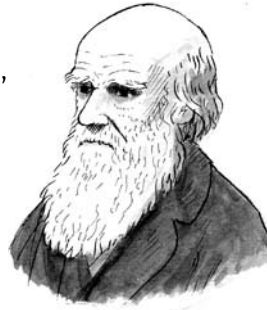


Judgment Day: Intelligent Design on Trial

PROGRAM OVERVIEW

Through courtroom scene recreations and interviews, NOVA explores in detail one of the latest battles in the war over evolution, the historic 2005 *Kitzmiller v. Dover Area School District* case that paralyzed a community and determined what is acceptable to teach in a science classroom.



The program:

- traces how the issue started in the small, rural community of Dover, Pennsylvania, and progressed to become a federal court test case for science education.
- defines intelligent design (ID) and explains how the Dover School Board was the first in the nation to require science teachers to offer ID as an alternative.
- chronicles the history of legal efforts involving the teaching of evolution, beginning with the Scopes Trial in 1925 and culminating in 1987 when the Supreme Court ruled against teaching creationism.
- summarizes Charles Darwin's original theory of evolution, as presented in his seminal 1859 work, *The Origin of Species*.
- recreates portions of the trial from court records, noting that parents who initiated the lawsuit set out to show that the board had religious motivations for teaching ID.
- presents evidence for the prosecution, including transitional fossils and genetic confirmation of Darwin's theory.
- reports testimony about the nature of science, including what a scientific theory is, how science is done, and why ID is not science.
- presents evidence for the defense, including the idea of irreducible complexity in structures like the bacterial flagellum, a system that provides propulsion for some bacteria.
- shows a structure similar to the flagellum, but less complex, that functions in bacteria as an apparatus for transmitting disease.
- recounts how the prosecution found evidence showing that the text referred to as a resource for ID, *Of Pandas and People*, had originally been a creationist text.
- presents closing arguments and the judge's decision finding both that members of the school board had religious motivations for introducing intelligent design into the classroom and that ID was not a scientific theory.

BEFORE WATCHING

- 1 Ask students to describe the nature of science and the process by which scientists investigate the natural world. Define "hypothesis" and "theory" for students and have them come up with examples of each (see *The Nature of Science* on page 3).
- 2 Organize students into three groups. Assign each group to take notes on one of the following program topics: evidence supporting intelligent design as a scientific theory, evidence that ID is not a scientific theory, and evidence supporting the theory of evolution.

AFTER WATCHING

- 1 Have each group meet and create a synopsis of its notes to present to class. What was the judge's final decision? Discuss his ruling with the class. What evidence did he base his decision on?
- 2 Ask students to describe some of the characteristics of science. (*Science is a systematic form of inquiry, based on observation, prediction, reasoning, and testing, that seeks to explain how the natural universe works. Scientific hypotheses can be tested and experimental results reproduced or observations repeated.*) What kinds of questions do scientists ask? (*A biologist might ask, "How do bees find pollen? When do they collect it? How do they find their way back to the hive? What is the pollen used for?"*) Would an investigation into animal migration be science? The predictions of an astrologer? The decoding of the human genome? Psychic mind-reading? Why or why not?

Taping Rights: Can be used up to one year after program is recorded off the air.

CLASSROOM ACTIVITY

Activity Summary

Students evaluate a variety of data for the common ancestry of humans and chimpanzees, and consider their level of confidence in their conclusions as they review each piece of data.

Materials for Each Team – Part I

- copy of “Weighing the Evidence” student handout
- photographs of chimpanzees (see page 5 for photo resources)
- copy of “Hominidae Family Tree” student handout
- copy of “Karyotype Idiograms: Human and Chimpanzee” student handout
- copy of “The Chromosome Shuffle” student handout
- copy of “Comparing Chromosomes” student handout
- scissors
- 1 light blue and 1 yellow highlighter

Materials for Each Student – Part II

- copy of “Sequence Search” student handout
- **optional:** printout of “Human Chromosome 2: Region 2q13” (55 pages) at www.pbs.org/nova/teachers/activities/3416_id_o6.pdf

Background

Evolutionary biologists assert that close biological relationships indicate common ancestry. Humans have long been classified with the great apes (the orangutans, gorillas, and chimpanzees) based on their very similar anatomy and physiology. More recently, molecular genetic data (DNA) has confirmed humans’ close biological relationship with the chimpanzee (and to a lesser extent the other great apes).

In this activity, students evaluate anatomical and genetic data regarding a shared ancestor for humans and chimpanzees. Students consider whether each piece of data supports the hypothesis that humans and chimpanzees share a common ancestor, and reflect on how confident they are in their conclusions with each piece of data they review. In this way, they come to understand how scientists become more confident in their conclusions as confirmation for their hypotheses accumulates. It is important in this activity to dispel the misconception that humans descended from apes and to emphasize that humans and chimpanzees share a common *extinct* ancestor that was different from either of them.

This common ancestor likely did not look like either of the modern species but shared characteristics of both. Both humans and chimpanzees are equally evolved from this ancestor but in different ways, like cousins with the same great-great-great grandfather. The attributes of the cousins come from the grandfather, not one another.

LEARNING OBJECTIVES

Students will be able to:

- define and differentiate fact, hypothesis, law, and theory.
- explain what a karyotype is.
- describe the similarities and differences between human and chimpanzee chromosomes.
- summarize the chromosomal evidence showing that humans and chimpanzees share a common ancestor.

Video is not required
for this activity.

DEALING WITH CONTROVERSY

In some communities, teaching evolution can be controversial. To learn more about strategies for preventing potential conflict when teaching evolution, see “Dealing with Controversy,” a unit that accompanied the PBS *Evolution* series, at www.pbs.org/wgbh/evolution/educators/teachstuds/pdf/unit7.pdf or “Overcoming Roadblocks to the Teaching of Evolution” from the University of California Museum of Paleontology at evolution.berkeley.edu/evosite/Roadblocks/index.shtml

To support educational leaders and other stakeholders in their understanding of and response to challenges to teaching evolution, NOVA has developed a briefing packet for educators. Find it online at www.pbs.org/nova/id/media/nova-id-briefing.pdf

Learn more about what both sides say about the issue and find more resources—including a two-session online professional development workshop on teaching evolution—at the NOVA Web site at www.pbs.org/nova/id

CLASSROOM ACTIVITY (CONT.)

The activity should take one to three class periods. If students have not learned how to read DNA code, you may want to do just Part I of the activity that compares karyotypes, explores phylogenetic relationships, and investigates chromosomal rearrangements. Part II of the activity further explores the DNA data that supports the fusion of two ancestral chromosomes to produce a single chromosome in humans. For this part of the activity, students should be familiar with how DNA bases complement each other and how DNA fits together (5'–3' orientations).


The following table from the "Weighing the Evidence" student handout shows how the lesson progresses. It outlines the evidence students will be considering and shows when students will rate how confident they are that the hypothesis is true based on the evidence.

Hypothesis: Humans and chimpanzees share a common ancestor.

Evidence and Task				
Data Set 1	Data Set 2	Data Set 3	Data Set 4	Data Set 5
compare human and chimpanzee physical traits	compare human and chimpanzee chromosomes	investigate the chromosome shuffle	investigate human chromosome 2	examine human telomere DNA code

Confidence in Hypothesis (1 – least confident to 10 – most confident)

Confidence based on Data Set 1				
Confidence based on Data Sets 1 and 2				
Confidence based on Data Sets 1, 2, and 3				
Confidence based on Data Sets 1, 2, 3, and 4				
Confidence based on all Data Sets				



THE NATURE OF SCIENCE

The terms *fact*, *law*, *hypothesis*, and *theory* are used frequently and sometimes interchangeably in day-to-day conversations. But for scientists, they have very specific meanings. The following definitions* were developed by members of the National Academy of Sciences:

fact: In science, an observation that has been repeatedly confirmed.

law: A descriptive generalization about how some aspect of the natural world behaves under stated circumstances.

hypothesis: A testable statement about the natural world that can be used to build more complex inferences and explanations.

theory: In science, a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses.

In science, a theory is often the end product of decades or centuries of scientific research that incorporates numerous observations about the scientific phenomenon it is trying to explain. A theory represents the best present explanation for a scientific phenomenon.

See *Scientific Term Examples* on page 4 for examples of each term.

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CLASSROOM ACTIVITY (CONT.)

Procedure

Part I

- 1 To get students thinking about the nature of science, introduce the following engagement activity: Tell students they have been hired to investigate a crime scene in which someone appears to have broken into the principal's office the day before and changed every student's science grade to an "F." In a preliminary analysis, police found blood on the floor where the principal's office glass door had been shattered. Ask students what types of evidence they might look for at the crime scene. (*Students might note physical evidence such as fingerprints, hair, fiber, DNA from the blood sample; or eyewitness reports from people who saw the crime committed.*) List student responses on the board. Now have students rank their confidence (from most to least) in each piece of evidence in terms of identifying the person who broke in. Which evidence would be least convincing by itself? (*Fingerprints, hair, and fiber samples, which could have come from any student visiting the principal's office.*) Which would be most convincing by itself? (*The DNA from the blood sample.*) What would strengthen the case? (*Additional evidence that supports the DNA evidence, such as eyewitnesses, additional physical evidence, or a motive for the person who changed the grades.*)
- 2 Similar to forensic experts, research scientists also gather evidence (data) to confirm or refute tentative explanations (hypotheses) that they have about the natural world. Both forensic experts and scientists use the word *theory*. But while a police investigator may have a theory about who committed a crime, in science, *theory* means something very different. Ask students to define what they think *theory* means in science. How does a scientific theory differ from a hypothesis? A law? A fact? (See *The Nature of Science* on page 3 for definitions.) Provide students with an example of each term. (See *Scientific Term Examples* on this page for some suggestions.) Have students compare the examples and elaborate on what is different about each of them. To ensure that students understand the differences, have them come up with examples of each term on their own.
- 3 Evolution is a theory. One of its core propositions is that organisms alive today can be traced back through time to a common ancestor. Evolutionary biologists investigate the similarities among organisms; they might hypothesize, for example, that the more similar organisms are genetically, the more closely related they are, and the more likely they are to have evolved from a recent common ancestor. In many ways, humans are more like chimpanzees than any other animal. Tell students that they are going to consider data to support or refute the following hypothesis:
 - **Hypothesis: Humans and chimpanzees share a common ancestor.**

SCIENTIFIC TERM EXAMPLES

The following examples are provided to demonstrate the differences in science terminology. **Facts** are repeatedly confirmed observations, **laws** describe aspects of the natural world (but do not explain them), **hypotheses** are testable statements, and **theories** use multiple lines of evidence to explain aspects of the natural world.

Fact: When a plant producing all round seeds is crossed with a plant producing all wrinkled seeds, the resulting plants will produce only round seeds.

Law: Allele (gene) pairs separate during meiosis and end up in different gametes. (Mendel's Law of Segregation)

Hypothesis: If a girl expresses a recessive trait, she will have two recessive genes for the trait.

Theory: Each chromosome contains a collection of small units called genes, which are the units of heredity. (Chromosome theory of heredity)

CLASSROOM ACTIVITY (CONT.)

- 4 Organize students into pairs and distribute the “Weighing the Evidence” handout to each team. Review the activity with students.
- 5 Tell students they will start the activity with **data set 1** (comparing traits). Provide each team with photographs of chimpanzees. Ask students to create a two-column table on a sheet of paper (humans in one column and chimpanzees in the other) to compare similarities and differences among physical traits between the two. Have students consider posture, leg and arm length, feet, teeth, skull, and facial features. *(Similarities include that both species have feet, legs, and grasping hands; both have eyes, a mouth, and a nose in about the same areas on the face; both have body hair and no tail. While some overall major features are similar, many differences exist in how these features are expressed: Chimpanzees have arms longer than legs (the opposite of humans); chimps have low foot arches, humans have high arches; chimps have long canine teeth, humans do not; chimps have a wide nasal opening, humans have a smaller opening; chimps have very hairy bodies, humans have relatively little hair. In addition, chimps walk on all fours while humans are bipedal.)*
- 6 Ask students to consider whether the physical characteristics comparison supports the hypothesis. Based on this data alone, have each team record how confident it is that humans and chimpanzees share a common ancestor (on a scale of 1 [least confident] to 10 [most confident]).
- 7 Tell students they are now going to consider some genetic evidence for common ancestry of humans and chimpanzees. Distribute the “Hominidae Family Tree” handout to teams. Inform student that this is what is known as a phylogenetic, or family, tree. This tree is based on DNA sequence comparisons among the species in this family. The resulting branches of the tree are what scientists infer to be the evolutionary relationships among these species.
- 8 The handout also includes the number of chromosomes for each species. Ask students what similarities and differences they notice among the number of chromosomes for these species. When students notice that humans have 1 pair (2 chromosomes) fewer chromosomes than the other species, have them consider what might explain this.
- 9 Ask students to develop two hypotheses that would explain why humans and chimpanzees—given a hypothetical common ancestor—have a different number of chromosomes. *(Two possible hypotheses for the difference in number of chromosomes between humans and chimpanzees might be either that one long ancestral chromosome split to form two shorter chromosomes in the chimp genome or that two short ancestral chromosomes fused to form one longer chromosome in the human genome.)*

CHIMPANZEE PHOTOS

Photos of chimpanzees can be found at the following sources:

Encyclopedia Britannica Online
updatecenter.britannica.com/art?assemblyId=91464&type=A

Pennsylvania State University
www.science.psu.edu/alert/photos/miscphotos/Chimp3.jpg

www.science.psu.edu/alert/photos/miscphotos/Chimp1.jpg

NOVA scienceNOW
www.pbs.org/nova/sciencenow/3209/images/01-diam-chimpscreaming-l.jpg

KEY TERMS

common ancestor: An extinct group of organisms that gave rise to two or more later groups.

evolution: Biological evolution is descent with modification. It includes both small-scale evolution (the cumulative changes that occur in a population over time) and large-scale evolution (the descent of different species from a common ancestor over many generations). Evolution is a scientific theory, supported by a great deal of evidence, facts, inferences, and tested hypotheses.

idiogram: A diagram of the chromosome complement of a species, showing banding patterns, that is often used to compare karyotypes of different species.

intelligent design: The idea that certain features of the universe and life are too complex to have arisen by natural causes and instead are best explained as being the product of an intelligent designer.

karyotype: A complete set of chromosomes that constitutes the entire genome of a species. Karyotypes are usually arranged in pairs by number and size (largest to smallest).

CLASSROOM ACTIVITY (CONT.)

- 10 Inform students that they will now look more closely at how the actual chromosomes themselves compare. Introduce **data set 2** (comparing chromosomes) to students—human and chimpanzee karyotype comparisons. Review what a karyotype is with students. (*A karyotype is a complete set of chromosomes that constitutes the entire genome of a species.*) Distribute the “Karyotype Idiograms: Human and Chimpanzee” student handout and a set of light blue and yellow highlighters to each team.
- 11 Explain that the idiograms are graphic representations of actual karyotypes and that, since both members of a matched pair of chromosomes look alike, only one member of each homologous pair is represented. Inform students that the banding patterns are created when the chromosomes are stained with a chemical. The chemical used for this karyotype is called Giemsa, which always attaches itself to regions of DNA with high concentrations of adenine-thymine (A–T) pairs. The dark bands are called G-bands. The bands do not represent genes (there could be hundreds of genes within one band) but they do give an indication of nucleotide sequences. Point out to students that the constricted portion of the chromosome is called the “centromere.”
- 12 Assign each team a specific set of chromosomes to compare (i.e., team A does sets 1, 2, and 3; team B does sets 4, 5, and 6; and so on). Have students use a light blue highlighter to mark banding areas on both chromosomes that are the same and a yellow highlighter to mark areas on both chromosomes that are different. Have students compare banding patterns, chromosome length, and positions of centromeres.
- 13 After all teams have finished, ask each team to report to the class the similarities and differences they observed. (*Students should note that there are some banding pattern and centromere differences between the two karyotypes, that human chromosome 2 is much longer than the chimpanzee chromosome 2, and that there is an extra chimpanzee chromosome.*) Then have each team on its own consider whether the karyotype comparisons support the hypothesis that humans and chimpanzees share a common ancestor. Then have students—taking into account both data sets they have reviewed so far—rate how confident (on the scale of 1–10) they are that humans and chimpanzees share a common ancestor.
- 14 Tell students they will now review **data set 3** (chromosome shuffle) to investigate some possible explanations for the banding pattern differences they noted. Distribute the “Chromosome Shuffle” handout to each team. Have students read about some of the different types of changes that chromosomes can undergo and correctly identify the types of changes shown on the handout.

KEY TERMS (CONT.)

mutation: A permanent change in the DNA sequence of a gene. Most mutations are harmless, though some can be harmful. Occasionally, a mutation can increase an organism’s chance of survival.

natural selection: A process in which genetically-based characteristics allow some individuals to survive, giving them a reproductive advantage in their local environments. These characteristics tend to increase in frequency in the population over time while those that are disadvantageous decrease in frequency.

phylogenetic tree: A graphical representation of the evolutionary relationships of a group of organisms. Phylogenetic trees can be based on different types of evidence, such as gene sequence, genomic data, or protein analysis. Dates are constantly being refined as scientists gain more information from fossil and molecular analyses and develop more sophisticated measuring techniques.

science: A systematic form of inquiry, based on observation, prediction, reasoning, and testing, that seeks to explain how the natural universe works. Science operates by means of the scientific method—the formulation of hypotheses that are consistent with observed phenomena and the subsequent testing of these hypotheses to determine their validity. Scientific knowledge is constantly refined or altered by new evidence; if a hypothesis is not supported by experimentation or observation, scientists reject it and formulate a new hypothesis that is tested against the observed data. Science involves reasoning about the natural world. It does not involve supernatural explanations of the physical universe. Authentic scientific inquiry is based on the things that can be studied and tested.

CLASSROOM ACTIVITY (CONT.)

- 15** Once students have learned about and identified the changes, distribute the “Comparing Chromosomes” handout and scissors to each team. Have students work in their teams to determine whether any of the chromosomal changes they learned about can account for the differences between these chromosomes (students are given extra chimpanzee chromosomes to cut out and manipulate if needed). Students will discover that the two chromosomes they have been given to compare (4 and 5) differ only in pericentric inversions (inversions that include the chromosome’s centromere).
- 16** After students have found the pericentric inversions in chromosomes 4 and 5, explain to students that pericentric inversions account for most of the differences between the two karyotypes and that scientists have determined that, when these chromosomal mutations are taken into account, the two karyotypes are virtually identical (homologous), with the exception of the longer human chromosome 2. (See *Activity Answer* on page 10 for details about how the two karyotypes compare.)
- 17** Ask teams to consider whether this data set supports the hypothesis that humans and chimpanzees share a common ancestor. Then have students—taking into account the three data sets they have reviewed—rate how confident they are (1–10) that humans and chimpanzees share a common ancestor.
- 18** Revisit the karyotype comparison and ask students to consider **data set 4** (human chromosome 2) to think about what might be responsible for the final difference between the two karyotypes (the long human chromosome 2). Have them refer to their “Chromosome Shuffle” handouts to identify whether one of the types of mutations could explain the difference. (*Some students may notice that fusion [or even fission] could have been the type of change responsible.*)
- 19** To test the idea that fusion is responsible, have students cut out the extra chromosome on their “Karyotype Idiograms: Humans and Chimpanzees” handout and see whether it would create a match with human chromosome 2 if fused with the current chimpanzee chromosome 2. (*Students should discover that the chromosome has to be inverted in order to match up correctly.*)
- 20** Ask teams again to consider whether this fourth data set supports the hypothesis that humans and chimpanzees share a common ancestor. Then have students—taking into account the four data sets they have reviewed—rate how confident they are (1–10) that humans and chimpanzees share a common ancestor.

STOPPING POINT

You can stop the activity here and use the questions on the “Weighing the Evidence” handout to guide a final discussion, and ask students which of their hypotheses about why humans and chimpanzees have a different number of chromosomes is best supported by the data. Or you can move to Part II of the activity in which students examine human DNA code for additional evidence regarding the common ancestry of humans and chimpanzees.



CLASSROOM ACTIVITY (CONT.)

Part II

- 1 Ask students what further evidence they could look for to test the hypothesis that the fusion of two ancestral chromosomes formed human chromosome 2. If students don't suggest looking at the DNA code for evidence, give them a clue by asking them what one of the strongest pieces of evidence was in the principal's office break-in. (*Some students will likely remember it was the DNA evidence.*) When students suggest DNA, tell them that the telomeres found at the tips of all chromosomes contain a unique sequence of DNA code that could be searched for in human chromosome 2.
- 2 Ask students what it would mean if the sequence were found and what it would mean if it were not found. (*If found, it would provide support for the hypothesis that two short ancestral chromosomes joined to create human chromosome 2; if not found, it would support the idea that the two ancestral chromosomes did not join, or if they did, that their telomeres may have been lost. Not finding the sequence could also suggest that human chromosome 2 may have represented the ancestral form that split during chimpanzee evolution, producing the two shorter pieces found in chimps today.*)
- 3 Tell students that they will now examine **data set 5** (DNA telomere sequence search) to look for the DNA sequence that would exist if telomere DNA met and joined. Distribute the "Sequence Search" handout to each student. Inform students that the letters on the page represent only one strand of bases from the DNA molecule, since the matching bases in the complementary strand are a given (A with T, C with G). Dealing with only one strand simplifies reading the code.
- 4 To help students know what to look for in the sequence where the two head-end telomeres attach, explain that the DNA molecule in one of the chromosomes needs to rotate on its axis a half-turn in order to connect properly with the telomere DNA in the other chromosome. (If your students are familiar with the 5'-3' opposite orientations of the parallel DNA strands, you could point out that this rotation is because the 5' end of the strand in one chromosome must join the 3' end of the strand in the other chromosome.) You can illustrate this by doing the following demonstration: Hook the curved fingers of one hand to the curved fingers of the other by rotating one hand, wrist, and forearm a half-turn. When the DNA rotates, the single strand looks like: ...
TTAGGGTTAGGGCCCTAACCCCTAA... (going from TTAGGG to CCCTAA, the sequence students will try to determine).
- 5 Point out that the sequence varies a bit in places due to mutations (i.e., an "A" may be replaced with a "G" in some sequences so that it reads TTGGGG, or with a "T" so it reads TTTGGG, and so on).
- 6 Have students work by themselves to determine what the sequence would be at the fusion point and search for a fusion site on their handout. Circulate among students to help any having trouble.

A LITTLE PERSPECTIVE

Students will be searching for the fusion point of the two ancestral chromosomes within just a *very small* section of a larger region that contains the sequence. If you would like to help students gain some perspective on the amount of DNA that is in this larger region, you can print out the entire 2q13 region that contains the fusion point (55 pages) from www.pbs.org/nova/teachers/activities/3416_id_o6.pdf.

For a visual demonstration of the amount of code you can tape the ends of the pages together and hang them around the classroom walls (about 15.4 meters long).

Before or after their search for the fusion point, you can present the following information to help students better understand the amount of DNA in chromosome 2:

- Point to the paper lining the classroom and tell students that it represents the complete sequence of region 2q13—nearly 177,000 base pairs. (The region is located on human chromosome 2, q arm, subsection 13. The "arms" appear on either side of the chromosome's centromere; the q arm is always the longest arm.)
- The page of DNA code that students are examining (lines 107881 through 109501 of the region) contains 1,680 base pairs. This represents about 1 percent of the region where the fusion is located and only about 0.0007 percent of entire chromosome 2 (more than 243 million base pairs long). Chromosome 2 is the second-longest human chromosome.
- If the entire chromosome 2 were printed out at the scale of the papers around the room it would extend about 20 kilometers (to help students appreciate that distance you may want to have them use a map to locate a point 20 kilometers from their school).

CLASSROOM ACTIVITY (CONT.)

- 7 After each student has tried to determine the sequence and locate the fusion site, as a class review what the correct sequence would be and why, and point out where the fusion site is if students have not already found it. Have students color the 2A telomere region with the light blue highlighter and the 2B telomere portion with the yellow highlighter. Point out to students that these segments are the remains of the ends of ancient chromosomes, and that each student has these molecular fossils in almost all of his or her cells.
- 8 Once everyone has located the site, have students discuss in their teams which of the two hypotheses they developed about why humans and chimpanzees have a different number of chromosomes is best supported by the chromosome fusion evidence. *(It supports the hypothesis that human chromosome 2 was formed by the fusion of two ancestral chromosomes. This would have likely occurred after humans and chimpanzees branched off from a common ancestor.)*
- 9 Have students consider in their teams whether the fifth data set they just evaluated—the fusion data—supports the original hypothesis they were investigating—that humans and chimpanzees share a common ancestor. Then have each team record a final 1–10 rating of how confident they are that humans and chimpanzees share a common ancestor based on *all* the data they have evaluated.
- 10 Have each team compare its original confidence ratings with its final ratings. As a class, discuss whether each team’s confidence about the hypothesis changed as new data was acquired. Use the questions on the student handout as a guide for the discussion. *(Answers are listed on page 10.)* Ask students what it would mean in terms of evolution if humans and chimpanzees were closely related. *(It would mean that humans and chimpanzees have a relatively recent extinct common ancestor [estimated to be between five and seven million years ago]. If needed, clarify that humans did not descend from chimps, but rather most likely share a common ancestor with chimpanzees [as well as other great apes in a more distant past]. Humans and chimpanzees have both evolved, or changed, from their extinct common ancestor.)*
- 11 To help students better understand the role of genetics in evolution, show the portion of the program that explains how genetics drives natural selection and how an expert witness used chromosome fusion to support the validity of evolution during the Dover trial. www.pbs.org/nova/teachers/activities/3416_id.html#video (QuickTime or Windows Media plug-in required.)
- 12 As an extension, have students investigate other lines of evidence supporting common ancestry, including the fossil record, homology, embryology, anatomical and molecular comparisons, and biogeography. For more information, see “What Is the Evidence for Evolution?” at evolution.berkeley.edu/evolibrary/search/topicbrowse2.php?topic_id=46

STANDARDS CONNECTION

The “Weighing the Evidence” activity aligns with the following National Science Education Standards (see books.nap.edu/html/nses).

GRADES 9–12

Life Science

- The molecular basis of heredity
- Biological evolution

History and Nature of Science

- Nature of scientific knowledge

Classroom Activity Author

Larry Flammer taught high-school biology in San Jose, California, for 38 years. He now serves as Webmaster for the Evolution and Nature of Science Institutes Web site, where he and other biology teachers develop lesson plans for the site’s collection. He has written for PBS’s *Evolution Teacher’s Guide* and *The American Biology Teacher*. For a version of this lesson that focuses mostly on chromosome fusion, and includes a PowerPoint presentation, visit www.indiana.edu/~ensiweb/lessons/mmm.html

ACTIVITY ANSWER

Weighing the Evidence Student Handout

Student Handout Questions

- 1 Regarding the hypothesis that humans and chimpanzees share a common ancestor, how much did your acceptance change from the first to the last piece of evidence you studied? How much did your confidence in your conclusions change as you accumulated more evidence? *Answers will vary, but it is likely that students were more certain that humans and chimpanzees share a common ancestor at the end of the activity and more confident in their conclusions with a larger body of evidence. To date, there is no generally accepted evidence that contradicts the theory of evolution.*
- 2 Are you 100 percent sure that the hypothesis that humans and chimpanzees share a common ancestor is true? Explain. *If any students are 100 percent sure, point out to them that scientists are never 100 percent sure of the certainty of their hypotheses. The more evidence that supports a hypothesis or theory, the more confident scientists can be in it, but there is always the possibility that a hypothesis or theory will be revised based on new, more compelling evidence.*
- 3 What data did you find the least convincing? What data did you find the most convincing? Explain your choices. *Students will likely say that the physical characteristics comparison was the least convincing and that the telomere DNA evidence was the most convincing.*
- 4 Could all the data be recreated by another scientist? Why is this important in science? *Yes, all the evidence could be recreated. Experimental reproducibility is a hallmark of a strong hypothesis. If an experiment cannot be recreated and results cannot be reproduced, or observations repeated, a hypothesis remains unconfirmed. Past organisms that cannot be directly measured, such as dinosaurs or ancestors of humans, can be inferred from fossil or molecular evidence.*

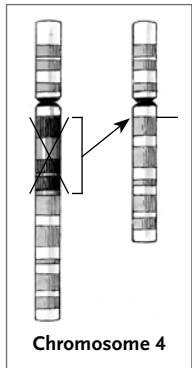
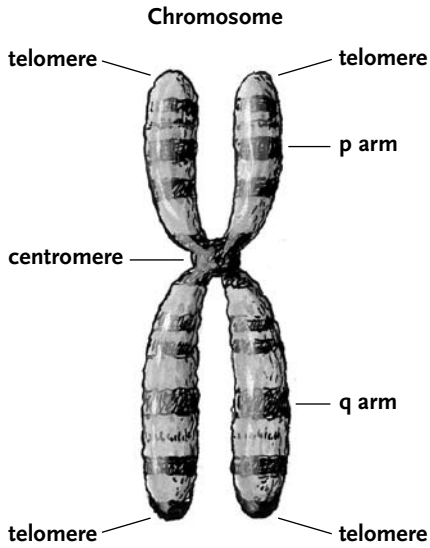
Karyotype Idiograms Student Handout

According to Jorge Yunis and Om Prakash, the scientists who authored the study* from which the karyotype idiograms in this lesson were drawn, human and chimpanzee have 13 “presumably identical” pairs of chromosomes (chromosomes 3, 6–8, 10, 11, 13, 14, 19–22, and XY) when heterochromatin is not considered. (Heterochromatin is tightly packed chromosomal material that stains deeply during interphase. It is believed to be genetically inactive.) Another six chromosomes only differ in pericentric inversions (chromosomes 4, 5, 9, 12, 15, and 16).

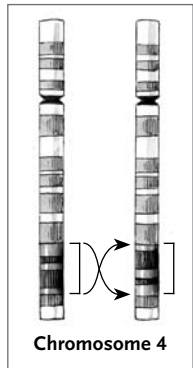
* “The Origins of Man: A Chromosomal Pictorial Legacy,” *Science*, Vol. 214, 19 March 1982, pages 1525–1530).

ACTIVITY ANSWER (CONT.)

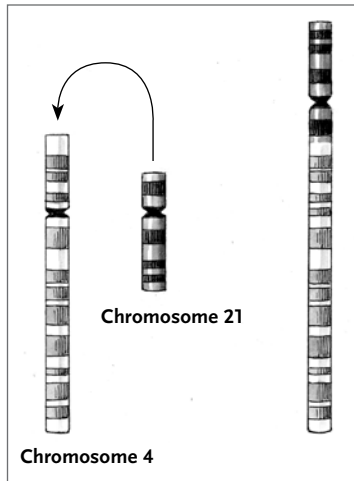
The Chromosome Shuffle Student Handout



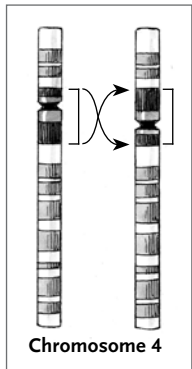
Deletion



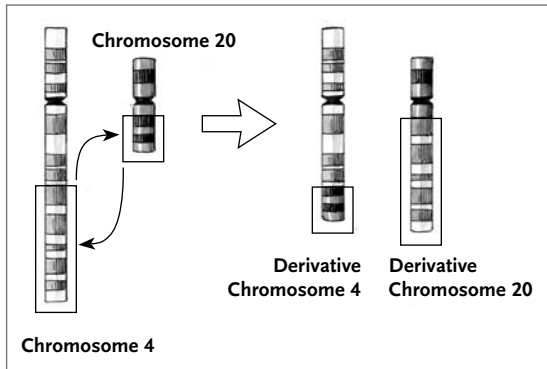
Paracentric Inversion



Fusion



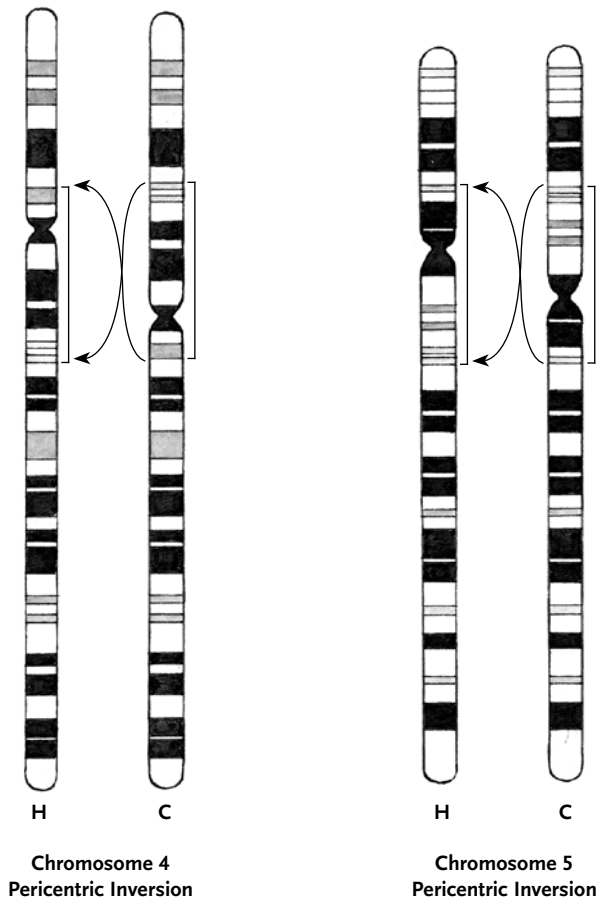
Pericentric Inversion



Translocation

ACTIVITY ANSWER (CONT.)

Comparing Chromosomes Student Handout



Sequence Search Student Handout

Fusion point search sequence:

The idealized sequence in the graphic would be

...TTAGGG <fusion point> CCCTAA...

Due to mutations, the actual sequence within human chromosome 2 is

...GGTTAG <fusion point> CTAACC...

The fusion point occurs on the line with bp 108541 (after the 21st base pair on that line). At the fusion point, the code turns from being mostly Gs and Ts (and hardly any Cs), to being mostly Cs and As (and hardly any Gs).

The 2A telomere region (to be colored light blue) begins at about the 10th base pair on line 108301 and runs to 108541 (through the 20th base pair).

The 2B telomere region (to be colored yellow) starts at line 108541 (from the 21st base pair on) and runs to line 109081 at about the 33rd base pair.

LINKS AND BOOKS

Links

NOVA—Judgment Day: Intelligent Design on Trial

www.pbs.org/nova/id

Contains articles and multimedia features as well as streaming video of the entire two-hour NOVA program.

Evolution

www.pbs.org/evolution

Offers a multimedia library of video clips, an online professional development course, and lesson plans to accompany the seven-part PBS Evolution series.

Evolution on the Front Line

www.aaas.org/news/press_room/evolution

Includes an abbreviated guide for teaching evolution, talking points for teachers, evolution in the news, the American Association for the Advancement of Science board resolution on ID, and more from the AAAS.

Intelligent Design

www.naturalhistorymag.com/darwinanddesign.html

Offers brief position statements by three leading proponents of intelligent design, along with three responses from proponents of evolution, as well as an overview of the ID movement.

National Center for Science Education

www.natcensci.org

Serves as a clearinghouse for information intended to keep evolution in public school science education.

The TalkOrigins Archive

www.talkorigins.org

Offers a collection of articles and essays to provide mainstream scientific responses to the frequently asked questions about evolution. Daily transcripts of the trial and the court's decision can be found at www.talkorigins.org/faqs/dover/kitzmiller_v_dover.html

Teachers' Domain

www.teachersdomain.org

Provides media-rich resources that highlight key issues in evolution and the evolution vs. intelligent design debate.

Understanding Evolution

evolution.berkeley.edu

Provides information about what evolution is and what evidence supports it, the history of evolutionary theory, and ways to teach evolution for K–16 educators.

Books

Evolution vs. Creationism: An Introduction

by Eugenie C. Scott.

Berkeley, Calif.: University of California Press, 2005.

Provides an introduction to evolutionary theory, a history of the controversy, source documents from both sides of the debate, and additional resources for further exploration.

Finding Darwin's God: A Scientist's Search for Common Ground Between God and Evolution

by Kenneth R. Miller.

New York: Cliff Street Books, 1999.
Analyzes the scientific faults of ID and presents a religious scientist's accommodation of faith and science.

The Making of the Fittest: DNA and the Ultimate Forensic Record of Evolution

by Sean B. Carroll.

New York: Norton, 2006.
Explains how DNA provides compelling evidence for evolution and reveals new details about the evolutionary process.

Not in Our Classrooms: Why Intelligent Design Is Wrong for Our Schools

by Eugenie Scott and Glenn Branch, editors.

Boston: Beacon Press, 2006.
Answers many questions regarding the teaching of intelligent design, provides historical context for the ID movement, and offers concrete advice for those seeking to defend the teaching of evolution in their own communities.

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"Judgment Day: Intelligent Design on Trial" is produced by NOVA and Vulcan Productions, Inc., in association with The Big Table Film Company. NOVA is produced for PBS by WGBH Boston. © 2007 WGBH Educational Foundation and Vulcan Productions, Inc.



Funding for NOVA is provided by The DOW Chemical Company, David H. Koch, the Howard Hughes Medical Institute, the Corporation for Public Broadcasting, and public television viewers.



ID VIEWPOINTS

Links

Discovery Institute's Center for Science and Culture

discoverycsc.org

Provides a blog, reading list, frequently asked questions and answers, and other information about intelligent design.

Intelligent Design Network

www.intelligentdesignnetwork.org

Features press releases, information about events, publications, and more related to the intelligent design movement.

Book

Darwin's Black Box: The Biochemical Challenge to Evolution

by Michael J. Behe.

New York: The Free Press, 1996.
Provides examples of five biochemical systems to argue that life is "irreducibly complex."

Weighing the Evidence

One of the core propositions of biological evolution is that organisms alive today can be traced back through time to a common ancestor. Evolutionary biologists assert that the more similar organisms are genetically, the more closely related they are, and the more likely they are to have evolved from a recent common ancestor. In this activity, you will be considering whether the data you review supports the hypothesis that humans and chimpanzees share a common ancestor.

You will review each data set with your team members. After you review each data set, consider with your team members whether you think that data set supports the hypothesis. Then record in the chart how confident you are that the hypothesis is true based on the evidence. With each new data set you review, record your confidence level based on all the evidence you have reviewed to that point.

Questions

Write your answers on a separate sheet of paper.


- 1 Regarding the hypothesis that humans and chimpanzees share a common ancestor, how much did your acceptance change from the first to the last piece of evidence you studied? How much did your confidence in your conclusions change as you accumulated more evidence?
- 2 Are you 100 percent sure that the hypothesis that humans and chimpanzees share a common ancestor is true? Explain.
- 3 What data did you find the least convincing? What data did you find the most convincing? Explain your choices.
- 4 Could all the data be recreated by another scientist? Why is this important in science?

Hypothesis: Humans and chimpanzees share a common ancestor.

Evidence and Task

Data Set 1	Data Set 2	Data Set 3	Data Set 4	Data Set 5
compare human and chimpanzee physical traits	compare human and chimpanzee chromosomes	investigate the chromosome shuffle	investigate human chromosome 2	examine human telomere DNA code

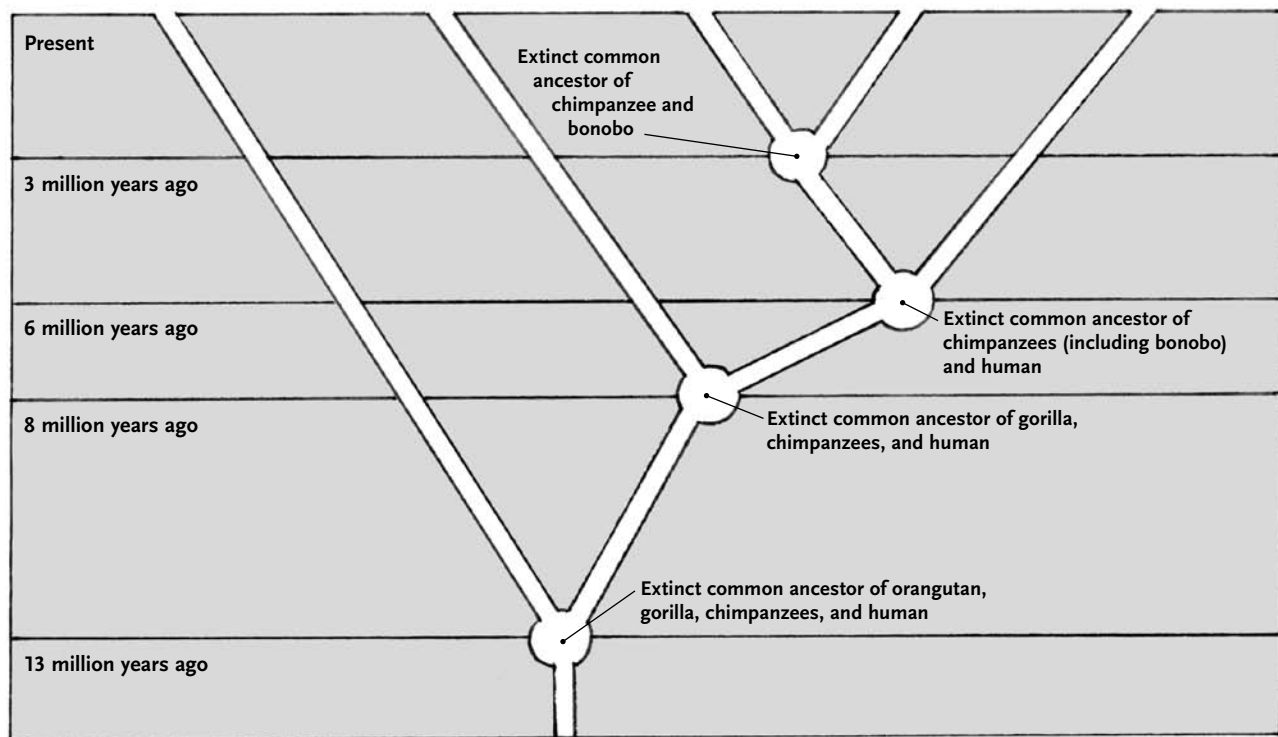
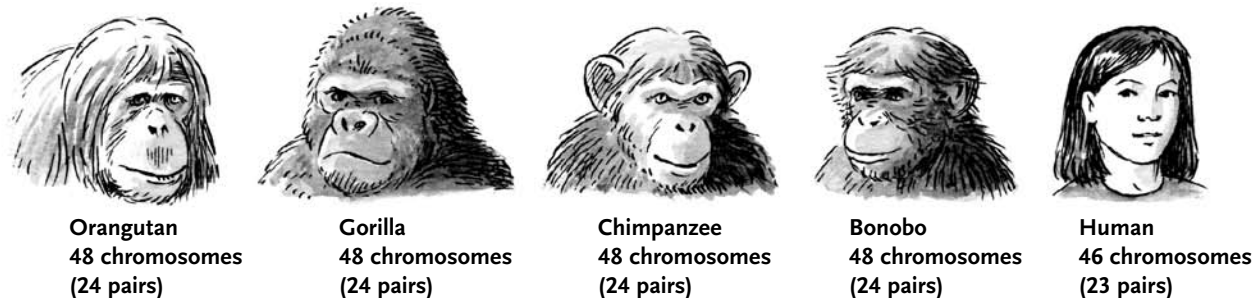
Confidence in Hypothesis (1 – least confident to 10 – most confident)

Confidence based on Data Set 1	
Confidence based on Data Sets 1 and 2	
Confidence based on Data Sets 1, 2, and 3	
Confidence based on Data Sets 1, 2, 3, and 4	
Confidence based on all Data Sets	

Hominidae Family Tree

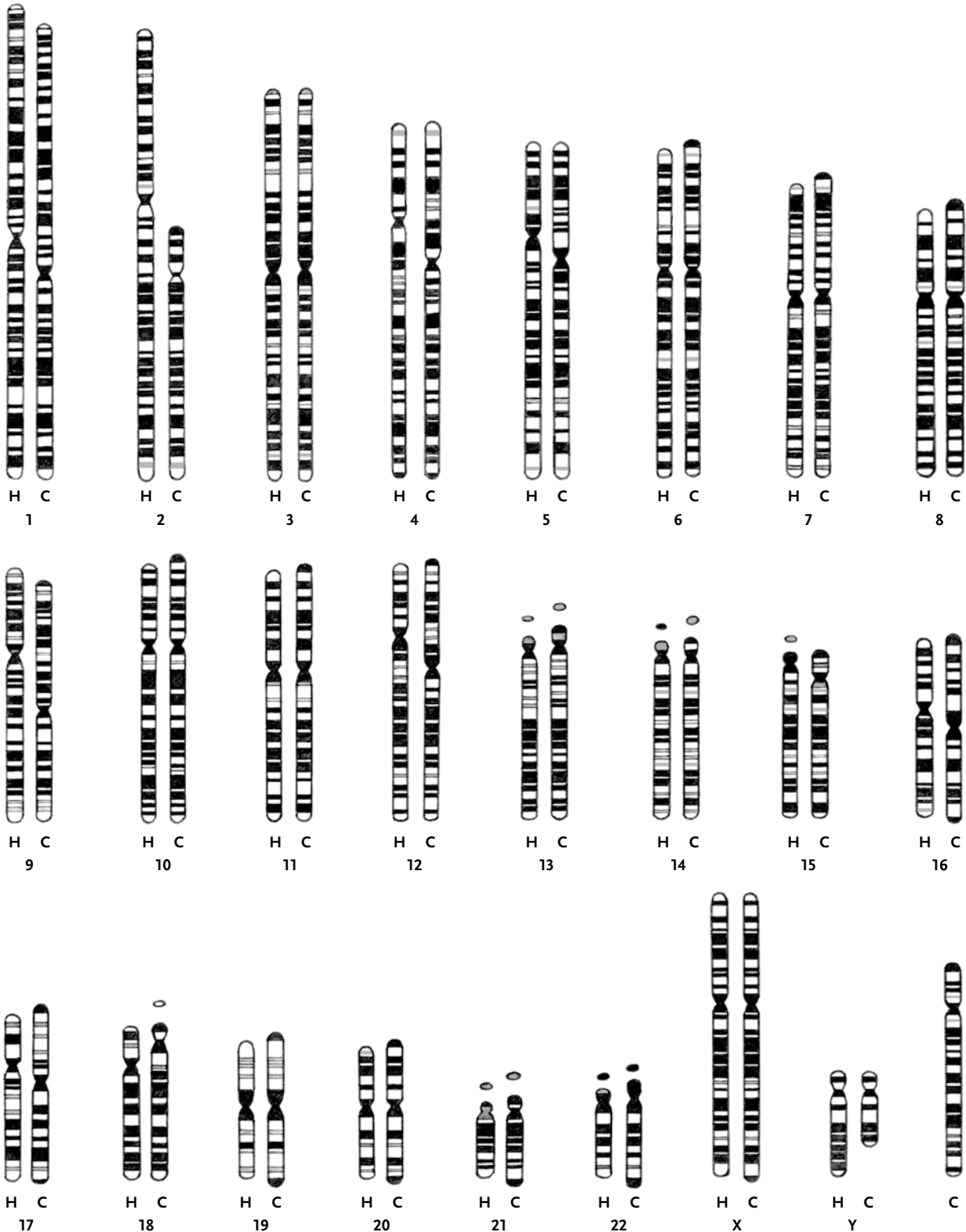
This is a phylogenetic tree, which is a hypothesis of the evolutionary history of a group of organisms. This tree is known as the Hominidae family tree. It was created by comparing the DNA sequences of humans, chimpanzees, bonobos, gorillas, and orangutans. Each juncture in the tree represents when a species is estimated to have branched off. For example, the chimp and bonobo have the most recent common extinct ancestor, some three million years ago. The next-most-recent common extinct ancestor—the one shared by chimpanzees and humans—is at about six million years ago. The next-most-recent common extinct ancestor—the one shared by chimpanzees and humans—is at about six million years ago.

This tree also includes information about the number of chromosomes for each species. What do you notice about the similarities and differences in number of chromosomes among the species in this family? If humans and chimpanzees share an extinct common ancestor, why do they have a different number of chromosomes? With your team members, **develop two hypotheses** that—given a hypothetical extinct common ancestor—would explain why humans and chimpanzees have a different number of chromosomes. Include in your hypotheses how many chromosomes you think an extinct common ancestor would have had. Write your hypotheses on a separate sheet of paper.



Note: Dates are based on genomic analysis and are approximate. Dates are constantly being refined as scientists gain more information from fossil and molecular analyses and develop more sophisticated measuring techniques.

Karyotype Idiograms: Human and Chimpanzee

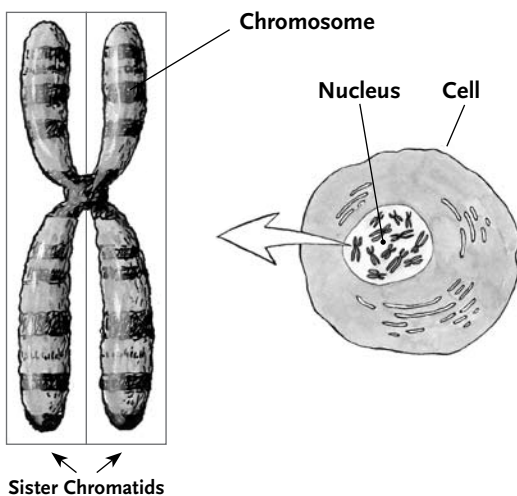


Based on idiograms from "The Origin of Man: A Chromosomal Pictorial Legacy," *Science*, Vol. 215, March 19, 1982; pages 1525–1530. Stained with Giemsa during late prophase (1000-band) stage.

The Chromosome Shuffle

Chromosomes contain all of our genetic code. Humans have 23 pairs of chromosomes that exist in nearly every cell in the body. As part of natural genetic changes over time, chromosomes are rearranged in a number of different ways, including inversions, deletions, translocations, fission, and fusion.

These mutations usually happen during the first prophase of meiosis, when sister chromatids twist around—or cross over—each other, and can lose, gain, or exchange parts to produce the kind of mutations shown here.



Procedure

1 Label these parts on the chromosome pictured.

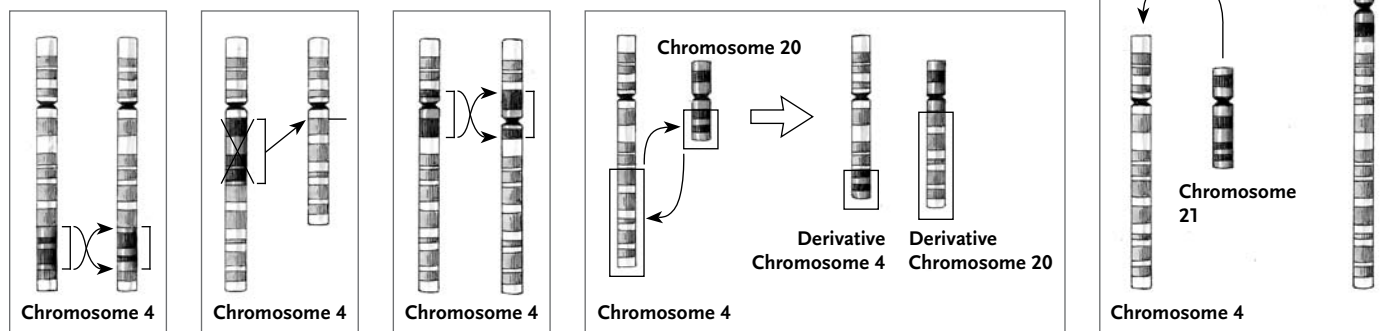
Telomere: At the ends of each chromosome are telomeres that help determine how many times a normal cell divides. Telomeres contain a unique repeating sequence of TTAGGG. Called tandem repeats, these show up 800 to 1,600 times in each telomere.

Centromere: The constricted region of the chromosome where two sister chromatids are joined and where spindle fibers attach. The centromere is essential for the division of the chromosome in the cell.

p arm: The p arm is the shorter arm of the chromosome.

q arm: The q arm is the longer arm of the chromosome.

The following idiograms—graphic representations of chromosomes—show only one half of the matched chromosome pair.



2 Read about each type of mutation below, and then write in the space under each set of chromosome drawings which type of change the drawing depicts. Not all definitions are pictured.

deletion: A segment of a chromosome is lost. Deletion of a gene or part of a gene can lead to a disease or abnormality.

duplication: A segment of a chromosome is duplicated on the same chromosome.

fission: A chromosome piece breaks apart, forming two shorter chromosomes.

fusion: Two different chromosomes are joined.

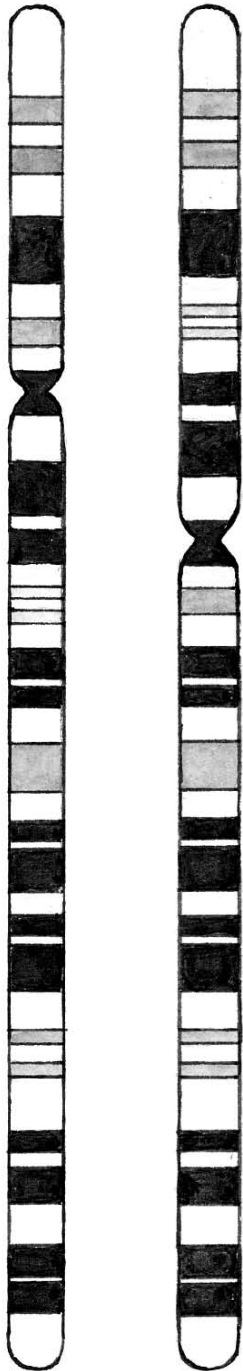
inversion (paracentric): A segment within just one arm (not including the centromere) of a chromosome is turned upside down.

inversion (pericentric): A segment containing both the centromere region and parts of both arms of a chromosome is turned upside down.

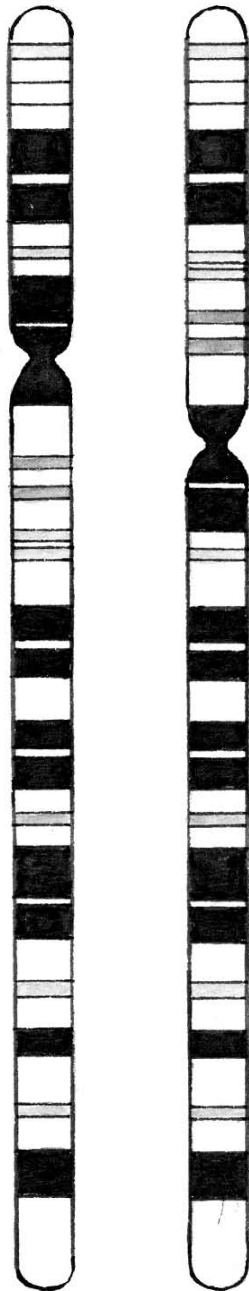
translocation (reciprocal): Two chromosomes trade pieces with one another.

Comparing Chromosomes

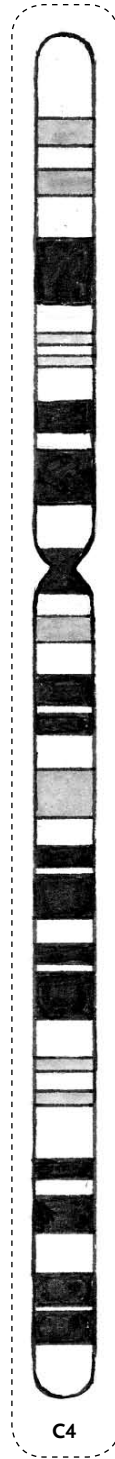
Cut out the extra chimpanzee chromosomes and compare them to their human chromosome counterparts to see if you can find any mutations that could account for the differences.



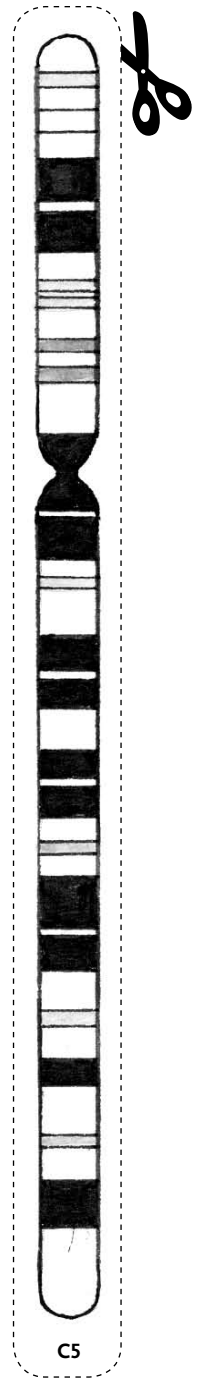
H
C
Chromosome 4



H
C
Chromosome 5



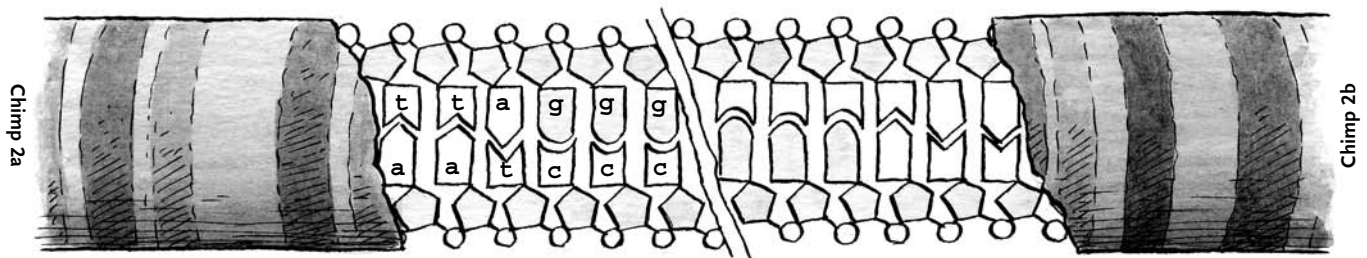
C4



Sequence Search

The following DNA base sequences are from a segment of present-day human chromosome 2. The graphic represents the ancestral condition of the chromosomes. In order for fusion to have occurred, the head-end telomere of chimpanzee chromosome 2b would have had to invert and rotate on its axis a half-turn to correctly join the head-end telomere of chimpanzee chromosome 2a. If this occurred, the fossil remnants of this fusion would be seen in

modern human chromosome 2 in the form of a DNA sequence showing head-to-head telomere DNA. If the two ancestral chromosomes fused, what would the sequence be at the fusion point? Write down the remainder of the DNA sequence in the graphic below. Then search the code below for the string of letters that most closely matches the **top line** of chimp 2a and chimp 2b segments in the code in the graphic. (Mutations may have caused some letters to change.)



107881	tgcgacggcg	gagttgcggt	ctcctcagca	cagaccgga	gagcaccgcg	agggcggacc
107941	tgcggtgtcc	tctgcacaga	tttcagtggg	actgcgaagg	cggagcagag	ttctcctcag
108001	gtcagaccgg	ggcgggcggg	cgggctgagg	ataccgcgag	ggcggagctg	cgttctgctc
108061	agcacagacc	tgggggtcac	cgtaaagggtg	gagcagcatt	cccctaagca	cagagggttg
108121	ggccactgcc	tggctttgtg	acaactcggg	gcgcatcaac	ggtgaataaa	atctttcccg
108181	gttgcagccg	tgaataatca	aggttagaga	ccagttagag	cggttcagtg	cggaaaacgg
108241	gaaagaaaaa	gccccctctga	atcctgggca	gcgagattct	cccaaagcaa	ggcgaggggc
108301	tgcattgcag	ggtgaggggtg	agggttaggg	tttggggttg	gtttgggggt	gggggtgggg
108361	taggggtggg	gttgggggtg	gggttggggg	taggggtagg	ggtaggggta	ggggtagggg
108421	cagggtcagg	gtcaggggta	gggttttagg	gttaggattt	taggggttagg	gtaaggggta
108481	aggggtgggg	ttgggggttag	ggttaggggt	taggggtggg	gttgggggtg	gggttggggg
108541	tgggggtggg	gttaggggta	gctaaaccta	accctaacc	ctaaccctaa	ccccaacccc
108601	aaccctacce	ctacccttac	ccctaaccce	aacccccacc	cttaaccctt	aacccttacc
108661	ctaaccctaa	cccaaaccct	aaccctacce	taaccctaac	ccaaccctaa	ccctaaccct
108721	accctaacc	taacacccta	aaaccgtgac	cctgaccttg	accctgacc	ttaaccctta
108781	accctaacca	taaccctaaa	ccctaaccct	aaaccctaac	cctaaaccct	aaccctaaca
108841	ctaccctacc	ctaaccctaa	ccctaaccce	ctaaccctaa	ccctaccctt	aacccccacc
108901	ccagccccaa	cccttaccct	aaccctacce	taacccttaa	ccctaaccce	taaccctaac
108961	ccctaaccct	aaccctacce	caacccccaa	cccaacccta	acccaaccct	aaccctaac
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109141	ccgcctttaa	ggtgcccccc	aggtctgtgc	tgaacagaac	gcagctccgc	cgctgcagtg
109201	ccctcagccc	gcccgcggcg	gtctgacctg	agaagaactc	tgctccgctt	tcgcaatagc
109261	cccgaagtct	gtgcagagga	gaacgcagct	ccgcctcgc	gatgctctcc	ggctgtgtgc
109321	taaagagaac	gcaactccgc	cctcgcaaac	gcgccgcgcc	ggcggaggcg	cggagaggcg
109381	caggcgcgcc	gagggcgagg	cgcgagagg	cgaggcgcg	ccgaggcgca	ggcgaggaga
109441	ggcgcggcgc	tcttgggggag	acgcggcgca	gggcatagac	gtacgcgggc	gcctccccgg
109501	aggggagggg	tcgctggggc	ggcgggagtg	agggcgggcg	ccggcgcaga	gacgcacgct