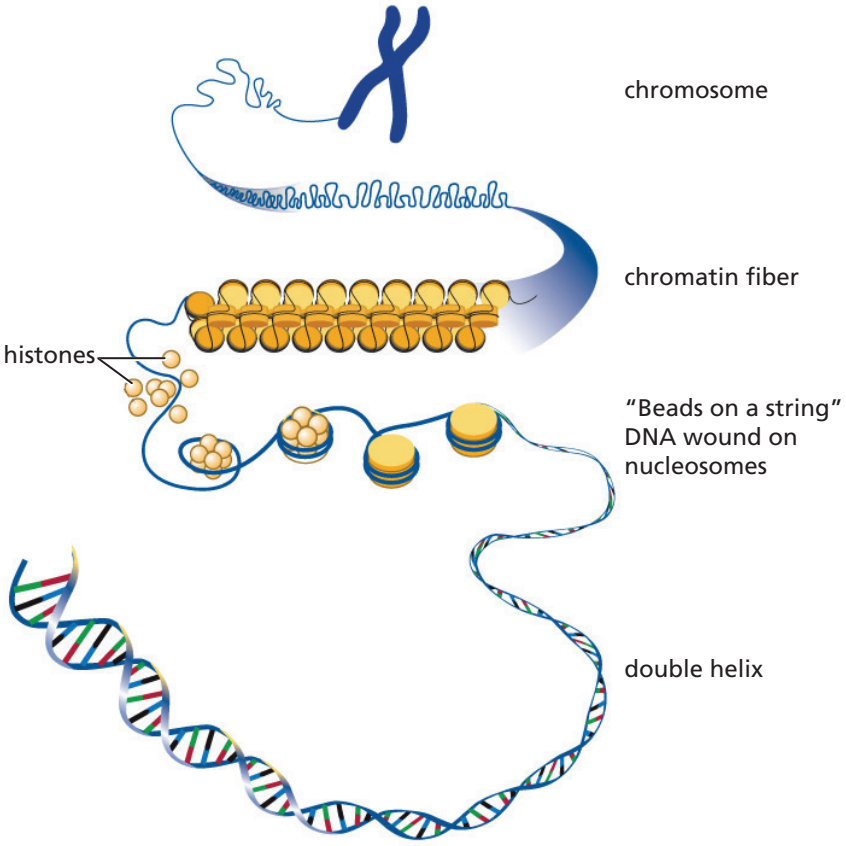
Modeling Meiosis

Background

What is a chromosome?

DNA is the recipe for life that is found in the cells of living organisms. A chromosome is a small set of an organism's DNA. If all of the chromosome strands from a human cell were put together and stretched out end to end, the total length would be about 2 meters. In order to fit all of that material into the nucleus of each one of our cells, the DNA is tightly coiled. DNA is most often found as long string-like strands called chromatin. During mitosis and meiosis, further packing occurs, resulting in the highly condensed pieces of DNA typically thought of as a chromosome.

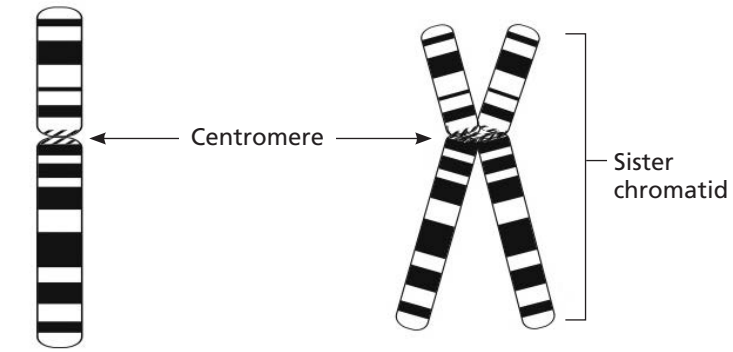


What are homologous chromosomes?

Humans have 46 chromosomes, grouped into 23 pairs. Everyone receives one of each chromosome pair from mom and one from dad. The two copies of each pair are known as homologs, or homologous chromosomes. Homologs are the same size and shape and have the same kind of genes in the same order. Genes are small sections of DNA that provide the instructions a cell needs in order to function properly. For example, imagine that scientists found a gene that controls the shape of the human hairline.* Also imagine that there are two versions of the gene, called alleles. One allele tells the scalp that the hairline should be a straight line across the forehead. The other allele produces a pointed hairline known as a widow's peak. Let's say that a child receives one chromosome from mom with the allele for widow's peak, while the chromosome received from dad has the allele for a straight hairline. The two chromosomes are homologs, and both contain the hairline gene at the same location along their length, but they differ in the specific allele of that gene.

What are replicated chromosomes?

Think about the two chromosomes containing the gene for hairline. Before a cell divides, all of the information on each chromosome must be copied. Initially, a chromosome and its replicated copy are attached at the centromere and referred to then as a replicated chromosome.



*In reality, human hairline is not controlled by a single gene, nor does the trait occur in two contrasting phenotypes.

What is ploidy?

The term ploidy refers to the number of copies of the chromosomes present in a cell. A cell in a haploid state (i.e., egg or sperm) contains one copy of each chromosome. A haploid state is often represented by the variable *n* where *n* equals the number of each chromosome present. A human haploid cell would contain 23 chromosomes or *n* = 23.

A cell in a diploid state contains two copies of each chromosome. Diploid cells are often represented by the variable 2*n*, where *2* indicates a copy present from each of two parents and *n* represents the types of chromosomes present. In a human cell, two times the number of types of chromosomes present (23) gives a total diploid number of 46 (2n = 2 × 23 = 46). A triploid cell would be 3n (69). The triploid state is not viable in human cells but often occurs in plants. For example, seedless watermelons are triploid. These triploid watermelons are the result of a tetraploid (4n) watermelon crossed with a diploid (2n) watermelon. The resulting watermelon offspring contain three of each type of chromosome. The chromosomes do not line up appropriately during meiosis and therefore meiosis does not proceed. Because meiosis is arrested, gametes are not formed, so there is no fertilization and there are no seeds.

What is meiosis?

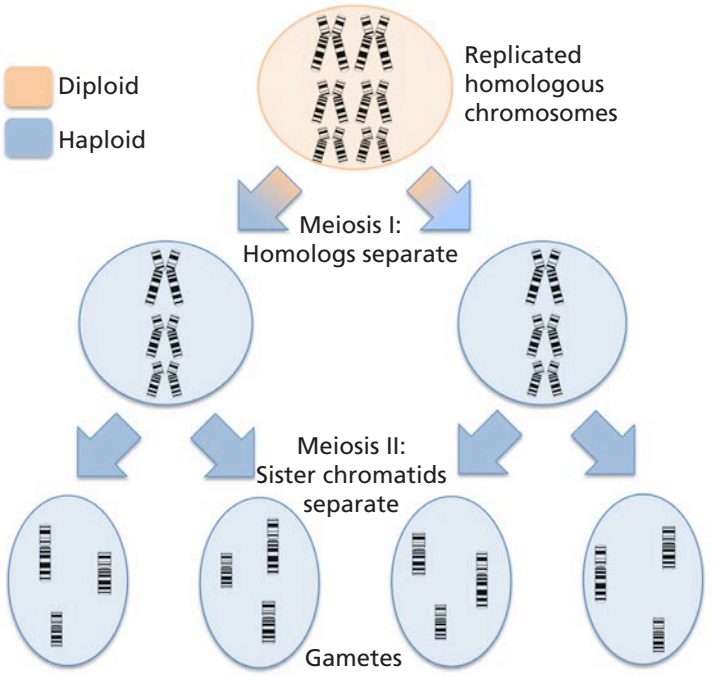
Meiosis is a type of cell division that occurs only in the sex cells of the body. The purpose of meiosis is to reduce by half the number of chromosomes present in a mature egg or sperm. That way, when the egg and sperm join at fertilization, the proper number of chromosomes is present in the offspring. Meiosis is often referred to as reduction division because the number of chromosomes is reduced from a diploid state (where two copies of each chromosome are present) to a haploid state (where each chromosome is present in only a single copy). For example, the diploid number for *Homo sapiens* (humans) is 46 and the haploid number is 23. Meiosis typically results in 4 haploid cells known as gametes.

Chromosome Number for Various Organisms

Organism	Common Name	Diploid Chromosome #
Giraffa camelopardalis	Giraffe	62
Panthera leo	Lion	38
Zea mays	Maize/Corn	20
Ananas comosus	Pineapple	50
Lumbricus terrestris	Earthworm	36

What are the stages of meiosis?

Meiosis is usually described as two distinct stages, meiosis I and meiosis II, each including a series of stages of its own. It is important to note, however, that meiosis occurs as a continuous process. Before meiosis begins, the cell's DNA must be replicated. That occurs during the S phase, or synthesis phase, of the cell cycle. It is important to note that even though the physical amount of DNA has doubled, the chromosome number remains diploid. A helpful rule of thumb for determining the number of chromosomes in any given cell is to count the number of centromeres present rather than the number of sister chromatids.



Meiosis I

Prophase I – The beginning cell is diploid, and in humans would contain 46 chromosomes. First, the replicated chromosomes condense and become visible under the microscope. Each replicated chromosome pairs with its homologous chromosome. These pairs of replicated chromosomes are called tetrads, due to the presence of the four chromatids. Crossing-over, sometimes referred to as recombination, occurs only during this stage.

During crossing-over, equal portions of DNA are exchanged between the maternal and paternal homologs. Crossing-over helps ensure proper separation and distribution of the chromosomes in later stages of meiosis. Crossing-over also contributes to genetic variation among the final gametes.

Metaphase I – Homologous chromosomes line up side by side in the middle of the cell. Their alignment and order are random (law of independent assortment). For example, not all the maternal homologs align on the same side of the cell.

Anaphase I – The homologous chromosomes separate to opposite ends of the cell, and the cell divides into two haploid cells.

Telophase I – The nuclear membrane separately re-forms around two distinct sets of chromosomes.

Cytokinesis – The cell divides around the two new nuclei. This division of cytoplasm may be relatively equal, as in spermatogenesis, or leave most of the cytoplasmic contents with one cell, as in oogenesis. The results are two haploid cells (counting centromeres yields only one of each pair of homologs present in each cell). In humans, each cell at this stage would contain 23 replicated chromosomes. Each cell would be genetically different from the other due to the random assortment of the alleles from the homologs.

The cells now enter interkinesis, a resting phase in which the cells prepare for a second division, called meiosis II. Note that the DNA does not replicate prior to entering meiosis II.

Meiosis II

Remember that there are two cells going through each of the following steps:

Prophase II – The centrioles and spindle fibers attach to the centromere of each chromosome. The centromeres of the sister chromatids behave independently at this step, with a spindle fiber from one pole attaching to the centromere of one sister chromatid and the centromere of the other sister chromatid attaching to a spindle fiber from the opposite pole. The nuclear membrane breaks down.

Metaphase II – Chromosomes line up along the middle of the cell.

Anaphase II – The sister chromatids are pulled to opposite ends of the cell due to the shortening of the spindle fibers.

Telophase II – The centrioles and spindle fibers break down, and the nuclear membrane re-forms.

Cytokinesis – The cytoplasm divides and the cell membrane pinches the cell in two. This process occurs for both of the cells formed at the end of meiosis I, resulting in four genetically diverse haploid cells. In humans, each cell at this stage would contain 23 chromosomes.

What Happens When Meiosis Does Not Go as Planned?

Meiosis is a type of cell division by which organisms produce sex cells, or gametes (egg and sperm). One key characteristic of meiosis is that it reduces the amount of genetic material in the cells. Each sex cell resulting from meiosis contains half of the genetic material found in the original cell (when the process works properly).

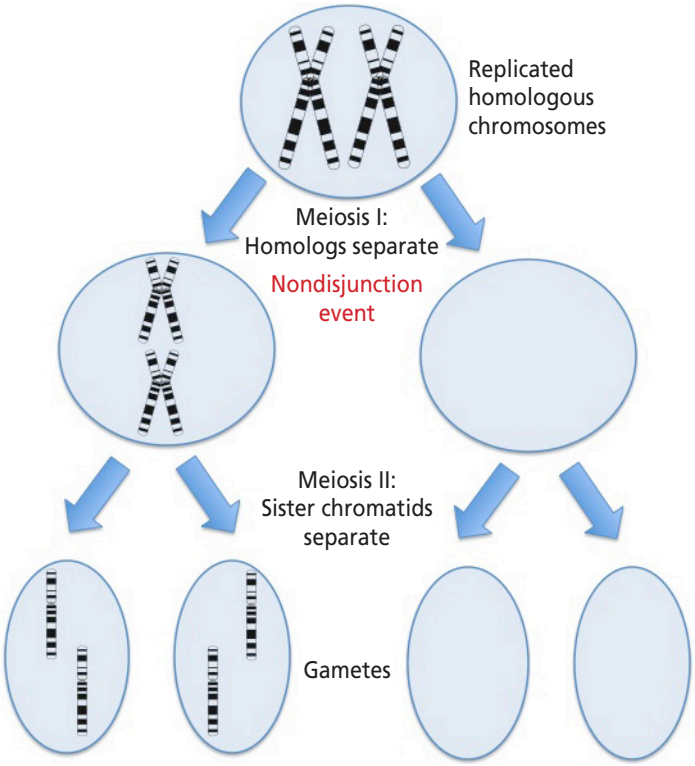
Many different events take place during meiosis. Each step must occur in a specific way for the sex cells to have the proper amount of genetic information. Sometimes, something does go wrong in the process of meiosis, resulting in an atypical sex cell. If this atypical sex cell participates in fertilization, the resulting offspring may be significantly affected.

Nondisjunction

The most frequent cause for meiotic errors is a process called nondisjunction. "Nondisjunction" is a word that essentially means something does not separate as it should. Think back to the steps in meiosis where separation is important.

Perhaps a pair of homologous chromosomes or sister chromatids fail to separate. That would result in a sex cell(s) with an extra copy of that particular chromosome, and a sex cell(s) with a missing copy of that particular chromosome. If one of those sex cells goes on to participate in fertilization, the offspring organism will likewise have an extra or missing chromosome. Having an extra chromosome is called trisomy. Lacking a chromosome is called monosomy.

Another type of nondisjunction happens if the cell fails to divide at all during meiosis, resulting in a sex cell with an extra copy of all of its chromosomes. Having extra copies of all chromosomes is called polyploidy.



A nondisjunction event in Meiosis I where homologous chromosomes fail to separate

Does the amount of information matter?

How important is it that an individual organism has the typical number of chromosomes for that species? The effect of extra or missing genetic information depends on several factors: what organism the change occurred in, how large the change is, and what specific information is involved. Having an extra chromosome means that the organism has an extra copy of all the genetic information found on that chromosome.

Many plants tolerate having an extra chromosome or chromosomes quite well. In fact, plants are often bred intentionally to have extra chromosomes. For example, our cultivated strawberries are octaploid, meaning they have eight haploid sets of their seven chromosomes. Octoploid strawberries are larger and juicier than their diploid strawberry relatives that have only two haploid sets of chromosomes.

Other organisms, including humans, do not tolerate extra or missing chromosomes very well. Most human embryos with extra or missing chromosomes or sets of chromosomes are miscarried, often before the mother even knows she is pregnant. Exceptions to that rule include trisomy 21 (Down syndrome), trisomy 18, trisomy 13, and extra or missing sex chromosomes.

Plant trisomy—the jimsonweed

Wild-type jimsomweed seedpod

In 1913, A.F. Blakeslee, a botanist, noticed that different individual plants of *Datura stramonium*, jimsonweed, produced seedpods in one of several variations. Later, Blakeslee and another scientist, John Belling, determined the cause for these different pod shapes—trisomy. *Datura* plants have 12 different chromosomes. A typical plant contains two copies of each chromosome (12 chromosome pairs) and produces a typical (wild-type) seedpod.

Datura plants are abnormally prone to nondisjunction and trisomy. Each type of seedpod, along with some other plant features, varies according to which of the 12 chromosomes is present in an extra copy. For example, *Datura* plants with trisomy 1 (3 copies of chromosome 1) will have tiny seedpods and leaves with rolled edges, while *Datura* plants with trisomy 9 (three copies of chromosome 9) will have a spreading growth habit and puckered leaves like spinach.

Human trisomy—Down syndrome

Humans typically have 23 chromosome pairs. As in *Datura*, nondisjunction can occur during human meiosis, and humans can have extra or missing chromosomes. However, there are only a few types of trisomies and monosomies in humans that do not lead to miscarriage of the pregnancy.

Individuals with Down syndrome have three copies of chromosome 21. The extra information is what causes the physical and developmental differences associated with Down syndrome. The physical features and medical symptoms associated with Down syndrome are distinctly different from those associated with other human trisomies such as trisomy 18 and trisomy 13.

Down syndrome is typically a result of nondisjunction.

References

Genetics Home Reference (http://ghr.nlm.nih.gov)
Miko, I. 2008. Mitosis, meiosis, and inheritance. *Nature Education* 1(1).

Modeling Meiosis Student Protocol

Overview

In this activity, you will use ChromoSock modeling to simulate the behavior of chromosomes during meiosis. You will visualize reduction division and relate that process to the maintenance of chromosome number during sexual reproduction.

Learning Targets

- Define "haploid" and "diploid."
- Identify chromosome number at several points during meiosis.
- Identify meiosis I as the division that reduces the chromosome number.
- Model meiosis.
- Correctly label centromere, chromosome, and chromatids in a diagram.

Materials

2 Chromosock bags for each pair of students. Each bag contains the following:

1 white sock with orange stripe, labeled "F"
1 white sock with orange stripe, labeled "f"
1 gray sock with black stripe, labeled "B"
1 gray sock with black stripe, labeled "b"
1 beige sock with green stripe, labeled "N"
1 beige sock with green stripe, labeled "n"

rubber bands
Modeling Meiosis Worksheet

Introducing Meiosis

Preparing for Meiosis

1. Working with a partner, open one ChromoSock bag. The socks represent the chromosomes that have been passed from parent to offspring.
2. Remove the socks and arrange them in pairs on your desk. Chromosomes, like socks, occur in pairs. Pairs of chromosomes are called homologs, or homologous chromosomes. Answer question 1 and draw the associated sketch on the Modeling Meiosis worksheet. Use an "I" shape to represent each single chromosome.
3. The socks will now be used to model the phases of meiosis.
4. Before any cell can enter meiosis, the DNA must be replicated. Open the second ChromoSock bag.
5. Use socks from the second bag to replicate the socks from the first bag. Match each sock from the second bag to an identical one from the first bag. Use rubber bands to connect the ChromoSock replicates. The rubber band represents the centromere, or region where sister chromatids attach in a replicated chromosome. Make sure to match uppercase- and lowercase-lettered socks appropriately.
6. Answer question 2 and draw the associated sketch on the Modeling Meiosis worksheet. Use an "X" to indicate each replicated chromosome in the sketches.
7. Sketch a replicated chromosome in the space provided for question 3 on the Modeling Meiosis worksheet.

Meiosis I

8. Use the ChromoSock models to depict each phase of meiosis I. Place homologous pairs of replicated socks near each other. Sketch the chromosomes in circle A, label the specific phase for A, and answer question A.
9. Line up the homologous pairs along the middle of the desk or table to represent how chromosomes line up along the equator of the cell. Sketch the chromosomes, label the phase, and answer the question for B on the worksheet.
10. Separate homologous pairs by moving each pair of replicated socks to opposite sides of the desk. Sketch the chromosomes, label the phase, and answer the question for C on the worksheet.
11. Collect the socks on each side of the desk into a tight bundle. Sketch the chromosomes in the two circles, label the phase for D, and answer the four questions in section D.

Meiosis II

12. At the beginning of meiosis II, there are two Chromosock piles, representing two cells. Sketch the chromosomes in both cells, label the phase for E, and answer question E.
13. For each "cell," line up the socks in a vertical line. Sketch the chromosomes in both cells for F on the worksheet, label the phase for F, and answer question F.
14. Remove the rubber bands, simulating the physical change in the centromere that allows chromatids to separate. At this point, the replicated chromosome no longer behaves as a single unit. Separate the sister chromatids by moving one of copy each sock to opposite sides of each "cell." Sketch the chromosomes in both cells, label the phase for G, and answer question G.
15. Collect the socks into tight bundles, simulating the reforming of the nuclear membrane. The remaining contents of each cell will separate in a process known as cytokinesis, resulting in a total of four cells. Carefully count the number of socks in each new cell. Sketch the chromosomes in all four cells, label the phase for H, and answer the questions in section H.
16. Return the socks to the bag. Make sure that each bag contains the six socks F, f, N, n, B, and b. Bags must be correctly packed to ensure appropriate starting material for the next class.

Modeling Nondisjunction

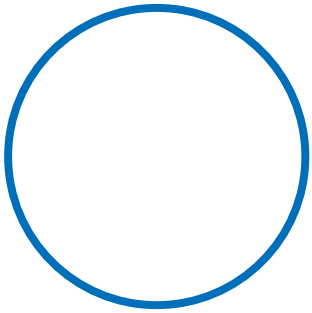
17. Nondisjunction occurs when chromosomes fail to separate properly during meiosis. Nondisjunction events change chromosome numbers, resulting in gametes with either too many or too few chromosomes. Predict the impact of "failure to separate" on the chromosome number found in the gametes formed and record your response for question 1 in the Nondisjunction section of the worksheet.
18. You will repeat the process of meiosis but model a nondisjunction event in meiosis I. Remove and arrange the socks from one bag exactly as in step 2.
19. Prior to entering meiosis, chromosomes replicate. Use the socks in the second bag to simulate replication. Use rubber bands to attach sister chromatids, forming replicated chromosomes as in step 5.
20. Model meiosis. At the point where the homologous pairs line up along the equator in this simulation, one pair of homologs does not separate, and both replicated chromosomes should be moved to the same side of the desk. That creates two piles with unequal numbers of replicated socks. Carefully observe the two piles of socks. Sketch the chromosomes in the two circles and sketch and answer question 2 in the Nondisjunction section of the worksheet.

21. Perform meiosis II by lining the replicated socks along the equator, removing the rubber bands and separating sister chromatids. This creates four piles with varying numbers of socks.
22. Based on the simulation of a nondisjunction event in meiosis I, create a diagram of the resulting gametes in the four circles provided for number 3. How does your response compare with your prediction in question 1? Answer a, b, and c.
23. Return the socks to the bag. Make sure that each bag contains the six socks F, f, N, n, B, and b.
24. Remove and arrange the socks from one bag exactly as directed in step 2.
25. Prior to entering meiosis, use the socks in the second bag to simulate replication. Use rubber bands to attach sister chromatids as in step 5.
26. This simulation will illustrate a nondisjunction event in meiosis II. Complete meiosis I in a normal manner, properly separating homologous pairs. Chromosome movement is not altered during the first cell division. This creates two piles with equal numbers of replicated socks.
27. Perform meiosis II by lining the replicated socks along the equator, removing the rubber bands, and separating sister chromatids. In this simulation, one replicated chromosome does not separate properly, but both sister chromatids segregate into the same cell. That leads to four piles with varying numbers of socks.
28. Based on your simulation of a nondisjunction event in meiosis II, describe the resulting gametes in the space provided for number 4 on the worksheet.
29. Return the socks to the bag. Make sure that each bag contains the six socks F, f, N, n, B, and b. Bags must be correctly packed to ensure appropriate starting material for the next class.

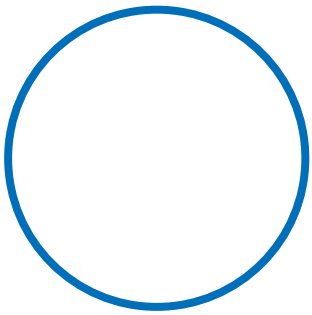
Modeling Meiosis Worksheet

In this activity, you will be using socks specially created to represent chromosomes. In your sketches on this worksheet, use an "X" shape to represent a replicated chromosome and an "I" shape to represent a non-replicated, or a single chromosome. Sketch chromosome diagrams in the circles provided and label stages in the blanks provided where appropriate.

1. Sketch an interphase cell prior to entering meiosis. How many chromosomes are present in the cell?



2. During interphase, DNA replicates. Sketch the cell following DNA replication. How many chromosomes are present in the cell?



3. In the box, sketch a replicated chromosome. Label the two sister chromatids and the centromere.

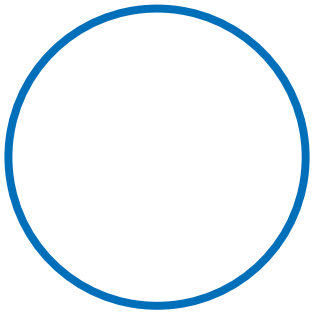
Meiosis I

Each phase of meiosis is labeled with a letter. Write the name of each phase in the blank and sketch the chromosome arrangement of each phase in the circle(s). The questions are accompanied by a letter to indicate the appropriate sketch from the drawings below it.

A. Phase: _____

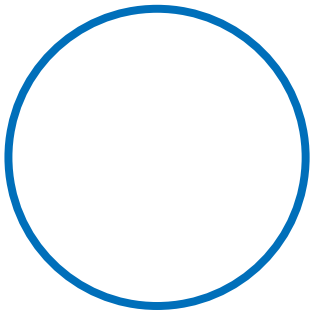
A. What is the total number of chromosomes?

This cell is diploid.
The diploid number is _____.



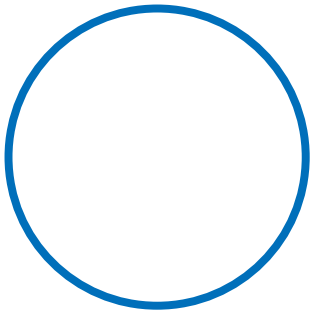
B. Phase: _____

B. How do the chromosomes line up at the cell's equator?



C. Phase: _____

C. Centromeres remain intact at this stage. How does this impact chromosome separation?



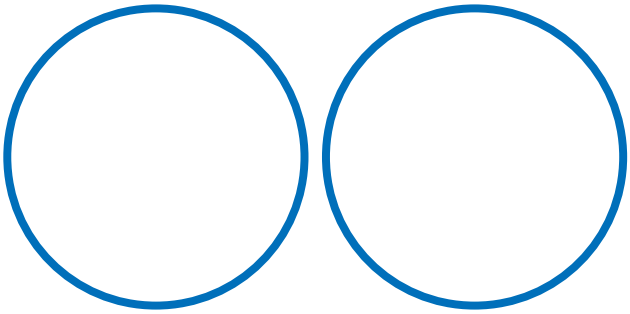
D. Phase: _____

D. Following cytokinesis, how many cells are present?

D. What is the total number of chromosomes in each cell?

D. These cells are haploid.
The haploid number is _____.

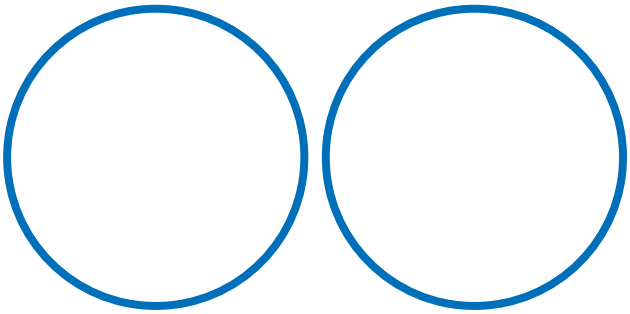
D. After the end of meiosis I, the cell enters a resting stage known as interkinesis. How is interkinesis different from the interphase that occurred before meiosis I?



Meiosis II

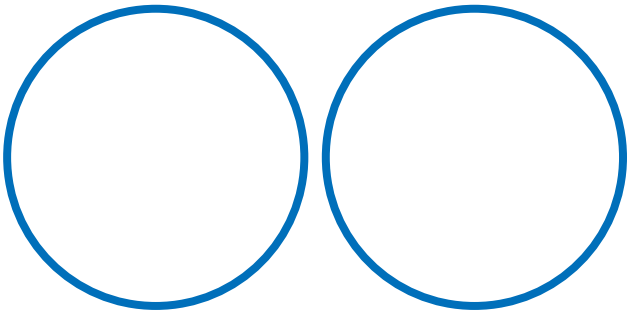
E. Phase: _____

E. How many homologous chromosome pairs are present in each of the cells as it enters the second cell division?



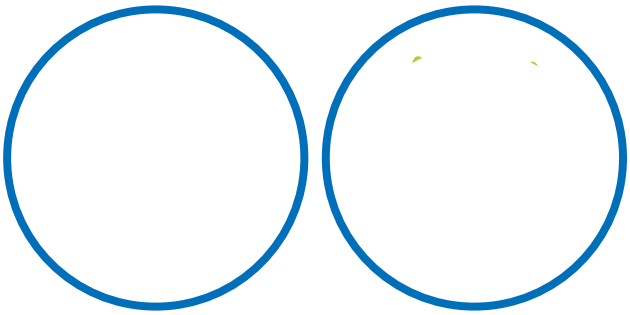
F. Phase: _____

F. How is this alignment different from that in sketch B?



G. Phase: _____

G. Centromeres are separated at this stage. Is each cell still haploid?

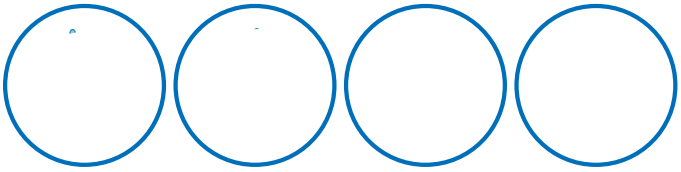


H. Phase: _____

H. How many cells are formed? How many chromosomes are in each new cell? Are these cells haploid or diploid?

H. Are any of the cells identical? Why or why not?

H. Are any of the cells exactly like the original cell that entered meiosis? Why or why not?

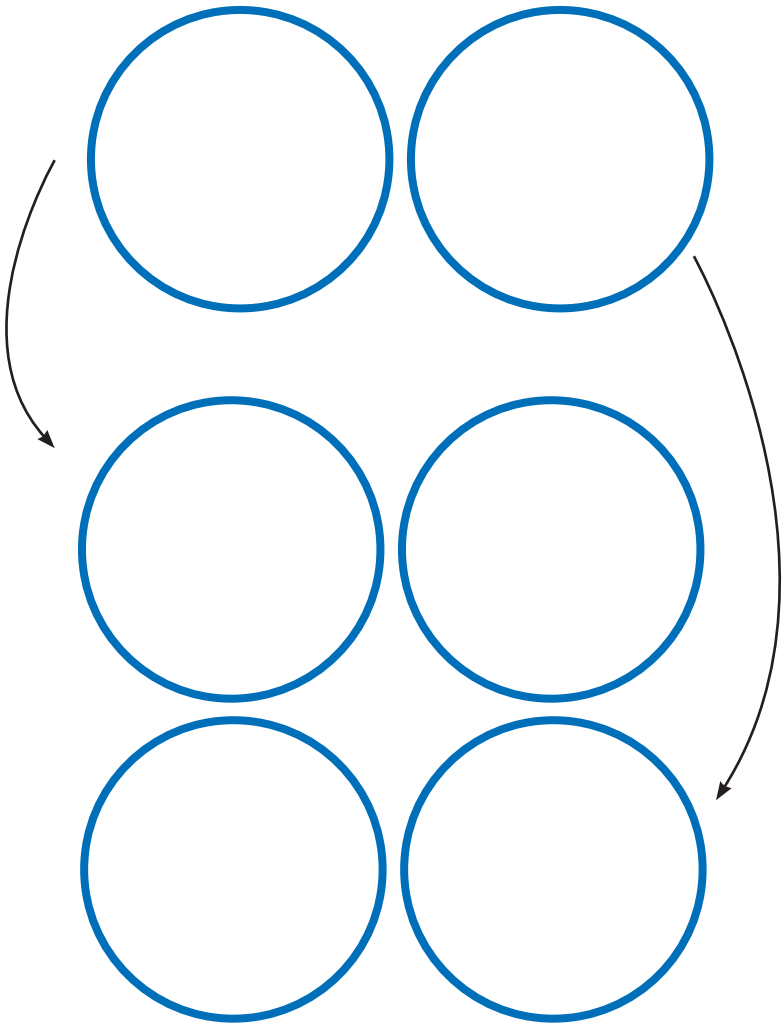


Nondisjunction

1. What impact would nondisjunction have on the number of chromosomes in the gametes formed during meiosis?

2. Sketch the chromosomes at the end of a meiosis I division where nondisjunction has occurred. How does this drawing differ from what is typically present at the end of meiosis I?

3. Sketch the chromosomes following meiosis II with nondisjunction in the four circles to the right. How does this drawing differ from your prediction and drawing in section H?



   a. How many chromosomes are in each cell?

   b. Do all the cells have too many chromosomes?

   c. Are any of the cells missing chromosomes?

4. This simulation showed a nondisjunction event during meiosis I. Describe two other ways that nondisjunction may occur and describe the resulting gametes. You may use the socks to model the process if needed. Record your descriptions in the box to the right.

Modeling Mendel

Background

Who is Mendel and what does he have to do with meiosis?

Gregor Mendel was a monk and scientist who lived in the 1800s and studied how physical traits are passed from generation to generation. He is often credited as the "father of genetics," as he was one of the first to identify important characteristics of the process of genetic inheritance. Discussion of Mendel usually focuses on his experiments with garden peas and often involves Punnett squares (a way to illustrate how traits are inherited from two parents). Mendel's work led him to develop three major laws. Each of these laws has a basis in the biological processes of meiosis. In this activity, we explore how Mendel's laws are connected to meiosis and to Punnett squares.

What are genotype and phenotype?

One of Gregor Mendel's revolutionary insights was that an organism could pass along to its offspring traits that were not outwardly visible in the parent. Although he did not use the terms, Mendel had identified the difference between phenotype, an organism's outward appearance and genotype, an organism's genetic contents. Phenotypes are apparent traits or characteristics such as seed type in plants or hair texture in animals. Genotypes are written as pairs of letters that represent different alleles, or versions of a gene.

Why is some corn purple and some corn yellow?

If pure-breeding purple corn is crossed with pure-breeding yellow corn, the result is purple kernel corn. Why is that? Let's take a closer look at corn anatomy and genetics. A corn kernel has a thin covering called the aleurone that surrounds the endosperm. This covering may be clear, allowing the endosperm to show through, or it may be colored, masking the endosperm. Purple aleurone is dominant to clear aleurone. Remember that a single ear of corn contains the results of multiple fertilization events and can contain both yellow and purple kernels.

At the DNA level, genes provide the instructions for making the proteins needed by the cells. A gene produces the protein involved in corn aleurone color. Different alleles (versions) of the gene lead to the various kernel colors. There is a purple allele and a clear allele. Only a single copy of the dominant, purple allele is required to produce a purple-kernel offspring. For a kernel to be yellow, it must have two copies of the recessive allele for clear aleurone. Mendel observed similar patterns of traits in the pea plants he studied and was the first to refer to such traits as dominant and recessive.

Mendel's Law of Dominance: Some alleles are dominant, and others are recessive. An organism with at least one dominant allele for a gene coding for a particular trait will exhibit the dominant form of the trait. An organism will express the recessive trait only if no dominant allele is present.

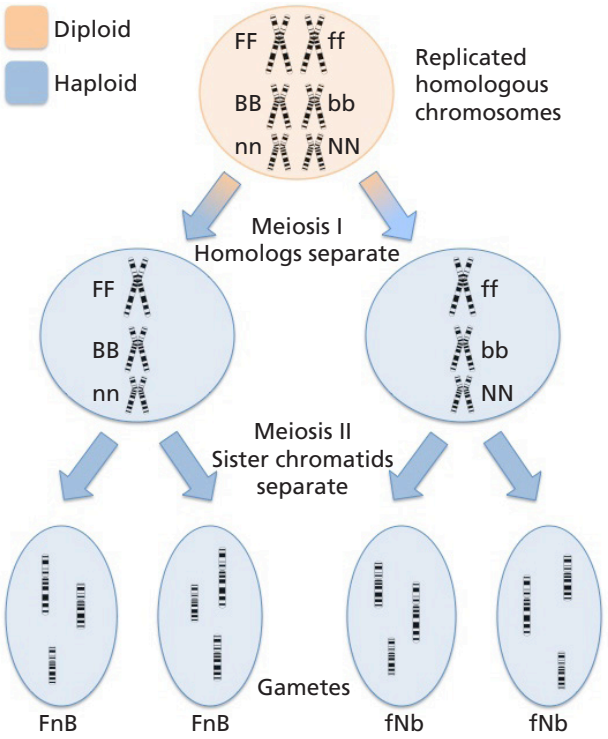
To recap:
An allele that behaves in a dominant manner requires only one copy to determine the trait, regardless of what other allele is present.

In contrast, two copies of a recessive allele must be present for the trait to be expressed. If a recessive allele is present in only a single copy, its impact will be hidden by the dominant allele.

How does a corn plant get only one copy of the color gene from each parent?

Flowering plants reproduce using pollen (containing sperm) and egg. The egg and the pollen are both produced through meiosis, the type of cell division that reduces the number of chromosomes in a cell from diploid to haploid. In the first part of meiosis, homologous chromosomes (the maternal and paternal copy of the same chromosome) separate from each other. This means that only one copy of the allele for the corn kernel color gene will end up in each of the haploid egg or sperm cells. Mendel described this process by saying that alleles segregate.

Mendel's Law of Segregation: During meiosis, the alleles for each gene separate from each other, so that each gamete (egg or sperm) carries only one allele (version) for each gene.



Independent assortment of genes during meiosis

Does corn have to be yellow to taste sweet?

No. Sweet corn could just as easily be purple. Why is that? The gene for sweetness is found on one chromosome, and the gene for color is found on another chromosome. Mendel realized that chromosomes not only separate but that they do so independently of each other during the formation of gametes.

Mendel's Law of Independent Assortment: Genes for different traits can segregate independently during the formation of gametes.

After Mendel's time, it was discovered that this independent assortment of genes occurs during the process of meiosis. The chromosomes randomly line up in the middle of the cell before they are separated, and specific allelle combinations for genes present on different chromosomes, such as sweetness and color, do not "stick together" as they travel through meiosis.

Tying Mendel to Meiosis Student Protocol

Overview

In this activity, you will use ChromoSock modeling to simulate the behavior of chromosomes during meiosis and to visualize Mendel's laws of genetics, including segregation of alleles and independent assortment.

Learning Targets

- Model Mendel's law of segregation.
- Model Mendel's law of independent assortment.
- Review the process of meiosis.
- Use alleles to predict phenotype.

Materials

2 ChromoSock bags for each pair of students. Each bag contains

- 1 white sock with orange stripe, labeled "F"
- 1 white sock with orange stripe, labeled "f"
- 1 gray sock with black stripe, labeled "B"
- 1 gray sock with black stripe, labeled "b"
- 1 beige sock with green stripe, labeled "N"
- 1 beige sock with green stripe, labeled "n"

rubber bands

Tying Mendel to Meiosis Worksheet

Meiosis Sequence Sort

Procedure

Reviewing Meiosis

Follow your instructor's directions for the Meiosis Sequence Sort activity.

Mendel's Laws

To explore Mendel's laws, you will use ChromoSock modeling to simulate the entire process of meiosis. Special attention will be given to specific events that illustrate these laws in action.

1. Observe diagram A on the worksheet and answer question 1 and 2.

Mendel's Law of Dominance: Some alleles are dominant, and others are recessive. An organism with at least one dominant allele for a gene coding for a particular trait will exhibit the dominant form of the trait. An organism will express the recessive trait only if no dominant allele is present.

2. Look at diagram A again. Purple flower color is determined by a single dominant allele, P. White flower color is the result of two recessive alleles. Respond to question 3 of the worksheet and revise your response to question 2, if needed.
3. Remove the socks from one bag and arrange them in pairs. This creates a starting set of homologous pairs.

Through the remainder of the activity, you will work with six alleles for three traits found in the ChromoSock organism and determine the appropriate phenotypes when necessary. The alleles operate in an autosomal dominant manner. The allele descriptors are given in the following table:

Trait	Allele
No Freckles	F
Freckles	f
Connected Eyebrows	B
Separated Eyebrows	b
Narrow Nose	N
Wide Nose	n

4. Replicate the ChromoSock DNA, creating replicated chromosomes, using the socks from the second bag. Replicated socks should be held together using rubber bands to represent centromeres.
5. Perform meiosis I—pairing homologs, lining them up in the middle, separating homologs, and completing cell division.
6. After that, you should have two piles of socks, representing the two cells that are formed by meiosis I. Each of these new cells has half of the original number of chromosomes.
7. Notice that when the homologs separate during meiosis I, the alleles are separated such that each of the newly formed cells has only one version of each allele.
8. Review Mendel's law of segregation:

Mendel's Law of Segregation: During gamete formation, the alleles for each gene separate from each other, so that each gamete carries only one allele for each gene.

During meiosis I, the homologous pairs of each chromosome separate, segregating the alleles of each gene. This is the mechanism of Mendel's law of segregation.

9. Look at the replicated beige socks with allele "N." Discuss with other groups which side of the desk their replicated "N" chromosome is on. Might there be a biological reason for all of the socks with uppercase letters to end up on the right side of the desk?

10. Focus on all the ChromoSocks containing dominant alleles (represented by uppercase letters). Look at the distribution pattern of the dominant alleles.
11. Are the newly formed "cells" different from the original cell?
12. Conduct meiosis II with the socks, lining up the replicated chromosomes in the middle, separating chromatids (removing rubber bands), and completing cell division.
13. At that point, you should have four piles of socks representing the four cells formed during meiosis II.
14. Review Mendel's law of independent assortment:

Mendel's Law of Independent Assortment: Genes for different traits can segregate independently during the formation of gametes.

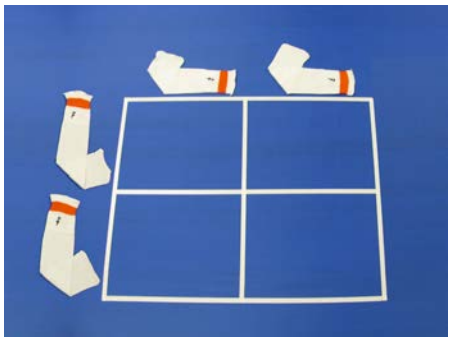
15. Answer questions 4 and 5 on the Tying Mendel to Meiosis worksheet. Identify which images in a diagram of meiosis illustrate Mendel's laws.
16. Use ChromoSock modeling to determine all of the possible gametes that could be formed and record them in the space provided with question 6 on the worksheet.

Modeling Fertilization

17. As you complete the last round of meiosis, randomly select one of the four piles of socks that represent the four gametes formed by meiosis.
18. Gather the socks found in that gamete, and combine with another group to form an offspring (combine the two sets of socks into one bundle).
19. Carefully observe the alleles found on each sock in the offspring. Record the alleles in the Genotype column in box 7 of the worksheet.
20. Based on the alleles, write the phenotype of the offspring in the Phenotype column in box 7 of the worksheet.
21. Return to your original partner(s) and use the socks to recreate the parent cell that you set up at the beginning of the activity. It will represent the premeiotic parent cell for the next section.

Mendel in a Box

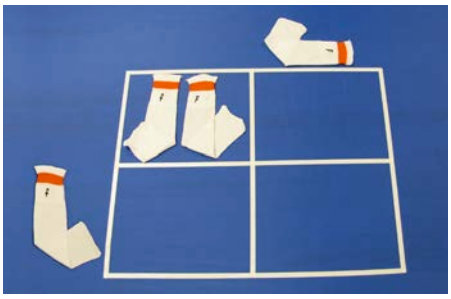
22. From the cell on your desk, select only the socks that represent Freckles (F and f). Those represent the alleles found in gametes that this parent could potentially contribute to offspring. All other socks can be returned to the bag.
23. You will work with another student pair to determine the possible genotypes of offspring of this pairing using a Punnett square.
24. Place the two socks that represent the father's gametes above the Punnett square. Record the possible paternal gametes in the space provided on the worksheet (8).



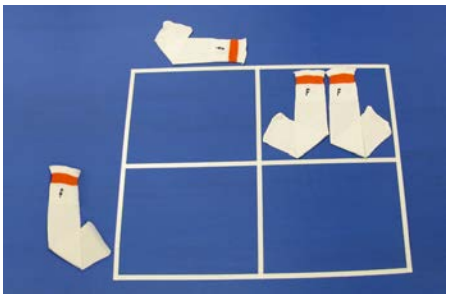
Setting up the Punnett square.

25. Place the two socks that represent the mother's gametes along the side of the Punnett square. Record the possible maternal gametes in the space marked 9 provided on the worksheet.
26. To fill the first box, move the appropriate paternal sock and maternal sock into the box and record the resulting genotype in box 10. Then, return the socks to the original position.

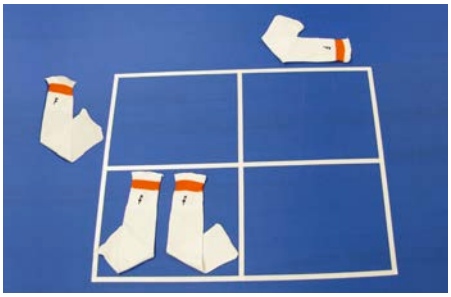
27. Repeat the process to fill the remaining three boxes (11–13), each time pulling the appropriate paternal and maternal match into the box and recording the genotype of the offspring.
28. Answer question 14: What is the likelihood that this pairing would produce an offspring with freckles?
29. Answer question 15: If this couple has four non-freckled children, what is the likelihood that the fifth child will have freckles?
30. Return the socks to the bag. Make sure that each bag contains the six socks F, f, N, n, B, and b. Bags must be correctly packed to ensure appropriate starting material for the next use.



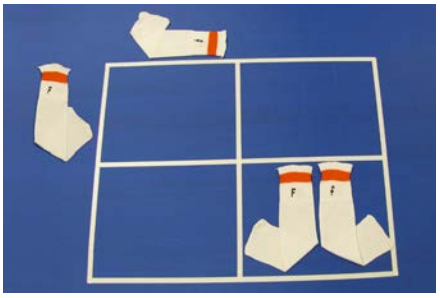
Gamete option 1



Gamete option 3



Gamete option 2



Gamete option 4

Tying Mendel to Meiosis Worksheet

Diagram A

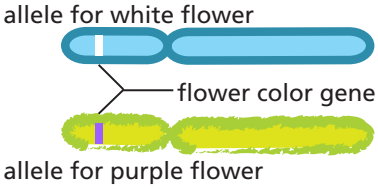
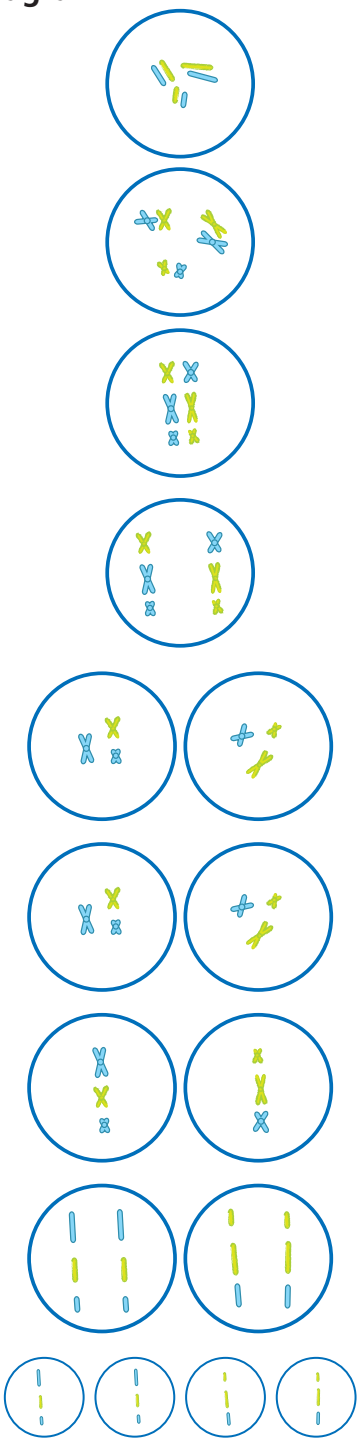


Diagram B



1. Gregor Mendel's three laws of genetics are completely linked to the biological process of meiosis. Observe the pair of homologous chromosomes in diagram A. How can one chromosome have the allele for purple flowers and the other chromosome have the allele for white flowers?

2. What color would you expect to see in the flowers of a plant with these chromosomes? Why?

3. What are the genotype and phenotype of the original plant cell? Explain Mendel's law of dominance using this information.

4. Using diagram B, draw a circle around the area of the diagram that clearly illustrates Mendel's law of segregation. Explain your response.

5. Using diagram B, draw a square around the area of the diagram that clearly illustrates Mendel's law of independent assortment. Explain your response.

6. Use the socks to determine all of the possible gametes that could be formed. Write the genotype of each possible gamete in the space below. Hint: There are eight possible combinations.

7. Select only one of the gametes formed by Chromosock meiosis. Combine with a gamete from another group. Describe the genotype and phenotype of the offspring.

Genotype	**Phenotype**

Return to your original group and repack the Chromosock bags. From one bag, select only the socks for the Freckles trait (F and f). Work with another group to complete a Punnett square cross using the socks instead of letters. Record the results of your cross in the space provided and answer the questions that follow.

8. **Possible paternal gametes:**

	_____	_____
9. **Possible maternal gametes:** _____	10.	11.
_____	12.	13.

14. What is the likelihood that this pairing would produce an offspring with freckles?

15. If this couple has four non-freckled children, what is the likelihood that the fifth child will have freckles?

Meiosis Sequence Sort

— — — — — — — — — — — — — — — — — — — —

DNA is copied in a process called replication.

— — — — — — — — — — — — — — — — — — — —

The cell divides. The two new cells are haploid, each containing half the normal number of chromosomes.

— — — — — — — — — — — — — — — — — — — —

DNA does not copy or replicate. The two cells enter a second round of cell division, called meiosis II.

— — — — — — — — — — — — — — — — — — — —

The cell enters meiosis I.

— — — — — — — — — — — — — — — — — — — —

The cells divide, forming four gamete cells. These gametes are haploid and contain single copies of the chromosomes.

— — — — — — — — — — — — — — — — — — — —

Homologous pairs separate and move to opposite sides of the cell.

— — — — — — — — — — — — — — — — — — — —

Sister chromatids separate from each other and move to opposite sides of the cell.

— — — — — — — — — — — — — — — — — — — —

Replicated chromosomes move to the middle of both cells.

— — — — — — — — — — — — — — — — — — — —

Similar or homologous pairs of replicated chromosomes join and move to the middle of the cell.

— — — — — — — — — — — — — — — — — — — —