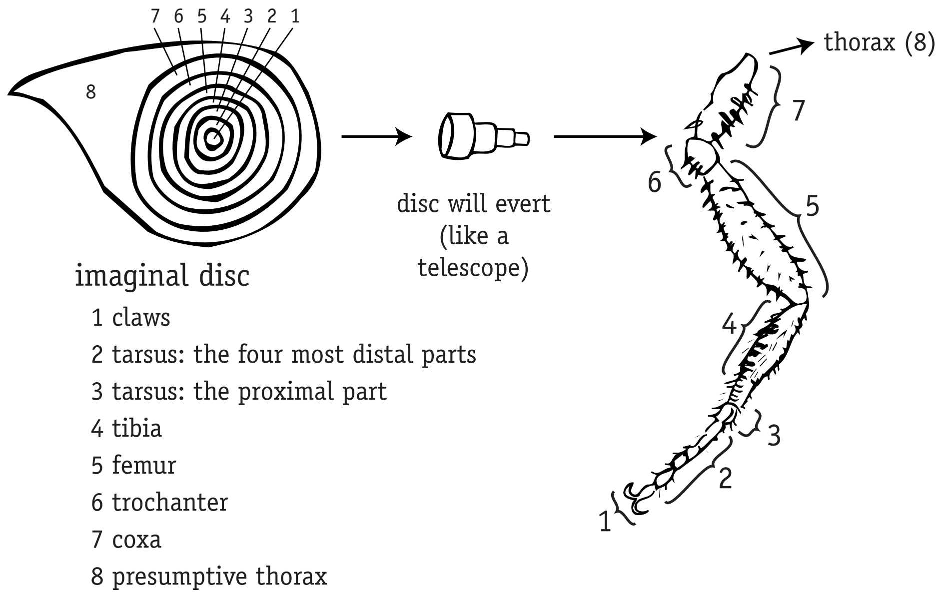
Development of the wing after turning and grafting the polarizing zone



normal chick embyo   after grafting

The resulting limb would be the mirror image of the wild-type limb; the resulting person would have 2 left hands or 2 right hands, depending on which side you transformed.

6. Insects provide another example of polarity or directionality playing a role in development. Several insect structures like antennae and wings form from imaginal discs. Each disc everts through development and elongates, eventually forming a body part.



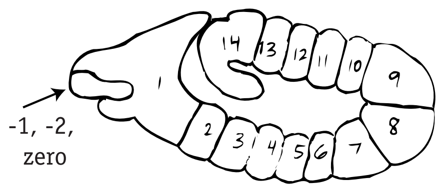
In *Drosophila* (fruit flies), the imaginal discs have been studied extensively. It is known that different levels of the disc specify different structures, as shown in the figure above. This occurs through gene activation. In addition, homeotic genes determine the developmental fate of specific segments of the body. In other words, they specify body parts. These genes can work hand-in-hand to determine the developmental fate of a fly.

Aeronautics

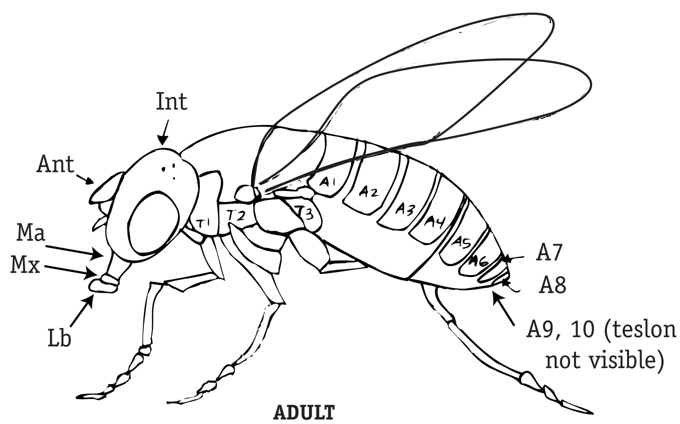
teacher guide

Activity I: Evolution of Flight

Below is a very simple picture of a fly and regions which express homeotic genes early in development. The genes shown are only a small fraction of the number of homeotic genes in a fly. Color code each region that is activated by a different gene. Use a key if your colors "black out" the gene name or region number.



BLASTODERM



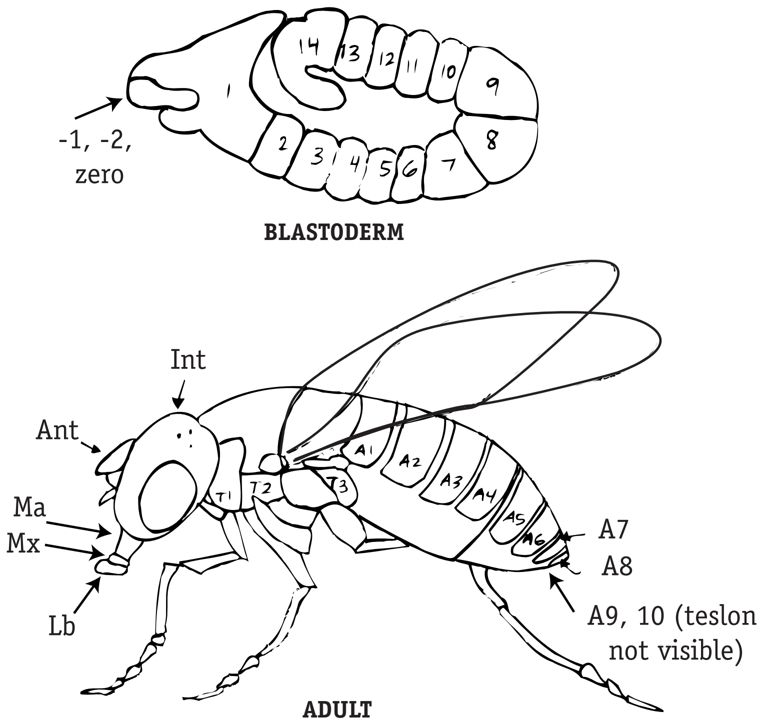
ADULT

Gene	Expressed Region																
Adult Fly Region	Ant	Int	Ma	Mx	Lb	T1	T2	T3	A1	A2	A3	A4	A5	A6	A7	A8	A9, 10
Blastodermal Segment	-2 -1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Labial		xxx															
Deformed			xxxxxxx														
Sex Combs Reduced				xxxxxxxxxxxx													
Proboscipedia					AAAAA												
Antennapedia						xxxxxxxxxxxxxx..											
Ultrabithorax							........xxxxx..										
Abdominal A									xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx...................								
Abdominal B												xxxxxxxxxxxxxxxxxxx					
Caudal																	xxxx

xx = strong expression .... = weak expression AAA= strong expression only in adults

Activity I: Evolution of Flight

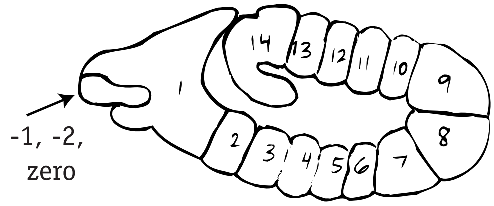
Mutations involving these genes have been known to result in aberrant phenotypes. Using the information in the picture above, determine which gene is being expressed "erroneously" and where this is influential. On the extra copies of the fly and blastoderm, indicate gene expression by shading regions appropriately. Also make changes in phenotype on the adult.



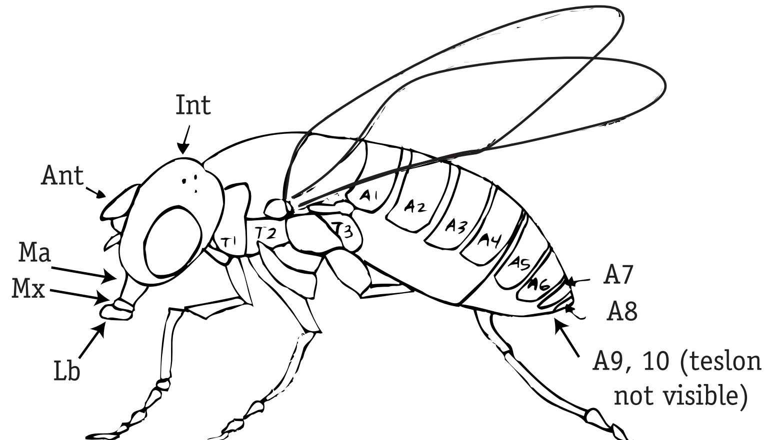
Phenotype a: two sets of wings formed in the second and third thoracic segments, respectively.

This occurs by putting in three mutations in cis regulators of the Ultrabithorax gene, effectively deleting the gene.

Some students might think that more expression of Antennaepedia in A1 might bring levels up enough to see this phenotype. Similarly, others might think reducing levels of expression of Abdominal A could cause more Thoracic traits (like wings) to occur.



BLASTODERM

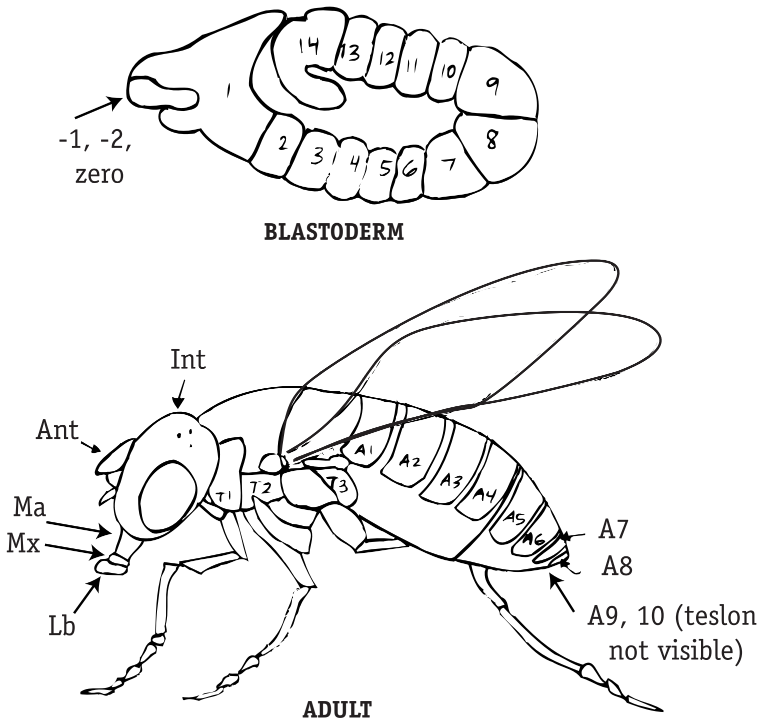


ADULT

Phenotype b: Legs replace the labial palps of the mouth.

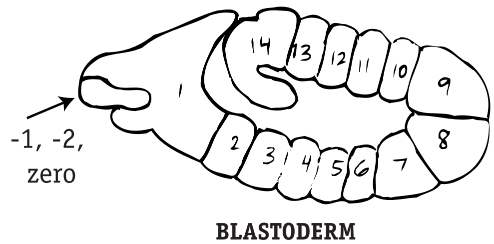
This occurs due to the absence of labial in head region. The proboscipedia gene is absent.

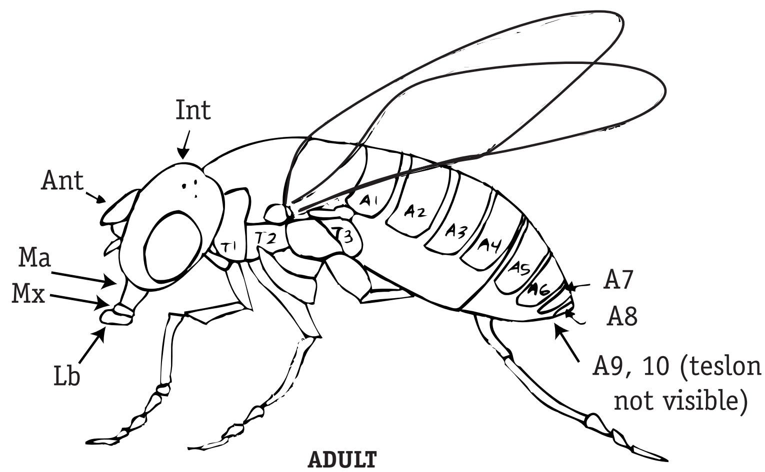
Students might also hypothesize an increase in expression of Antennapedia, as this occurs primarily in legged regions.



Phenotype c: Legs grow out of eye sockets, while eyes and other legs are normal.

Imaginal discs of head region are specified as thoracic; Antennapedia is expressed dominantly (mutation), so it is expressed in head and thorax.



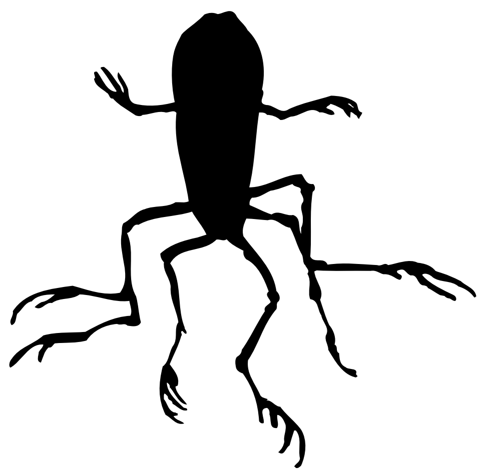


Phenotype d: Antennae grow out of region where legs would form (at imaginal discs), and there are also normal antennae on the head.

Imaginal discs at leg region are specified as antennal; Antennapedia is expressed recessively (mutation) so it is not expressed in the second thoracic segment.

Conceptually, it seems pretty easy to sprout new legs, huh? But the real question is, how likely is this to occur in nature? The next question answers this question to some degree.

7. We can manipulate imaginal discs by cutting them. If most of the disc remains, a new limb or wing will form. This occurs in salamanders and frogs that can regenerate limbs. In vertebrates, the imaginal disc-like region is called a limb field. At a pond in Santa Cruz, California, many multilegged salamanders and frogs have been found on more than one occasion. These animals apparently were infested with parasitic trematode worms when in larval form. The eggs of the worms split the limb fields when the frogs and salamanders were forming.



There are everyday plants and animals that undergo processes of rebuilding themselves like this all the time. Can you think of examples of animals and/or plants that are capable of recreating portions of themselves when part of them is removed? What kind of requirements are there in order for this to work (how much of the body or what part of the body needs to be retained)?

Students might think of plants, which can continue growing after shoots or limbs are removed. Many flowers can regrow shoots or roots after they have been cut - Carnations, Succulents, Spider Plants for example. Root growth can occur when the plant is soaked in water or when put in water and a mineral solution. Students can research such solutions to understand what minerals / products are useful in stimulating root growth.

A good animal example is earthworms, which can be cut in half (or less), then grow back the appropriate section of body. Starfish also have this ability. However, certain organs must remain, or the organism will die.

8. As was already mentioned, communication between the AER and mesoderm is important. This communication can cause some interesting changes in limb formation as well. When the mesoderm induces too much AER, just as in a graft, extra digits occur on the limb. This mutation is called Polydactylous.

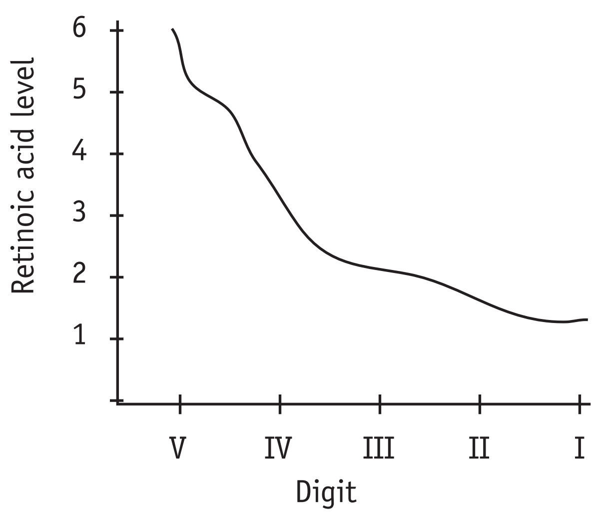
   If this were to occur in a human, what do you think the phenotype would look like? Draw a picture and explain your response. Keep in mind that polarity is still significant in development, even with this mutation.

   Students should draw more fingers, similar to what they saw in the graft example with birds. There should be different kinds of fingers and duplication of fingers in some way - a mirror image effect perhaps.

9. As soon as cell groups were identified as being in some way responsible for limb development, scientists narrowed their focus to understand the specific chemicals involved in development. They found retinoic acid, a common chemical found in carrots, appeared to play a large role.

   Retinoic acid produces a gradient across the limb. It is highest at the pinkie finger and lowest at the thumb. Retinoic acid binds cell receptors and causes the cells to express new sets of genes as a response.

   The graph below illustrates relative quantity of retinoic acid and the feature to which it is related.
   a) Determine which digits are the pinkie and thumb.



(circle one) I is a) pinkie or b) thumb?
V is a) pinkie or b) thumb?

b) If retinoic acid is doubled, what does the resulting hand look like, assuming 5 digits are still made?

The resulting hand may have two pinkies, two ring fingers, and a middle finger.

c) If retinoic acid is halved from the original situation, what will the resulting hand look like, assuming 5 fingers are made?

One ring finger, one middle finger, one index finger, and two thumbs.

10. Because the limb bud does not have a large retinoic acid content, it appears that retinoic acid is not the main chemical involved in inducing development of limbs. How could retinoic acid produce such effects when it is present only in small quantities in the limb bud?

Retinoic acid has a similar structure or receptor to a protein or other signal present in the limb bud. In other words, retinoic acid works in conjunction with another agent.

Teacher: Collect student responses and gain specific ideas about how the acid works with another agent before continuing. Students should believe a receptor is important before continuing on to design the test.

How could we test your idea?

We could produce an antibody or similar product that binds retinoic acid, then apply it to limb bud components (perhaps ground up). Then we could separate these components from the man-made receptors and determine what they were.

*A problem here is the assumption that there is a single receptor or we can identify the receptor for retinoic acid.

Plenty of studies have been conducted with retinoic acid and hedgehog or sonic hedgehog (below). Advanced students should appreciate trying to find their test in literature, although literature may be very technical.

11. *Hedgehog* in *Drosophila* is a segment polarity gene that is thought to encode a diffusible protein that reacts with neighboring cells. Scientists used PCR to identify a homologous gene in chicks, called *sonic hedgehog*, that is localized exclusively to a polarizing region in the limb bud. *Sonic hedgehog*'s product has been classified as a secreted growth factor that binds receptors on cell membranes. It serves to organize limb axis formation. In studies, retinoic acid applied to this same polarizing region causes *sonic hedgehog* to become expressed.

How is this similar to your test? How is it different? What new questions are raised by these results?

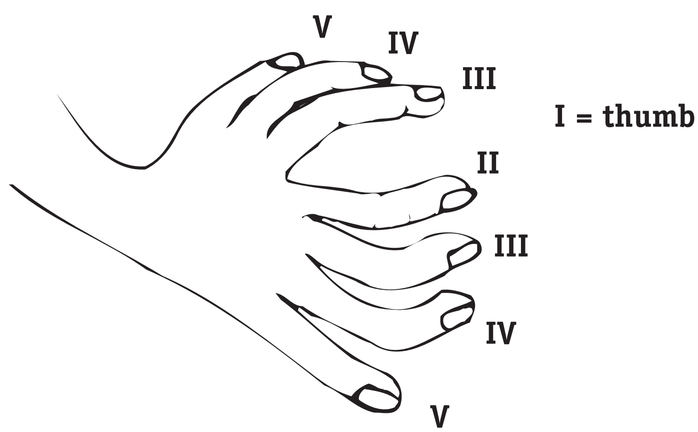
Binding is involved in sonic hedgehog's function, but we are not ensured that retinoic acid and sonic hedgehog are binding together. However, there is clearly an interaction between the two chemicals. The test shows that if we apply retinoic acid (from outside the body), an event occurs. What do we know about retinoic acid already in the body or naturally produced in this polarizing region?

Other studies show that *sonic hedgehog* can function in the absence of retinoic acid. Thus, the two chemicals may work together or apart, and appear to have similar functions.

Teachers might note that *sonic hedgehog* (in italics) refers to the gene or DNA, while sonic hedgehog (in plain type) refers to the protein product.

12. It is relatively easy to find and create mutations in the laboratory, where they can be selected for and/or are not selected against, but how likely are they to occur in nature? An example follows.

A condition similar to that seen in the AER grafting situation from question #3 in chickens was seen in a machinist from Boston. The man said that such a condition "not only helped him do his job, but also gave him certain advantages in playing the piano."

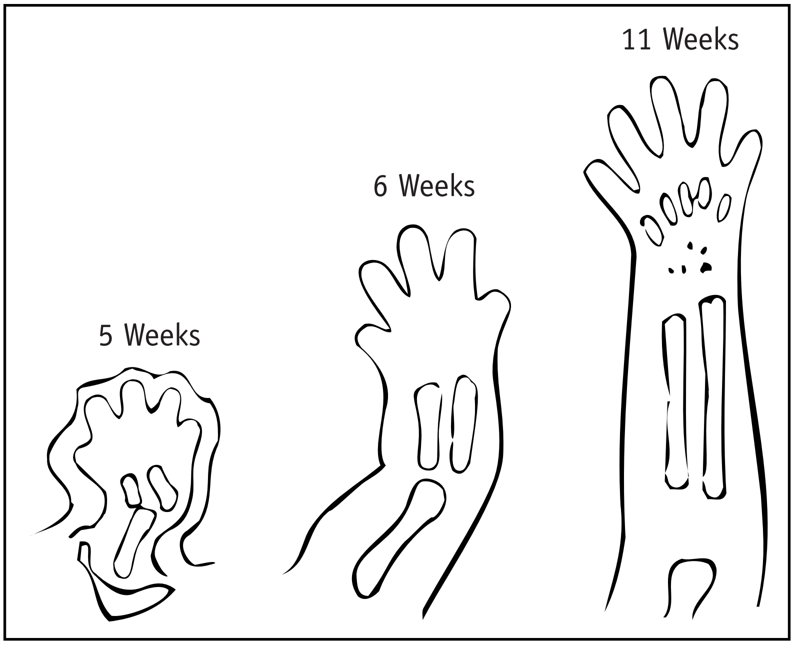


Now that you are an expert in genetics of this type of situation, what do you think caused this machinist's condition?

Changes in retinoic acid / *sonic hedgehog* activity so that either or both were expressed in two gradients (as if two AERs or polarizing areas occurred). Activity was increased such that no thumbs occured.

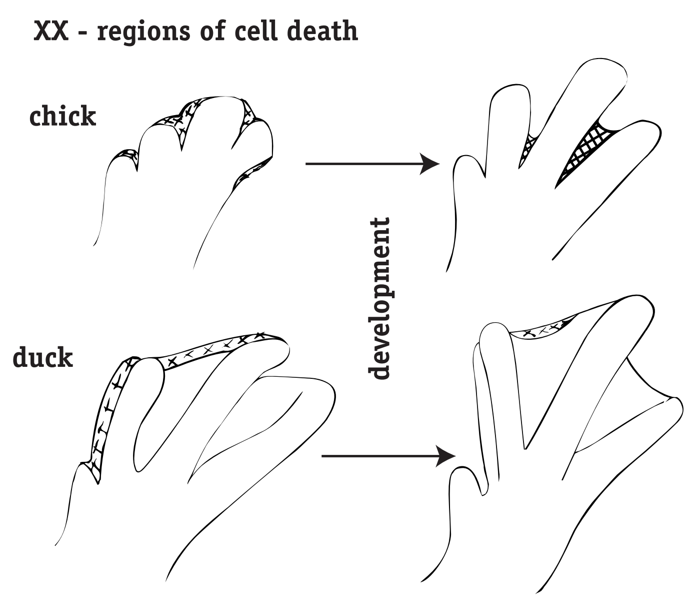
13. The bone structure of a wing on a chicken and the arm of a human are not very different. What is on the outside of the structure IS different, however. Extra tissue spans the distance between bones, providing more surface area on the appendage, which is essential for any of the flight-related motions. This brings us to ask: Could changes in the "webbing" of tissue be largely responsible for evolution of wings?

Perhaps. If it were, we would want to discover when "webbing" and "nonwebbing" occured. We use duck feet and human hands as examples. The development of the upper extremity in humans progresses through multiple stages beginning with the formation of the small arm bud 26 days after conception. Further development includes bud enlargement, neurovascular growth, and cartilage formation. By the 33rd day, the hand appears as a paddle which forms a basis for individual, separated digits through the death of interdigital ("between the fingers") tissue by the 54th day. The interdigital tissue is analagous to the embryonic "webbing" of duck limbs.



embryonic development of the human hand

14. One would also notice that some webbing is lost in duck embryos, but much more is lost in people. The regions where webbing is lost are very similar in both forms. Note the following illustration that shows cell death (de-webbing) in ducks and chickens. It occurs in a manner similar to people.



15. What does this indicate to you about the conserved nature of webbing regulation.

Webbing regulation appears to vary at a genus or species level; it does not appear conserved based on these two observations.

16. In question #14, the issue is the amount of webbing lost in various animals. A related issue may be the timing when de-webbing takes place. Heterochrony refers to a change in developmental time when an event occurs. How could the timing of de-webbing differ across our organisms? Use a specific time for each organism to make this example more tangible.

You might recommend to your students to have them use variables to make this more realistic. For instance, x for a duck, 3x for a chicken…

Regardless of how duck and chicken are compared, duck de-webbing has occured over less developmental time than chicken de-webbing.

If the time for de-webbing among different animals differs, then the animals will result in having different amount of webbing. Timing will vary.

17. Complete the following statement, providing specific examples and reference to natural selection. Compared to evolution of a new structure, evolution in amount of webbing would be relatively likely to occur because ….

No new structure is being formed; in fact all critters (we're assuming) pass through a stage of webbedness. What would be changing would be the timing of cell death (less or more time), or the expression of cell-death imposing chemicals (more or less expression). Having or not having webbed feet is not likely to be selected against because it does not appear to yield a dramatic change in behavior. The body is probably investing very little energy into making or destroying web.

Part E - Animal Flight Mechanics

People have been attempting to fly for centuries, and flying birds and insects have proved the perfect inspiration. Most modern airplanes do not have flapping wings, and hence do not "fly" (by the biological definition), but still use other methods of movement borrowed from nature.

Use the web site http://www.catskill.net/evolution/flight/birdsfly/birdsfly.html to obtain answers to the following questions.

1. Which method of flight in a bird (Parachuting, Gliding, Soaring, or true Flight) is analogous to that done by an airplane?

   gliding

2. In addition to forward motion, what are the three important motions for flight?

   (1)flapping, (2) twisting, (3) folding

3. Why is twisting important for flying, specifically during flapping?

   Without twisting, the drag is too high or lift is not sufficient to keep the bird from losing altitude. Twisting is needed so the wing is tilted up enough to be slightly above airflow (but low enough so drag is not too high).

   Teacher note: Swimming is a great analogy, here. Ask students why twisting is important for swimming, as well. If students are not swimmers, they can watch a televised swimming event to gain insight from their observations.

4. How is folding useful during flight?

   Without folding, the wing remains straight during flight and the wingspan does not change. This means that the same amount of surface area is in contact with the wind at all times. However, if the wing can fold, then wingspan decreases, and surface area decreases. It is ideal to have an unfolded wing for the down stroke, but upon upstroke it is best to have less surface area in contact with the air so drag is minimized.

5. How does a bird balance during flight?

It moves its wings frontward and backwards. It laterally twists its wings.

15. At http://www.catskill.net/evolution/flight/freefly/freefly.html and http://www.catskill.net/evolution/flight/freebird/default.htm there are photos, videos, directions, and simple plans for making small ornithopters. There is also a fairly active chat room where issues regarding construction of ornithopters, modifications, and new research in flight are discussed.
At http://www.naturalflight.com/evolution/seagull.avi there are many movies of Ornithopters in action, including historic early flights and more modern ones.

At minimum, watch a few movies!