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The Difference Makers



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About this Issue

The article "[The difference makers](#)" (10.9 readability score) gives an overview of transposons, or "jumping genes," and how these bits of genetic material have affected genetic variety and evolution in humans and other organisms. Students can focus on details reported in the article, follow connections to earlier articles about transposons and human evolution, explore cross-curricular connections to other major science topics, and construct a phylogenetic tree of primate evolution based on the locations of retroviral sequence insertions in chromosome 21.

Science News for Students provides related articles written at lower Lexile levels: "[Scientists say: DNA sequencing](#)" (8.2 readability score), "[The rest of your DNA](#)" (8.5 readability score), "[Scientists say: Mutation](#)" (8.5 readability score) and "[How a moth went to the dark side](#)" (7.2 readability score).

Want to introduce your students to an interesting STEM career using genetic research? Check out "[Cool jobs: Crime scene investigators](#)" (8.5 readability score), by *Science News for Students*.

Connections to Curricula:

Transposons
DNA and DNA replication
Evolution
Genome and chromosomes
RNA and RNA replication
Population ecology
Genetics
Epidemiology
DNA metabolism

What's in this Guide?

- s [Article-Based Observation](#): These questions focus on reading and content comprehension by drawing on information found in the article "[The difference makers](#)." Questions focus on defining transposons and their effect on evolution.
- s [Quest Through the Archives](#): With Internet access and your school's digital access to *Science News*, your students can use this short section to explore the history of research on transposons and genetic variations as reported by *Science News* since 1924.
- s [Cross-Curricular Discussion](#): These questions and extension prompts connect to the article "[The difference makers](#)" and encourage students to think in more detail about scientific areas related to the article. The section is divided roughly by science subdiscipline for educators who would like to focus on one topic area. The extension prompts are either more topic-specific or more conceptually advanced. **Chemical and Biological Sciences** questions cover a range of areas from the basics of DNA and RNA to the implications of transposons for evolution. **Engineering and Experimental Design** questions focus on potential applications of transposons.
- s [Activity](#): Students can analyze data showing the locations of retroviral insertions in chromosome 21 for humans and several other apes and monkeys, and use that data to construct a phylogenetic tree for these primates.

Standards Alignment

Next Generation Science	Common Core
From Molecules to Organisms: Structures and Processes: HS-LS1-1 , HS-LS1-2 , HS-LS1-3 , HS-LS1-4 , HS-LS1-6 , HS-LS1-7	ELA Standards: Reading Informational Text (RI): 1, 2, 4, 5, 7
Heredity: Inheritance and Variation of Traits: HS-LS3-1 , HS-LS3-2	ELA Standards: Writing (W): 1, 2, 3, 4, 6, 7, 9
Biological Evolution: Unity and Diversity: HS-LS4-1 , HS-LS4-2 , HS-LS4-3 , HS-LS4-4	ELA Standards: Speaking and Listening (SL): 1, 2, 4, 6
Engineering Design: HS-ETS1-1 , HS-ETS1-2	ELA Standards: Reading for Literacy in Science and Technical Subjects (RST): 1, 2, 3, 4, 5, 7, 8, 9
Matter and Its Interactions: HS-PS1-2	ELA Standards: Writing Literacy in History/Social Studies and Science and Technical Subjects (WHST): 1, 2, 4, 6, 7, 9

Article-Based Observation

Directions: Read the article "[The difference makers](#)" and then answer these questions.

1. What are transposons and what do they have to do with evolution?
2. Based on the section titled "Propagating parasites," what does propagation mean and why does the author refer to transposons as parasites? What is the microbiome and what role does it play in the body?
3. Using the diagram on Page 23, titled "Copy or cut," what are the two types of transposons and how does each type move?
4. What is the transposon that scientists know is still "hopping" around the human genome? What are some potentially negative and positive effects of this activity?

5. What happens to make a live transposon a “transposon fossil”? What are a few positive outcomes that have come from “transposon fossils”?
6. What is the benefit of having hundreds of copies of the now-extinct retrovirus MER41 in our human genome? Explain.
7. The graphic on Page 26, titled “Colorful effects,” shows some examples of genetic variations caused by transposons. Summarize your favorite example.
8. Developmental biologist Joanna Wysocka and her colleagues are interested in the effect of transposons on human development. What connection between chimps and humans did the researchers simulate, and what did they learn from their research?
9. Suggest another possible title for the article.

Responses to Article-Based Observation

- 1. What are transposons and what do they have to do with evolution?** Possible student response: Transposons, also known as jumping genes or transposable elements, are mobile segments of DNA that can insert themselves into different parts of an organism's genome. A transposition event can disrupt a gene or regulatory region of the DNA. Since transposons can alter the genetic code, they can contribute to the changes seen during evolution.
- 2. Based on the section titled "Propagating parasites," what does propagation mean and why does the author refer to transposons as parasites?** Possible student response: Propagation means multiplication or reproduction of something. Propagating transposons means increasing the number of transposons spread throughout the genome. The author refers to transposons as parasites because they insert themselves into their hosts' DNA and their sole purpose is to make more of themselves.
- 3. Using the diagram on Page 23, titled "Copy or cut," what are the two types of transposons and how does each type move?** Possible student response: There are retrotransposons and DNA transposons. Retrotransposons use the "copy-and-paste" technique and DNA transposons use the "cut-and-paste" technique. Retrotransposons in an organism's DNA are first transcribed into many RNA copies, and then an enzyme called reverse transcriptase converts the RNA copies to DNA. The DNA copy inserts back into the genome at random. DNA transposons don't actively copy themselves – they are cut out of DNA by the enzyme transposase and are reinserted in a new location.
- 4. What is the transposon that scientists know is still "hopping" around the human genome? What are some potentially negative and positive effects of this activity?** Possible student response: A retrotransposon called Long Interspersed Element-1, or LINE-1, is still "hopping" around the human genome and accounts for about 18 percent of it. Though most jumps are inconsequential, when LINE-1 jumps into a gene called APC, it can lead to colon cancer. If LINE-1 jumps into a gene coding for a blood clotting protein, it can cause hemophilia. According to pathologist Kathleen Burns and her colleagues, pancreatic tumors collect LINE-1 insertions as they grow. Scientists suggest that the frequency of LINE-1's hopping in brain cells could allow new capabilities that were not previously encoded in the genome, such as differences in the brain that make genetically identical twins different from one another.

5. **What happens to make a live transposon a “transposon fossil”? What are a few positive outcomes that have come from “transposon fossils”?** Possible student response: If the mobile elements of a transposon are not fully copied, either because of partial copying or a mutation, the transposon will no longer be able to move or jump on its own. Small and large RNAs and some proteins from recycled transposons can boost or dampen protein production and gene activity in cells and can generate antibodies and other immune proteins.
6. **What is the benefit of having hundreds of copies of the now-extinct retrovirus MER41 in our human genome? Explain.** Possible student response: Retrovirus MER41 invaded the primate genome about 45 million to 60 million years ago. Today humans have hundreds of copies of the now-extinct retrovirus spread throughout their genome. This is important because the sites of these insertions include transcription factors that call the immune system into action.
7. **The graphic on Page 26, titled “Colorful effects,” shows some examples of genetic variations caused by transposons. Summarize your favorite example.** Possible student response: A transposon jumped into the *Ruby* gene in oranges. This insertion created a red color inside the blood orange. Different types of blood oranges are the results of different jumps.
8. **Developmental biologist Joanna Wysocka and her colleagues are interested in the effect of transposons on human development. What connection between chimps and humans did the researchers simulate, and what did they learn from their research?** Possible student response: The researchers used cells from humans and chimpanzees and reprogrammed them to act like stem cells, and eventually, cranial neural crest cells, which help form the face. The process allowed the researchers to watch how facial development differs between humans and chimps. The team found that hundreds of gene regulatory switches are used differently by the two species. Recycled, mutated transposons were frequently found around the regulatory switches, leading to different activity.
9. **Suggest another possible title for the article.** Possible student response: “Transposons: Rolling the evolutionary dice with each jump.” Responses might include the idea of “jumping genes,” explaining genetic differences between species or individuals, human evolution or cut-and-paste and copy-and-paste.

Quest Through the Archives

Directions: After reading the article "[The difference makers](http://www.sciencenews.org)," use the archives at www.sciencenews.org to answer the related questions.

1. Though evolutionary biologist Josefa González notes that "transposable elements have been with us since the beginning of evolution," research on transposons is relatively new to the world of science. Search for the earliest published article that mentions transposons. What does it say?
2. Barbara McClintock was the first researcher to identify "jumping genes." Search for an article about her Nobel Prize and summarize it. What year did she receive the Nobel Prize? What year was the article published?
3. Transposons can change genetic sequences in ways that disrupts normal coding or can forge new genetic variety. CRISPR is based on a system for bacterial immunity that can prevent this form of gene editing. Search for an article about CRISPR. Explain it.

Responses to Quest Through the Archives

1. Though evolutionary biologist Josefa González notes that “transposable elements have been with us since the beginning of evolution,” research on transposons is relatively new to the world of science. Search for the earliest published article that mentions transposons. What does it say? Possible student response: The article “[In and out chromosomes](#),” published 6/17/1978, discusses research on insertable elements that change the genetic code of organisms. It states that transposons are large movable elements that can be drug resistant and contain insertion codes at either end of their sequence. They seem to insert at preferred sites in a sequence.

2. Barbara McClintock was the first researcher to identify “jumping genes.” Search for an article about her Nobel Prize and summarize it. What year did she receive the Nobel Prize? What year was the article published? Possible student response: The article “[Nobel prize to McClintock and her Mobile Elements](#),” published 10/15/1983, discusses Barbara McClintock’s research with corn. Prior to her work, it was thought that DNA was arranged in a fixed linear sequence. McClintock learned that some segments of DNA that control other genes could jump from one area to another. Her work led the way for subsequent investigations of mobile elements. The article was published in the same year Barbara McClintock won the Nobel Prize.

3. Transposons can change genetic sequences in ways that disrupts normal coding or can forge new genetic variety. CRISPR is based on a system for bacterial immunity that can prevent this form of gene editing. Search for an article about CRISPR. Explain it. Possible student response: The article “[CRISPR had a life before it became a gene-editing tool](#),” published 4/15/2017, describes how CRISPR helps bacteria defend against invaders by retaining a memory of these invaders. More specifically, when an invader injects its genetic material into a bacterium’s DNA, the cell adds a DNA sequence called a spacer into its CRISPR cluster. RNA copies of the spacer are transcribed into guide RNA, and with the help of Cas proteins, can recognize and disable phage DNA. Researchers are trying to study this mechanism so they can better understand immunity.

Cross-Curricular Discussion

After students have had a chance to review the article "[The difference makers](#)," lead a classroom discussion based on the questions that follow. You can copy and paste only the questions that apply to your classroom into a different document for your students.

Chemical and Biological Sciences**Discussion Questions:**

- 1. What are some of the important molecular and functional differences between DNA and RNA?**
[DNA and RNA have extremely similar molecular structures, but DNA is double-stranded while RNA is most often single-stranded. Instead of the base thymine, which is used in DNA, RNA has uracil which has a slightly different molecular structure. DNA is generally used to store genetic information, because of its greater chemical stability. RNA is generally used to make temporary copies of genes (messenger RNA) that encode proteins, or to make specialized RNA structures such as ribosomal RNA, transfer RNA or small interfering RNAs.]
- 2. What are some of the important differences between DNA replication and RNA replication?**
Explain how retroviruses and retrotransposons replicate. *[DNA is generally double-stranded. During replication, a number of enzymes pull the two strands apart and add complementary DNA nucleotides to each strand, producing two complete copies of double-stranded DNA. Cellular RNA is generally single-stranded. Cells generally do not replicate RNA (they just make RNA copies of DNA), but many viruses store their genes as RNA and must replicate that genetic material. Some use enzymes to assemble RNA nucleotides on one existing RNA strand, analogous to DNA replication. Retroviruses and retrotransposons use reverse transcriptase or retrotransposase enzymes to make a DNA copy of their RNA genes, then insert that DNA copy into a host's genome, wait for the host's genome to replicate and make more RNA copies from the DNA copies in the host genome.]*

Extension Prompts:

- 3. How could transposons and viruses have originally developed?** *[Perhaps a transposon got so good at jumping within the genes of a host that it became the first virus, able to jump to the genes of another host. Or perhaps a virus inserted its genes into a host's genome and was able to replicate successfully within the same genome rather than constantly hopping into new hosts as a virus. Perhaps the very first transposon or virus came into existence when a natural mechanism of DNA copying or splicing went awry, leading to a small region of the genome with the ability to replicate independent of the rest of the genome. Anything that can make lots of copies of itself can win out in the long run over things that cannot.]*

4. **Would evolution still happen if there were no transposons, retrotransposons or retroviruses messing with the genome?** *[Yes, but it would probably be slower, relying on ordinary mutations that arise during DNA replication when cells divide or genetic recombination of chromosomes in a new generation.]*
5. **Why do transposons appear to have been important for the evolution of the immune system?** *[The human immune system can make trillions of different antibodies (which also serve as B-cell receptors) and T-cell receptors to detect and fight trillions of different possible pathogens or other targets. However, the human genome contains only around 20,000 protein-encoding genes, and they have to take care of a lot more than just the immune system. The immune system uses a transposon-like ability to hop/splice/transform DNA to turn a small number of immune system genes into a vast number of sequences for antibodies and T-cell receptors. This process is called V(D)J recombination, because it uses gene segment hopping and splicing to mix and match various V gene segments, D gene segments and J gene segments to create a wide variety of possible complete V-D-J gene sequences for antibodies or for T-cell receptors. For more information, see the chapter "The Immune System" in Campbell's Biology.]*
6. **The X-Men comics and movies never explain how the same "mutant gene" or "X-gene" can give different superpowers to different people. How could transposons help to explain that?** *[If the "mutant gene" were a very active transposon, it could hop to different places (or even several places) each time it is passed from parent to child, causing new mutations in each generation. People without the very active transposon would be "normal" and much less likely to have mutations. Of course, in the real world the mutations generally would not be as cool, and in fact many of them would be harmful.]*

Chemical and Biological Sciences Question Bank

What are some of the important molecular and functional differences between DNA and RNA?

What are some of the important differences between DNA replication and RNA replication? Explain how retroviruses and retrotransposons replicate.

How could transposons and viruses have originally developed?

Would evolution still happen if there were no transposons, retrotransposons or retroviruses messing with the genome?

Why do transposons appear to have been important for the evolution of the immune system?

The X-Men comics and movies never explain how the same "mutant gene" or "X-gene" can give different superpowers to different people. How could transposons help to explain that?

Engineering and Experimental Design

Discussion Questions:

1. **How are transposons analogous to computer viruses?** *[A computer virus inserts into computer code and causes changes to operating systems, just as transposons insert into genetic code and cause changes in an organism's genome (though the changes are often inconsequential). Computer viruses make copies of themselves; some will fill a computer's entire memory with copies of themselves.]*
2. **If someone were suffering from a disease that involved hyperactive retrotransposons, what sort of treatment might be developed?** *[A retrotransposase inhibitor might prevent the retrotransposons from making DNA versions from their RNA copies. Other normal cellular functions do not typically use retrotransposase or reverse transcriptase, so such an inhibitor should not interfere with other functions. Inhibitors that target enzymes involved in splicing transposon copies into the genome might also be useful.]*

Extension Prompts:

3. **What are some ways in which you could deliberately use transposons for practical applications?** *[Examples include: Inducing lots of mutations to accelerate evolution, for example to force bacteria to become good at consuming oil spills. Letting transposons randomly hop into different places in a genome, then learning about the natural function of those places in the genome by seeing what phenotypic changes result in the organism. Using hyperactive transposons as a sort of natural polymerase chain reaction (PCR) to make lots of copies of a gene of interest. Using transposons as a vector to deliver a gene of interest into a particular organism.]*
4. **How would you actually implement some of those various applications of transposons?** *[Help students think through the steps that would be required for each of their ideas.]*

Engineering and Experimental Design Question Bank

How are transposons analogous to computer viruses?

If someone were suffering from a disease that involved hyperactive retrotransposons, what sort of treatment might be developed?

What are some ways in which you could deliberately use transposons for practical applications?

How would you actually implement some of those various applications of transposons?

Teacher Guide: Jumps to Speciation

Class time: 30-50 minutes.

Purpose: Students will learn to construct a phylogenetic tree of primates based on the locations of inserted retroviral DNA in chromosome 21.

Notes to the teacher: If your students are not already familiar with phylogenetic trees, take some time to explain the concept using the fictional example in the student handout, [Blackline Master 4](#), or real examples in biology textbooks. You may also want to show a video and incorporate other activities from these resources:

- [PBS's NOVA Evolution Lab](#): Introduces evolution and allows students to explore a phylogenetic tree online.
- [HHMI's BioInteractive, The Origin of Species: Lizards in an Evolutionary Tree](#): Explores the evolution of lizards, their phenotypic traits and their DNA differences.

Students should arrive at something similar to the primate phylogenetic tree solution, [Blackline Master 3](#), for the primate phylogenetic tree. You may want to have them work with a partner and talk through how to determine the oldest and most recent primates. From the data presented to the students, there is no way to work out how long ago the lineages diverged, only the order in which they each split off. However, the answer key shows those approximate divergence times, based on the best fossil and genetic evidence.

If students are confused about how to start, you can guide them. The seven ape and monkey lineages all refer to modern creatures, so those will all be listed down the right side. Humans will be on top. Just below humans will be whatever lineage is most genetically similar to humans, based on the provided HERV-K data; the human lineage and its closest lineage can be followed back to the most recent node (node F), where those two lineages had split apart. Just below humans and our closest cousin will be our second closest cousin, based on the provided HERV-K data, whose lineage can be traced back to an older node (node E) where it split off from a common ancestor of humans and our closest cousin. More genetically different modern lineages will be lower down, and connected to the others by nodes that occurred further back in time.

One thing to emphasize to the students is that the phylogenetic tree does not mean that a common ancestor instantly turned into either a modern human or a modern chimpanzee. The tree simply indicates when the last common ancestor was. Each branch continued to evolve after that, so the

animals at the end of a horizontal line may be quite different from the animals at the beginning of that same line.

Students looking at this data may wonder why humans appear to have so many more copies of the retrovirus than other lineages. For simplicity, copies of the retrovirus that were inserted at other locations in nonhuman lineages but were not inserted in humans are not included in this data. The genomes of all seven lineages are littered with copies of the retrovirus, some at the same locations as in human chromosome 21 and some at other locations.

When they are finished with their tree, have students answer the related analysis questions. You may want to check their tree before they move on to the analysis questions. If they are having trouble, ask them pointed questions to lead them to the right answers.

Citation:

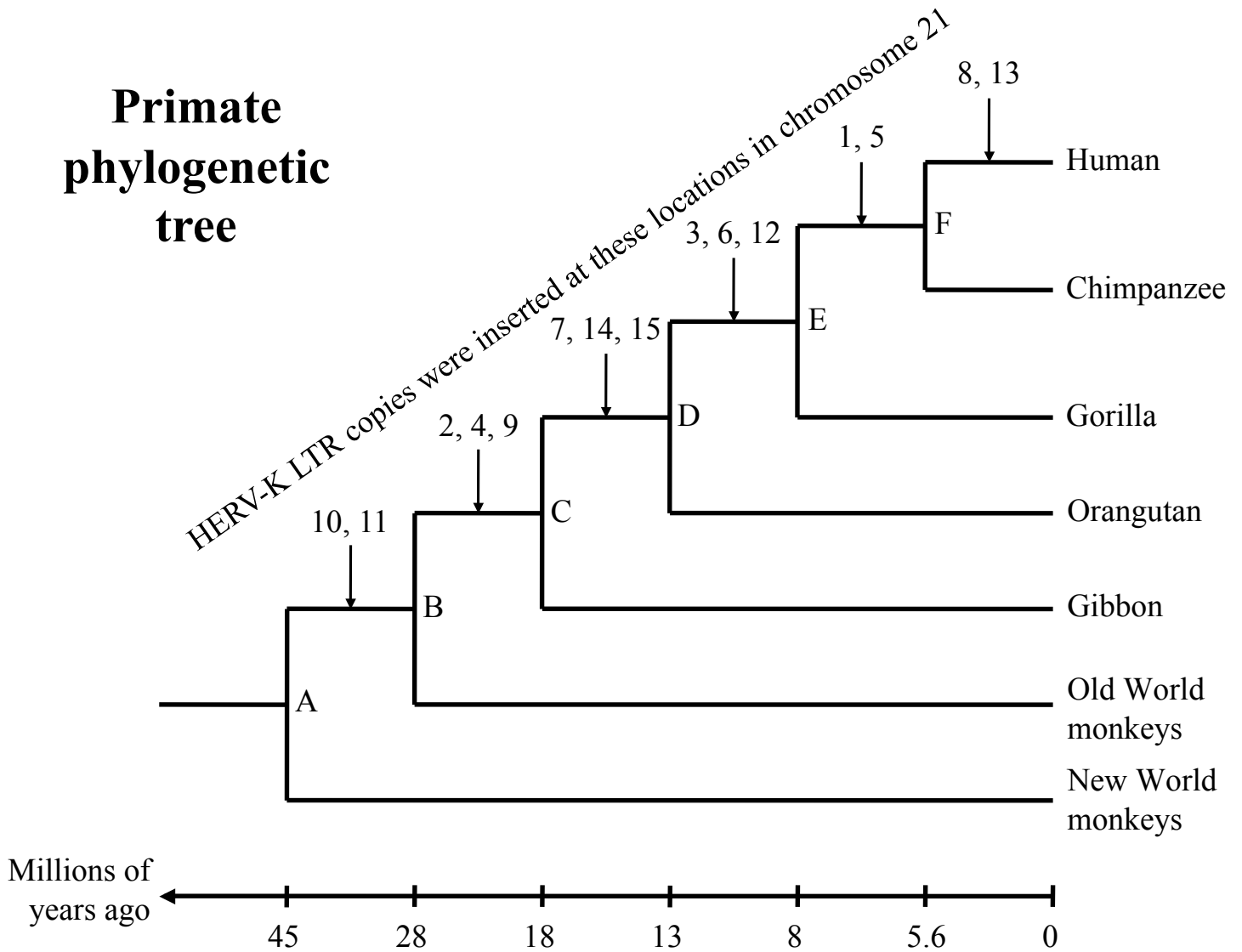
This activity has been adapted from data presented in Sergey G. Kurdyukov *et al.*, Full-sized HERV-K (MHL-2) human endogenous retroviral LTR sequences on human chromosome 21: map locations and evolutionary history. *Gene* 273 (2001) 51-61.

Analysis Questions and Answers (for Educators):

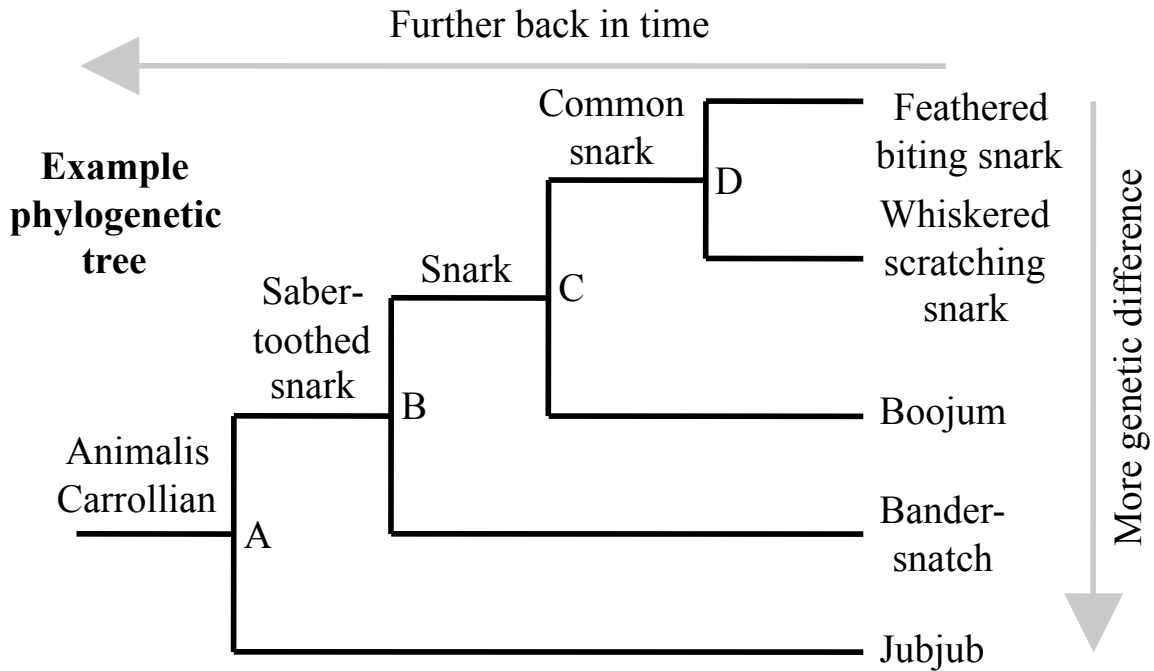
1. **Label the relative change in time on your diagram.** *[See horizontal time axis on answer sheet.]*
2. **Label all nodes using letters A-F. The node labeled “A” should indicate the earliest node in time.**
[Node “A” indicates where the central lineage of all listed taxa diverges – it is the node closest to the bottom of the paper. Node “F” should indicate the most recent divergence, closest to the top of the paper.]
3. **Which node represents the common ancestor of all listed primates?** *[Node “A.”]*
4. **Which node indicates the most recent common ancestor of humans and chimpanzees?** *[Node “F.”]*
5. **Which node indicates the most recent common ancestor of chimpanzees and gibbons?** *[Node “C.”]*
6. **Is a gorilla more closely related to a chimpanzee or an orangutan? Explain.** *[A gorilla is more closely related to a chimpanzee, because it shares a more recent common ancestor with a chimpanzee than it does with an orangutan.]*
7. **Which two lineages are most closely related on this tree? Explain.** *[Humans and chimpanzees are the most closely related, as they share the most recent common ancestor.]*
8. **According to your diagram, how many divergences occurred since the most recent common ancestor of New World monkeys and the gorillas?** *[Ancestors of gorillas diverged from the New World monkeys four times (with ancestors of gorillas shown as Node E on the tree).]*

9. **Research each primate's evolutionary history. Try to indicate the number of millions of years ago for each divergence. Label these approximate times on your phylogenetic tree.** *[See timeline on answer sheet.]*
10. **Choose a primate lineage to research further. Describe its physical appearance and behavior.** *[Answers will vary, but have students share the information with each other when they are finished researching.]*
11. **Did retrovirus HERV-K affect the evolution of primates? Explain. What other data might be collected to help answer this question?** *[Answers will vary.]*

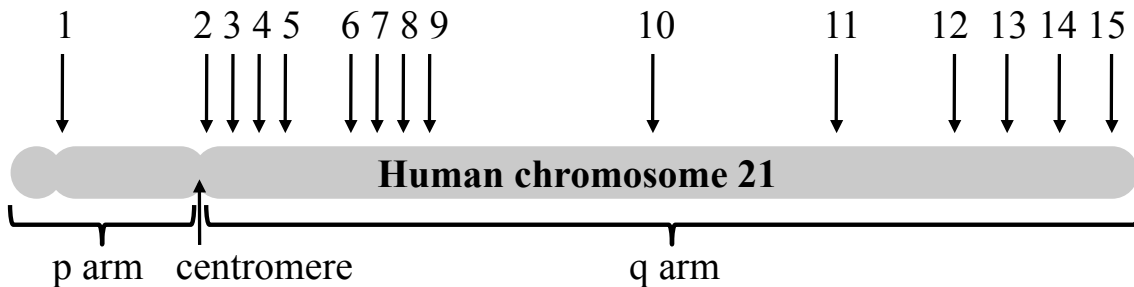
Primate phylogenetic tree



Student Guide: Jumps to Speciation



15 locations where copies of human endogenous retrovirus K (HERV-K) long terminal repeat (LTR) sequences have been inserted



HERV-K copies are present at these locations															
Primates	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Chimpanzee	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓
Gibbon		✓		✓					✓	✓	✓				
Gorilla		✓	✓	✓		✓	✓		✓	✓	✓	✓		✓	✓
Human	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
New World monkey															
Old World monkey										✓	✓				
Orangutan		✓		✓			✓		✓	✓	✓			✓	✓

Purpose: Construct a phylogenetic tree of primates based on the locations of inserted retroviral DNA in chromosome 21.

Background: A phylogenetic tree is a family tree showing which organisms are more closely or more distantly related to each other. The positions of branches on the tree indicate relatively how far back in time the lineages shared common ancestors. See the example phylogenetic tree (at the top of the first page of this handout) and check in with your teacher for further instruction.

Your mission is to draw a family tree of humans, other apes and monkeys based on evidence from DNA. A number of transposons, retrotransposons and retroviruses have inserted copies of themselves at locations throughout the human genome. For simplicity, you will consider only copies of a retrovirus called human endogenous retrovirus K (HERV-K), and you only have to consider one part of the human genome, chromosome 21.

As shown in this handout's diagram (in the middle of the first page), humans have 15 copies of the HERV-K long terminal repeat (LTR) DNA sequence inserted into chromosome 21. As seen in the chart (at the bottom of the first page), some of those copies are missing in various apes and monkeys.

Procedure:

With the phylogenetic tree example and the chart indicating where the HERV-K copies are present in each lineage, draw a phylogenetic tree for the seven ape and monkey lineages. Indicate which lines of common ancestors first received copies of the HERV-K LTR at each of the 15 different locations. (Write the location number or numbers above each horizontal line of common ancestors.)

Analysis:

1. Label the relative change in time on your diagram.
2. Label all nodes using letters A-F. The node labeled "A" should indicate the earliest node in time.

3. Which node represents the common ancestor of all listed primate lineages?
4. Which node indicates the most recent common ancestor of humans and chimpanzees?
5. Which node indicates the most recent common ancestor of chimpanzees and gibbons?
6. Is a gorilla more closely related to a chimpanzee or an orangutan? Explain.

7. Which two lineages are most closely related? Explain.
8. How many divergences occurred since the most recent common ancestor of New World monkeys and the gorillas?
9. Research each primate's evolutionary history. Try to indicate the number of millions of years ago for each divergence. Label these approximate times on your phylogenetic tree.
10. Choose a primate lineage to research further. Describe its physical appearance and behavior.
11. Did retrovirus HERV-K affect the evolution of primates? Explain. What other data might be collected to help answer this question?