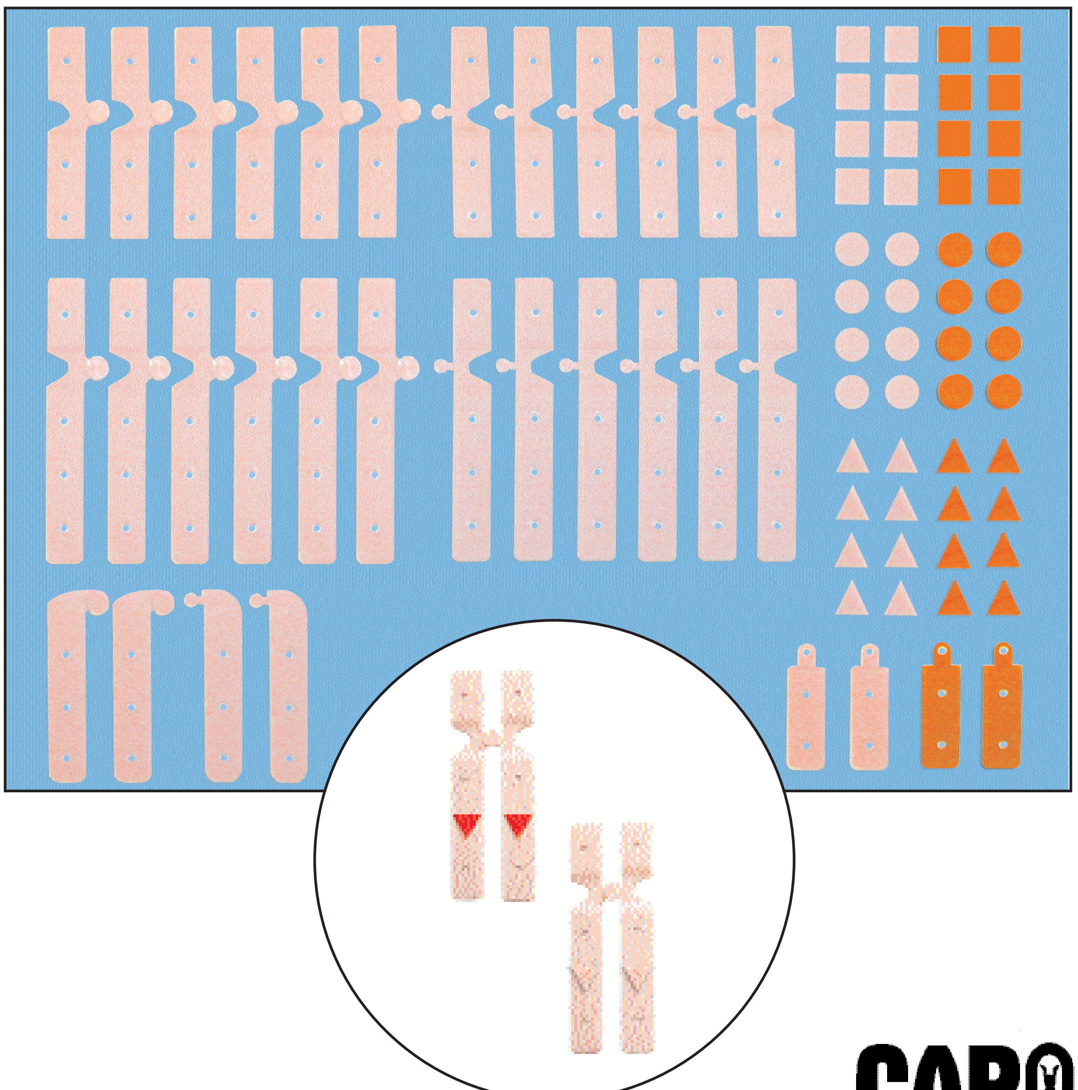
17-1120
Eight-Station Kit

17-1121
One-Station Kit

Modeling Mitosis and Meiosis Kit

TEACHER'S MANUAL WITH STUDENT GUIDE



World-Class Support for Science & Math

Modeling Mitosis and Meiosis

Teacher's Manual

Photocopy Masters

Modeling Mitosis and Meiosis

Overview

Mitosis, meiosis, and genetic inheritance can be confusing concepts for students to grasp and challenging processes for teachers to describe. The Modeling Mitosis and Meiosis kit allows teachers and students to use manipulatives to visualize the cellular processes of mitosis and meiosis as they occur in most animal cells, and to simulate processes of genetic variation by modeling crossing-over and independent assortment of chromosomes. The eight-station kit (17-1120) is suitable for a class of 32 students working cooperatively in groups of four. The one-station kit (17-1121) is ideal for homeschooling, for small groups, and for teacher demonstrations. Multiple one-station kits are appropriate for smaller classrooms. This comprehensive Teacher's Manual provides preparation and classroom management options, extension activities, and answers to questions in the Student Guide. Also included in this manual is a blackline master Punnett Square Activity Sheet designed to allow students to use the model pieces to represent various genotypes. The reproducible Student Guide includes background information for students, detailed activity instructions, illustrations, and assessment questions.

Content Standards

This kit is appropriate for high school students and addresses the following National Science Content Standards:

Grades 9–12

C: Life Science

- The Cell
- Molecular Basis for Heredity

Materials

The one-station Modeling Mitosis and Meiosis kit contains one chromosome model set. The eight-station kit contains eight chromosome model sets. Each set includes these model pieces (the Student Guide includes a key depicting each type of model piece):

6 pairs of autosomes
6 pairs of female (X) sex chromosomes
2 pairs of male (Y) sex chromosomes
4 chromosome fragments, 2 red and 2 pink
16 square genes (8 red and 8 pink alleles)
16 triangular genes (8 red and 8 pink alleles)
16 circular genes (8 red and 8 pink alleles)

Needed, but not supplied (for each station):

1 piece of yarn or string, 122 cm (48″) long
2 pieces of yarn or string, 92 cm (36″) long

Classroom Options

The five activities in the Modeling Mitosis and Meiosis kit are designed to allow teachers, students, and demonstrators a great deal of flexibility. Each activity can be conducted in approximately 50 minutes. If several sets of model pieces are available, multiple activity centers can be set up, each with a different activity and focus. Students or groups can then rotate among the activity centers. You may wish to have students answer the assessment questions and draw Punnett squares on a separate sheet of paper.

Teacher Tips

- This manipulative set of chromosomes is designed so that sister chromatids can be connected at the centromere. Even though the centromere connections (large knob on some chromosomes and smaller knob on corresponding chromosomes) are always present, make sure students realize that this is just for modeling purposes. In reality, centromeres are only present when replicated sister chromatids are connected. Even if the chromosomes have different centromere connections, they should be considered identical, for these activities, as long as they have identical alleles at identical locations on the chromosomes.
- In activities 1, 2, and 5, students simulate cytokinesis by crossing a loop of string or yarn over itself to form a figure eight. Emphasize to students that this is a simplified simulation of the division of one cell into two cells. An alternative method of modeling cytokinesis is to have students pinch the loop inward until it resembles two separate cells. You may also refer students to Figure 5 in the Background section.

Preparation

- Photocopy the Student Guide at the end of this manual for each student or group of students in your classroom, or for each activity center that you will set up.
- You can save class time by measuring, cutting, and tying the yarn or string loops for cell membranes (Activity 1) and daughter cells (activities 2 and 5) in advance. Distribute the loops along with the chromosome model set or place them at the appropriate activity centers, and modify the activity instructions accordingly.
- For activities 3 and 4, photocopy the blackline master Punnett Square Activity Sheet for each participating student or group of students, or for each activity center that you set up.

Instructions

Activity 1: Modeling Mitosis

Required Knowledge

Make sure students have some prior knowledge of the following concepts and terms: autosomes, cell division, chromosomes, chromosome replication, genes, mitosis, and sister chromatids.

Procedure

Refer to the Student Guide for step-by-step instructions for this activity.

Questions

Answers to questions in the Student Guide are given in *Italics* following each question.

1. Define interphase and describe what happens during this part of the cell cycle.
   Interphase is the period between cell divisions. During interphase, a cell grows, replicates its chromosomes, and produces and assembles the cellular structures required for cell division.
2. Define mitosis in terms of the genetic material in the original and daughter cells.
   Mitosis is the division of the nuclear material within a cell, the process of one parent cell dividing to create two genetically identical daughter cells. This form of cellular reproduction ensures that the daughter cells produced by the parent cell contain genetic material identical to that of the parent cell.
3. List the four stages of mitosis and the final step in mitotic cell division.
   The four phases of mitosis are prophase, metaphase, anaphase, and telophase. The final step of mitotic cell division is cytokinesis. In animal cells, this is the division or "pinching" of the parent cell's cytoplasm to form two separate daughter cells.

Activity 2: Modeling Meiosis

Required Knowledge

Make sure students have some prior knowledge of the following concepts and terms: chromatids, diploid, gametes, haploid, homologous chromosomes, meiosis, and tetrad.

Procedure

Refer to the Student Guide for step-by-step instructions for this activity.

Questions

Answers to questions in the Student Guide are given in *Italics* following each question.

1. How is the end result of meiosis different from the end result of mitosis?
   Unlike mitosis, meiosis occurs in sexually reproducing organisms to create sex cells that contain half the number of chromosomes of the original cell. In meiosis, a diploid parent cell produces four haploid cells that are genetically different from each other and the parent cell. In mitosis, a diploid parent cell divides to produce diploid daughter cells that are genetically identical to the parent.
2. What are some differences in the processes of meiosis and mitosis?
   Cells that undergo mitosis divide only once. Cells that undergo meiosis proceed through two cell divisions. Chromosomes do not form tetrads during mitosis, but homologous pairs of sister chromatids do form tetrads, groupings of four chromatids, during prophase I of meiosis I. Further, there is no crossing-over during mitosis, but this genetic exchange does occur during meiosis I.

3. How is meiosis I different from meiosis II?
   Answers will vary, but student responses should reflect knowledge that no chromosome replication takes place during meiosis II.

Activity 3: Modeling Independent Assortment

Required Knowledge

Make sure students have some prior information on the following concepts and terms: genes occur in pairs, alleles, dominant traits, genotype, heterozygous, homozygous, phenotype, recessive traits, and Punnett square.

Procedure

Refer to the Student Guide for step-by-step instructions for this activity.

Activity 4: Modeling Linked Genes

Required Knowledge

Make sure students understand that each chromosome contains many different genes, numbering in the hundreds or even thousands. Genes located on the same chromosome are referred to as syntenic. Some genes are located very close together on the same chromosome and do not independently assort. These chromosomes are referred to as being linked to one another.

Procedure

Refer to the Student Guide for step-by-step instructions for this activity.

Activity 5: Modeling Crossing-Over

Required Knowledge

Make sure students have some prior knowledge of the following concepts and terms: crossing-over, genes, homologous chromosomes, meiosis, and tetrad.

Procedure

Refer to the Student Guide for step-by-step instructions for this activity.

Questions

Answers to questions in the Student Guide are given in *Italics* following each question.

1. Why did the modeling of the process of crossing-over include sex chromosomes?
   Crossing-over occurs during meiosis, which is a process in sexually reproducing organisms that creates haploid sex cells. In animals, these sex cells are called gametes; in plants, they are referred to as spores. Gametes contain both autosomes and sex chromosomes.

2. Examine each of the autosomes in the four gametes that you have modeled and compare them with the drawing of your original autosome pair. How many are different from the original autosome pair? How are they different?

   Answers will vary, but student responses should reflect knowledge of the exchange of genetic information between homologous chromosomes in a tetrad during meiosis I.

3. Take two gametes from your model and simulate fertilization by pairing up the autosomes and the sex chromosomes from the two gametes. Does the new fertilized cell have chromosomes and alleles identical to those of the original cell? If not, explain how and why it is different.

   Answers will vary, but student responses should reflect knowledge that the process of crossing-over leads to genetic variation between parents and offspring.

Extension Activities

- Have your students use the chromosome model set to model additional inheritance scenarios, as in Activity 3. Encourage students to assign different attributes to the model genes, so that different characteristics are modeled using the red and pink squares, circles, and triangles. You may want to use this to assess students' understanding of some of the concept covered in these activities, such as dominance, recessiveness, homozygous traits, heterozygous traits, and inheritance ratios.
- Have students repeat the mitosis and meiosis activities using multiple chromosome pairs for each activity.

Student Guide

17-1120, 17-1121

Modeling Mitosis and Meiosis

Overview

During the following activities, you will use chromosome model pieces to visualize the cellular processes of mitosis and meiosis as they occur in most animal cells as well as to simulate processes of genetic variation by modeling crossing-over and independent assortment of chromosomes.

Background

Mitosis and meiosis are the means by which genetic information, the DNA encoded in threadlike structures called chromosomes, is passed from one generation of cells to the next. In mitosis, the nucleus of a diploid cell (containing replicated chromosomes) divides. The result of mitosis is two cells that are genetically identical, with the same (diploid) number of chromosomes as the parent cell. In meiosis, the nucleus of a diploid cell, containing a complete set of chromosomes, divides twice. Genetic information is exchanged between homologous chromosomes. The result of meiosis is four genetically diverse haploid cells, called gametes, each with half the number of chromosomes of the parent cell.

In terms of the life of a cell, reproduction is a crucial but relatively brief part of an ongoing process known as the cell cycle. The longer period between cell divisions is called interphase. During **interphase**, the cell grows, replicates its chromosomes, and produces and assembles the cellular structures needed for cell division.

For most of the cell cycle, chromosomes are dispersed throughout the nucleus of a cell. During chromosome replication, however, chromosomes thicken and become tightly coiled structures that can be observed under a light microscope. They are connected at a point called the centromere. Each chromosome of the double-chromosome structure is known as a “sister” chromatid.

Mitosis

Mitosis is the division of the nuclear material within a cell, the process of one parent cell dividing to create two genetically identical daughter cells. This form of cellular reproduction ensures that the daughter cells produced by the parent cell contain genetic material identical to that of the parent cell. Mitosis is usually viewed in four phases: prophase, metaphase, anaphase, and telophase. During **prophase** (Figure 1), each chromosome, now a pair of identical chromatids joined at the centromere, thickens and becomes tightly coiled within the nucleus, so that it is visible under a light microscope. A mitotic spindle forms within the cell, outside the nucleus. The mitotic spindle is made up of microtubules, long strands of proteins that have a pair of centrioles on either end. The mitotic spindle helps separate the identical chromatids of each replicated chromosome. During prophase, the microtubules lengthen and the centriole pairs move to opposite ends of the cell. The cell’s nuclear membrane begins to break down as the cell transitions from prophase to metaphase, allowing microtubules to attach to each of the chromatids.

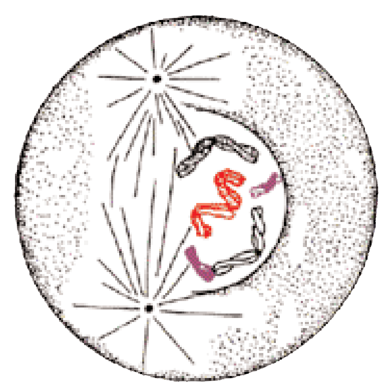


Figure 1: Prophase

During **metaphase** (Figure 2), the chromosomes line up in the center of the cell along an equatorial plane called the metaphase plate. Each sister chromatid is attached at the centromere to a microtubule of the mitotic spindle. This will allow one identical sister chromatid of each chromosome to be pulled to opposite ends of the cell by the mitotic spindle apparatus during the next phase, anaphase.

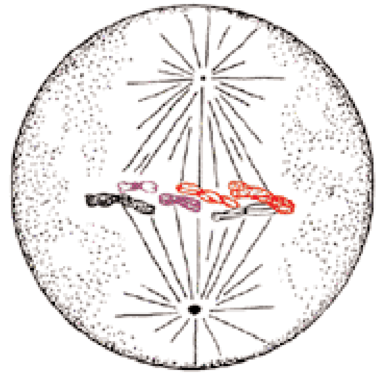


Figure 2: Metaphase

Anaphase (Figure 3) begins as the microtubules on both sides of the chromosome pair pull on the attached chromatid. This pull separates the sister chromatids at the centromere and begins the movement of the chromatids to opposite ends of the cell. The chromatids can now be referred to as daughter chromosomes. At the end of anaphase, each pole of the cell has an equal and complete collection of daughter chromosomes.

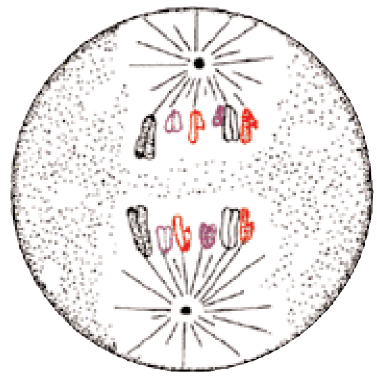


Figure 3: Anaphase

The cell elongates even more during **telophase** (Figure 4). A nuclear membrane begins to form, from fragments of the parent cell's nuclear membrane, around each set of chromosomes at the poles of the cell. The chromosomes become less tightly coiled and less apparent. The division of genetic material from one nucleus into two identical nuclei is complete, signaling the end of mitosis. However, this is not the end of cell division. The final step of the cell cycle is **cytokinesis** (Figure 5). This is the division or "pinching" of the parent cell's cytoplasm to form two separate daughter cells. Cytokinesis usually begins during the latter stages of mitosis and, although not considered a stage of mitosis, indicates the end of cell division. The daughter cells progress into interphase and the cell cycle begins again.

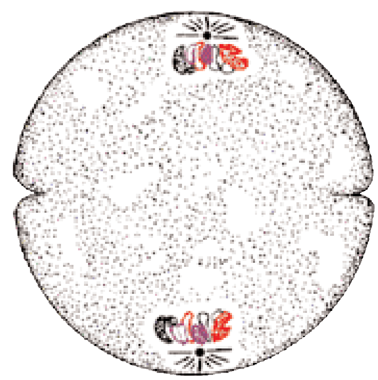


Figure 4: Telophase

Meiosis

The names of the stages of meiosis and some of the processes involved in meiosis are similar to those in mitosis, but meiosis has a dramatically different purpose. Meiosis occurs in sexually reproducing organisms to create sex cells that contain half the number of chromosomes of the original cell. Cells that have half the original number of chromosomes are described as *haploid* cells; they are called gametes in animals and spores in plants. When maternal and paternal gametes fuse during fertilization, the offspring of these organisms then posses a complete set of chromosomes and can be described as diploid cells. Among diploid sets of chromosomes, two corresponding chromosomes are called homologs; the pair is considered homologous.

Cells that reproduce through meiosis undergo two cell divisions, known as meiosis I and meiosis II (see Figure 6 on page S-3). Meiosis I has five phases: prophase I, metaphase I, anaphase I, telophase I, and cytokinesis. In meiosis, cytokinesis is considered an actual stage of the process, because the cytoplasm must divide completely before meiosis II can begin. **Interphase** takes place prior to prophase I and is much like interphase prior to mitosis: the cell grows, replicates its chromosomes, and produces and assembles the cellular structures needed for cell division. All chromosomes of the cell consist of two genetically identical sister chromatids joined at their centromeres.

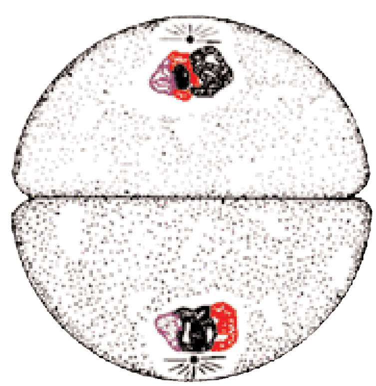


Figure 5: Cytokinesis

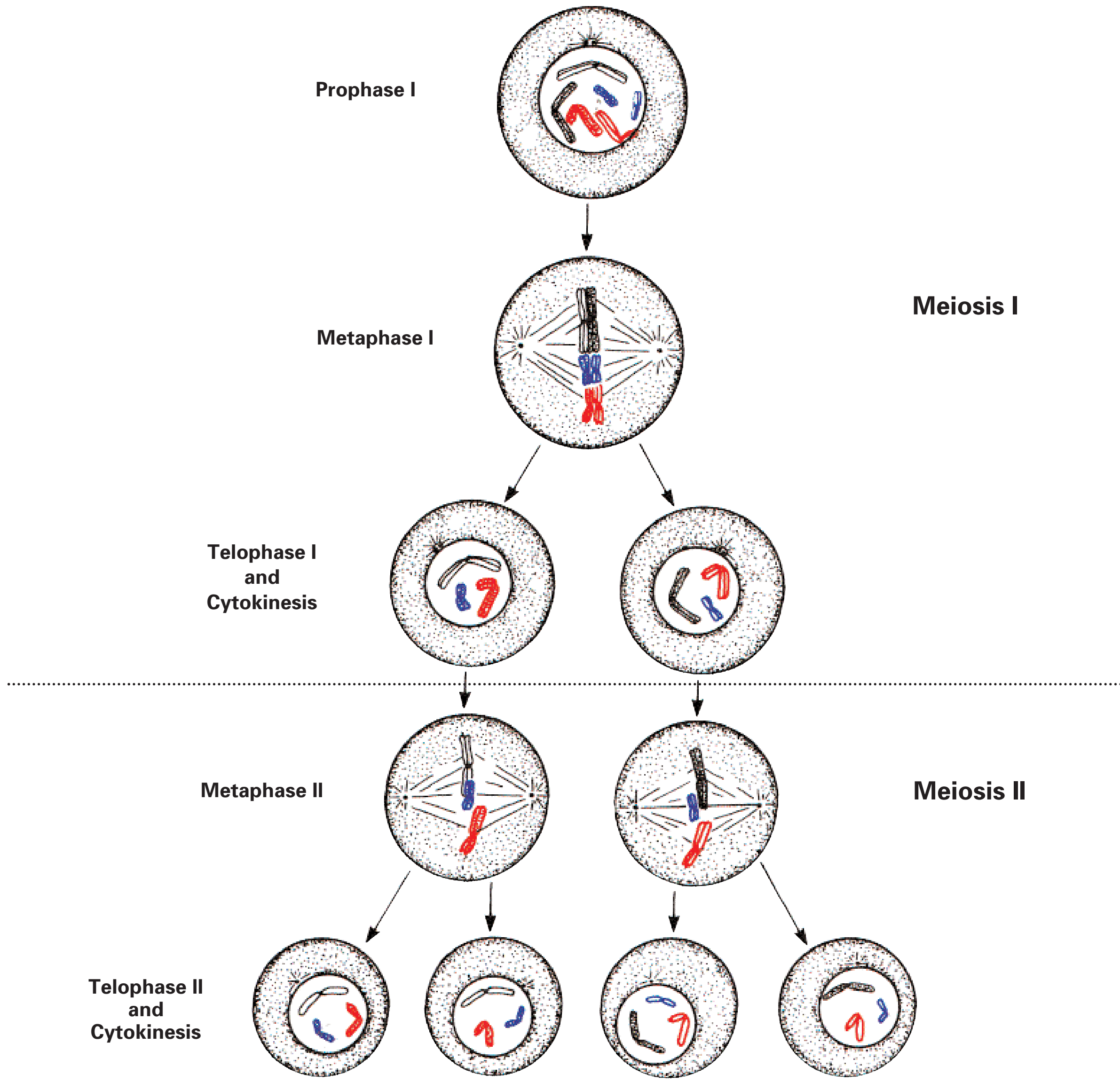


Figure 6: Meiosis

During **prophase I**, the homologous chromosomes (both consisting of two identical sister chromatids, due to replication during interphase) come together to form a tetrad, a grouping of four chromatids. An important step in maintaining genetic variation takes place within the tetrads; this is an important difference between meiosis and mitosis. Along the lengths of the homologous chromosomes, genes from non-sister chromatids may cross over one another, exchanging genetic material. This **crossing-over** mixes maternal and paternal genetic material, ensuring that daughter cells produced by meiosis I will be genetically different from each other and from the original parent cell. As prophase continues, a spindle forms. The ends of the spindle move toward the poles of the cell. As in mitosis, this spindle will be responsible for separating the chromosomes.

During **metaphase I**, the tetrads line up in the center of the cell along the metaphase plate. Spindle fibers from each pole of the cell attach to one pair of sister chromatids in each tetrad. The chromatid pairs are separated and pulled to opposite ends of the cell for the first cell division. This is another important difference between mitosis and meiosis. In mitosis, the spindle pulls one sister chromatid to

opposite sides of the cell, but in meiosis I, the spindle pulls a pair of sister chromatids to opposite sides of the cell. This allows each cell in the first cell division of meiosis to contain a pair of connected sister chromatids for each chromosome.

During **anaphase I**, the spindle fibers separate the tetrad, moving a pair of connected sister chromatids to each pole of the cell. The homologous chromosome pairs reach the poles of the cell and the cell begins to divide from one parent cell into two daughter cells during **telophase I** and **cytokinesis**.

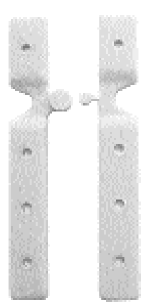
The two daughter cells now enter the second cell division stage of meiosis, known as meiosis II. Like meiosis I, meiosis II has five phases: prophase II, metaphase II, anaphase II, telophase II, and cytokinesis. There is no interphase period between meiosis I and meiosis II, because no further replication of chromosomes occurs at this stage of cell reproduction.

During **prophase II**, the pairs of sister chromatids in each of the two daughter cells move toward the metaphase plate, the spindle forms, and each end of the spindle moves toward the poles of the cells. **Metaphase II** is much like metaphase during mitosis. The chromosomes align in the center of the cell along the metaphase plate, with the sister chromatids of each chromosome pointing toward opposite poles of the cell. Spindle fibers attach to each of the sister chromatids by microtubules, in preparation for the separation of the chromosome pairs.

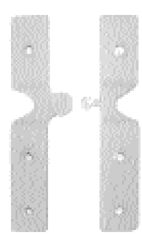
During **anaphase II**, microtubules pull the sister chromatids, causing them to separate at the centromere. The chromatids, now separate chromosomes, move toward opposite poles of the cell. Nuclei begin to form at the opposite poles. The two daughter cells begin to divide during **telophase II** and **cytokinesis**. These two divisions create four daughter cells, each containing only one copy of each chromosome from the original parent cell. Therefore, each of the four daughter cells has half of the original number of chromosomes of the parent cell, and some of the maternal and paternal genes have crossed over.

Chromosome Model Set Key

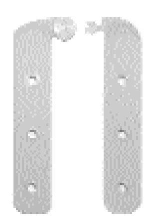
Each chromosome model set includes a number of different pieces representing different genetic materials. Before beginning any of the modeling activities, refer to the key below to familiarize yourself with the model pieces and the genetic materials that they represent.



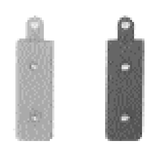
autosomes



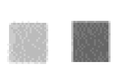
X (female) sex chromosomes



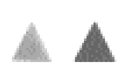
Y (male) sex chromosomes



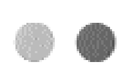
chromosome fragments, pink and red



gene, square (pink and red alleles)



gene, triangular (pink and red alleles)



gene, circular (pink and red alleles)

Modeling Mitosis and Meiosis
Activity 1: Modeling Mitosis

Procedure

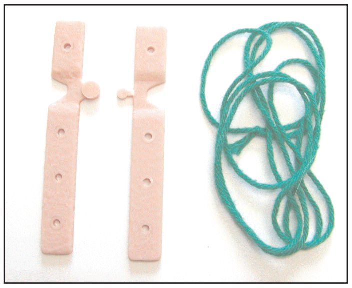


Figure 7: Step 1

1. From the chromosome model set, obtain two autosomes and one 122-cm (48″) piece of yarn or string (Figure 7).
2. Tie the ends of the piece of yarn or string together to make a loop. This loop represents the cell membrane.
3. Place the two chromosomes inside the cell membrane. At a corresponding point on each chromosome, place a similar gene. The genes should be the same shape, but can be of different colors. This model represents a cell with one chromosome pair (Figure 8).

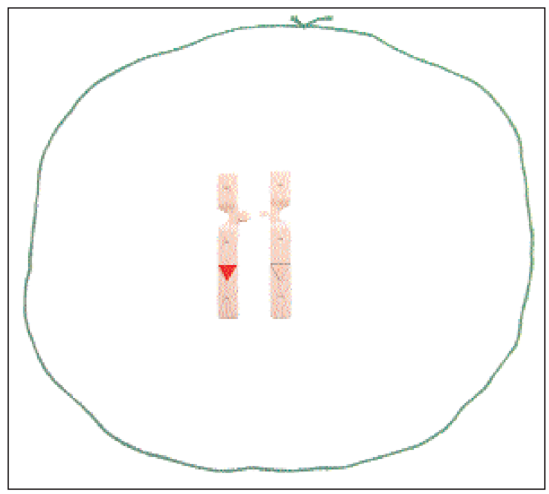


Figure 8: Step 3

4. Cells prepare for mitosis by first replicating the chromosomes in their nucleus. This occurs before mitosis, during interphase. To model this process, create a duplicate of each chromosome by making a matching autosome for each; each replica should possess the same gene as the original autosome. Attach the corresponding replicated chromosome to each original chromosome. The point at which the two identical chromosomes are connected represents the centromere that joins the two identical sister chromatids (Figure 9).

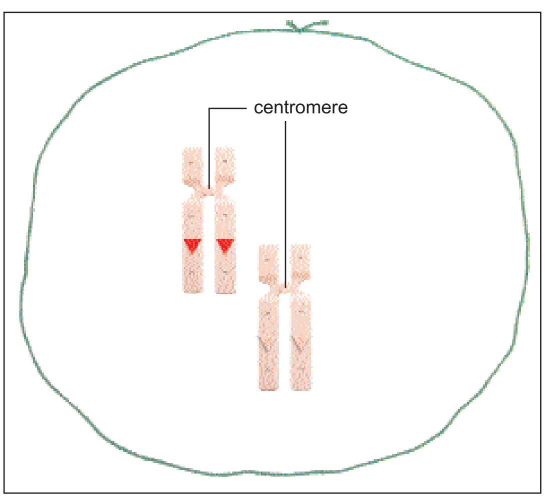


Figure 9: Step 4

5. During metaphase of mitosis, the sister chromatids line up across the metaphase plate in the center of the cell. Line up the replicated chromosome pairs end-to-end in the center of the cell, with the centromeres aligned (see Figure 10 on page S-6).
6. Disconnect the identical sister chromatids from one another at the centromere and move each chromatid away from its sister chromatid to opposite sides of the cell. This step is representative of what occurs during anaphase of mitosis (see Figure 11 on page S-6).

Punnett Square Activity Sheet

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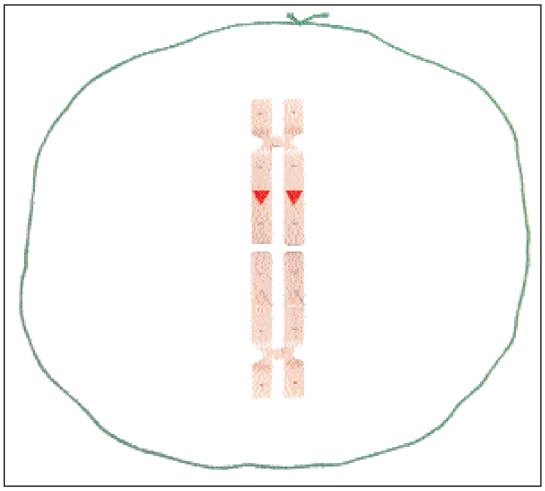

Figure 10: Step 5

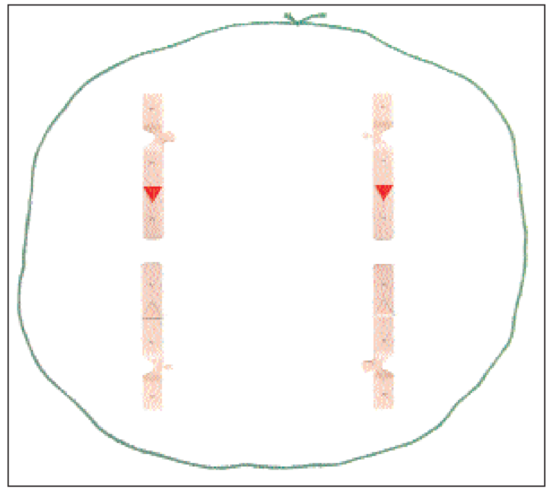

Figure 11: Step 6

7. Lift the loop "membrane" and cross it over itself to create a figure eight. This step simulates the division of one cell into two genetically identical cells during final phases of the cell cycle. Compare the two sides of the figure eight. Each side of the figure eight should possess the same two chromosomes and be identical to the original cell (Figure 12).

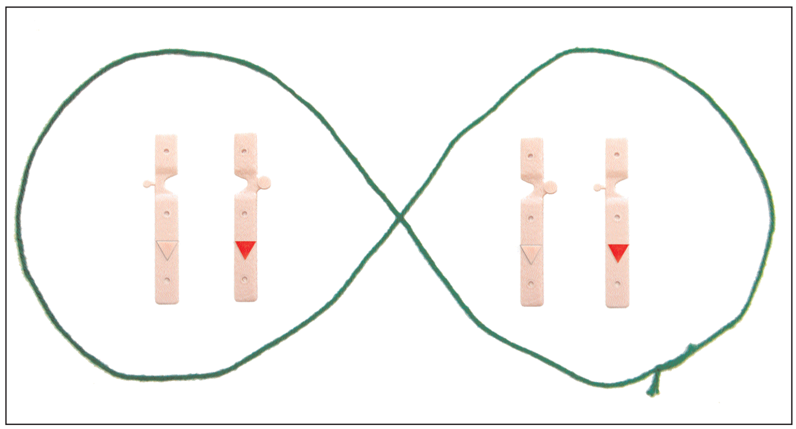

Figure 12: Step 7

Questions

1. Define interphase and describe what happens during this part of the cell cycle.

2. Define mitosis in terms of the genetic material in the original and daughter cells.

3. List the four stages of mitosis and the final step in mitotic cell division.

Modeling Mitosis and Meiosis
Activity 2: Modeling Meiosis

Procedure

1. Obtain two pieces of yarn or string about 92 cm (36″) in length. Tie the ends of each piece of yarn or string together to make a loop. These loops represent cell membranes.

2. Using the chromosome model set and one loop, model a cell that contains two autosomes and two sex chromosomes: one X chromosome and one Y chromosome (Figure 13).

3. Place a similar gene on each autosome. Place the autosomes and sex chromosomes side-by-side (Figure 14).

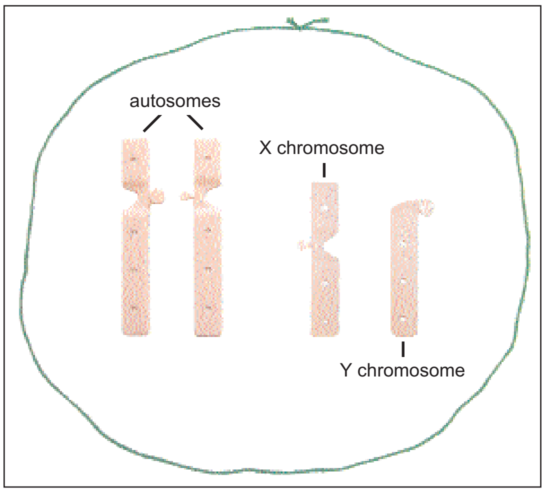

Figure 13: Step 2

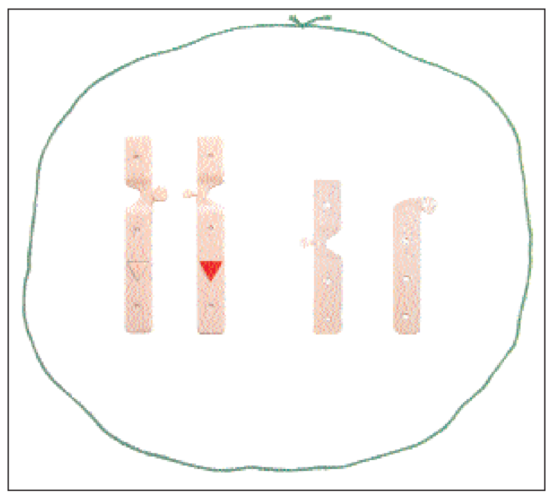

Figure 14: Step 3

4. Create a duplicate of each autosome and sex chromosome by making a matching chromosome for each. Make sure that each replica possesses the same gene as the original. Connect each of the replicated chromosomes in the cell. This simulates the replication of chromosomes within the nucleus of a cell during interphase, which occurs prior to prophase I of meiosis. The connection between the chromosome copies represents the centromere that joins the two identical sister chromatids (see Figure 15 on page S-8).

5. Line up the chromosomes side-by-side in the center of the cell. Connected pairs of autosomes should be together and connected pairs of sex chromosomes should be together. Each side-by-side pair forms a tetrad, a paired chromosome structure comprised of four chromatids. This represents the alignment of tetrads during metaphase I of meiosis (see Figure 16 on page S-8).

6. Place the other loop of string beside the loop containing the chromosomes. Keeping each pair of chromosomes connected, place one pair of chromosomes from each of the two tetrads in the second loop. This represents the first cellular division in meiosis, which occurs during anaphase I, telophase I, and cytokinesis of meiosis I. You should now have two daughter cells containing one connected pair of autosomes and one connected pair of sex chromosomes.

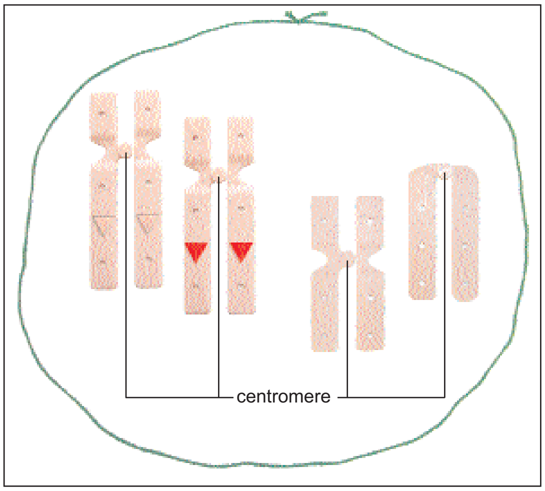

Figure 15: Step 4

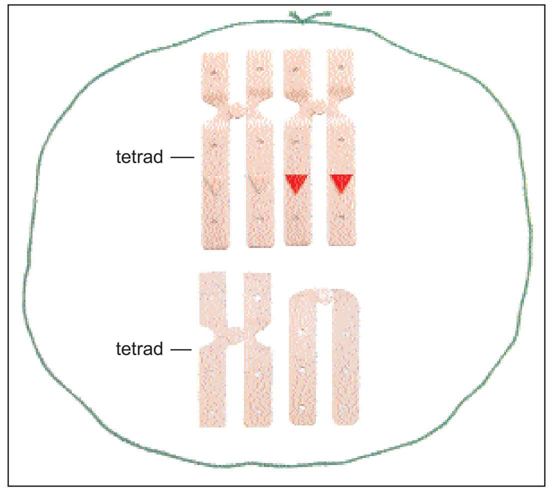

Figure 16: Step 5

7. As the two daughter cells enter meiosis II, the chromosomes do not go through replication again. Instead, the paired chromosomes in each move toward the center of the cell, with their centromeres aligned. Place the chromosome pairs end-to-end in the center of each cell, with the centromeres aligned. This represents metaphase II (Figure 17).

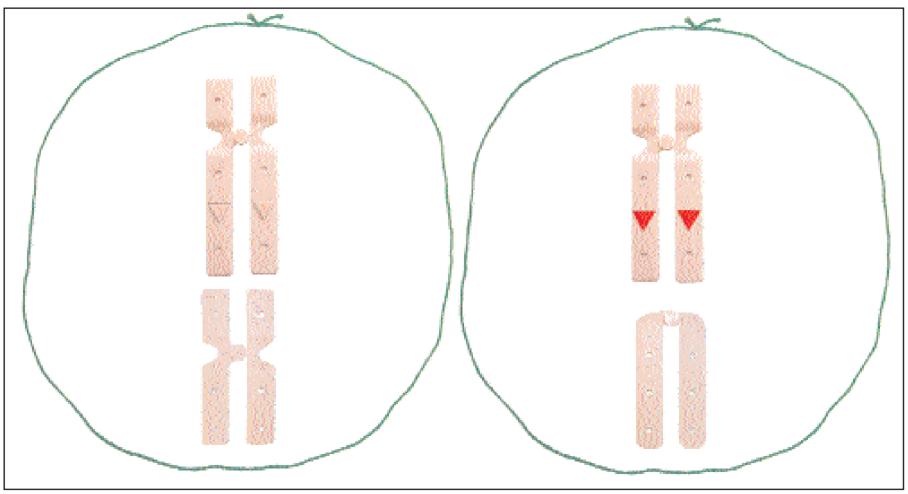

Figure 17: Step 7

8. Separate the connected pairs of chromosomes in each cell at their centromere and move one chromosome from each pair in the cell toward the opposite sides of the cell. This represents the separation of chromosomes during anaphase II of meiosis.

9. Lift one loop "membrane" and cross it over itself to create a figure eight. Repeat this procedure with the other loop. For each figure eight, place one chromosome from each of the unconnected pairs into each side of the figure eight (the new daughter cells). This represents the division of two cells into four cells during telophase II and cytokinesis of meiosis II. You should now have four gametes, each with one autosome and one sex chromosome (see Figure 18 on page S-9).

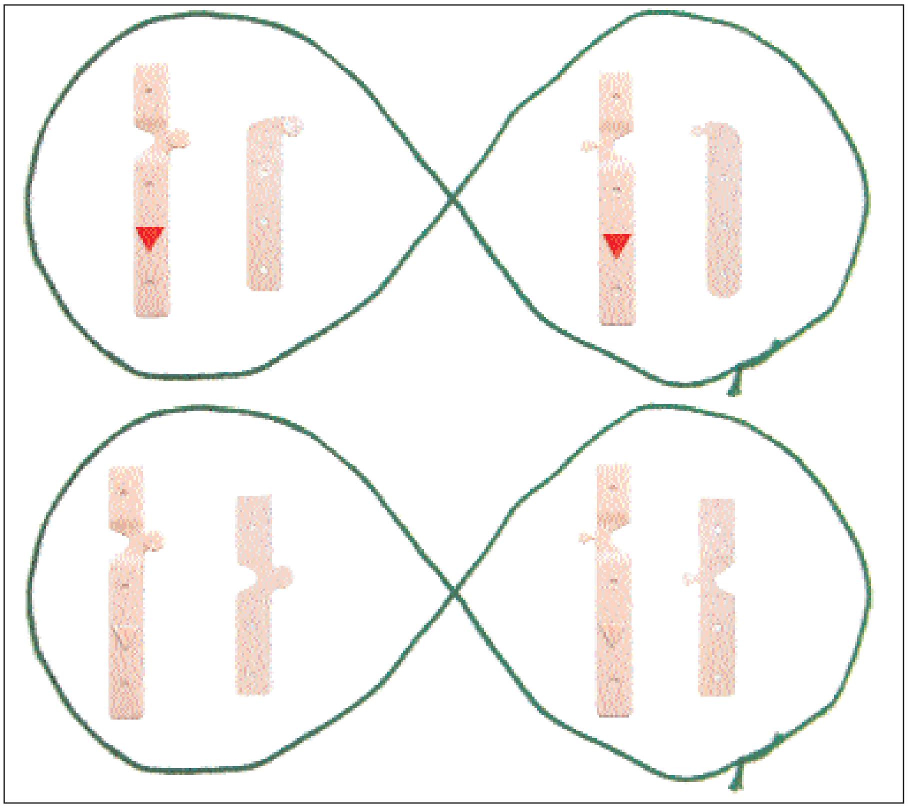

Figure 18: Step 9

Questions

1. How is the end result of meiosis different from the end result of mitosis?

2. What are some differences in the processes of meiosis and mitosis?

3. How is meiosis I different from meiosis II?

Modeling Mitosis and Meiosis
Activity 3: Modeling Independent Assortment

Procedure

1. Assume that the different shapes and colors of chromosome model pieces represent different pea plant traits and dominant and recessive alleles of those traits. Let a red square represent the dominant allele for stem length in pea plants, tall. Let a pink square represent the recessive allele for stem length, which is dwarf. Let a red triangle represent the dominant allele for the texture of a pea pod, which is smooth, and let a pink triangle represent the recessive allele for pea pod texture, wrinkled.
2. Assume that one pair of chromosomes contains the genes for stem length in pea plants, and another chromosome contains the genes for pea pod texture. Assemble a set of chromosomes representing a pea plant that is homozygous dominant for pea plant stem length and homozygous recessive for pea pod texture.
3. What are the possible gene combinations for stem length and pod texture that this pea plant could donate to its offspring? Show all of the genotypes possible for the offspring of two pea plants possessing this genetic makeup. Use the chromosome model pieces and the Punnett Square Activity Sheet to represent each of the possible genotypes.
4. Describe the genotypes and phenotypes for all offspring combinations in terms of homozygous/heterozygous and dominant/recessive traits.
5. If two of the offspring of the original pea plants reproduced, what would the genotypes and phenotypes of their offspring be? Use the chromosome model pieces and the Punnett Square Activity Sheet to help you represent each of the possible genotypes.

Modeling Mitosis and Meiosis
Activity 4: Modeling Linked Genes

Procedure

1. Assume that the different shapes and colors of chromosome model pieces represent different pea plant traits and dominant and recessive alleles of those traits. Let a red square represent the dominant allele for stem length in pea plants, tall. Let a pink square represent the recessive allele for stem length, which is dwarf. Let a red triangle represent the dominant allele for the texture of a pea pod, which is smooth, and let a pink triangle represent the recessive allele for pea pod texture, wrinkled.
2. Suppose that one pair of chromosomes contain the genes for both stem length and pea pod texture in pea plants. Assemble a pair of chromosomes representing a pea plant that is heterozygous for pea plant stem length and homozygous recessive for pea pod texture.
3. What are the possible gene combinations for stem length and pod texture that this plant could donate to offspring? Use the chromosome model pieces and the Punnett Square Activity Sheet to help you represent each of the possible genotypes. Explain how this situation is different from having the genes for stem length and pea pod texture occur on separate pairs of chromosomes (as in Activity 3, Independent Assortment).
4. Suppose that a pea plant that is heterozygous for pea plant stem length and homozygous recessive for pea pod texture is crossed with a pea plant that is homozygous dominant for stem length and pod texture. Describe the genotypes and phenotype of all of the offspring combinations in terms of homozygous/heterozygous and dominant/recessive traits. Use the chromosome model pieces and the Punnett Square Activity Sheet to help you represent each of the possible genotypes.

Modeling Mitosis and Meiosis
Activity 5: Modeling Crossing-Over

Procedure

1. Obtain two pieces of yarn or string about 92 cm (36″) in length. Tie the ends of each piece of yarn or string together to make a loop. These loops represent cell membranes. Using the chromosome model set, assemble a cell that has two autosomes and two sex chromosomes: two X chromosomes (Figure 19).
2. Place the same type (shape) of gene on each autosome. These genes can be of different colors. Pair up the autosomes and the sex chromosomes, but do not connect them (Figure 20).

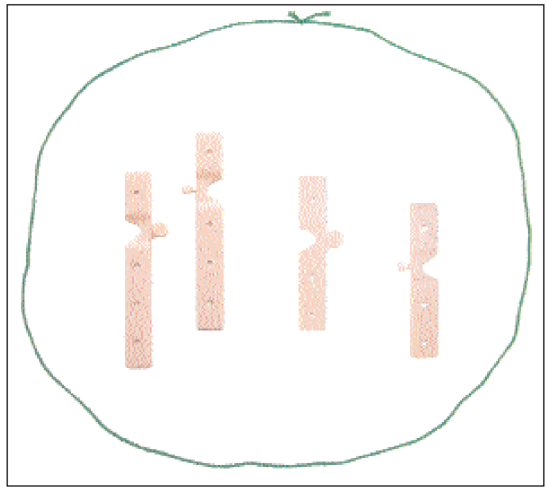

Figure 19: Step 1

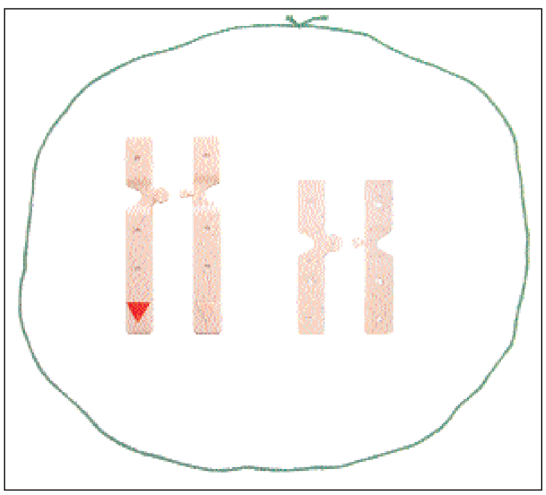

Figure 20: Step 2

3. Obtain two chromosome fragments, one red and one pink. Attach one fragment to the top of each autosome. Place a differently colored allele of the same gene (shape) at corresponding locations on each chromosome fragment.
4. Draw a diagram of the chromosome pairs. Label the color of the chromosome fragments and the shape and color of the genes on the autosomes.
5. Create a duplicate of each autosome and sex chromosome by making a matching chromosome for each. Make sure that each replica possesses the same gene as the original. Connect each of the replicated chromosomes in the cell. Remember to attach fragments to the replicated autosomes, too. This simulates the replication of chromosomes within the nucleus of a cell during interphase prior to meiosis. The connection between the chromosome copies represents the centromere that joins the two identical sister chromatids.
6. Line up the chromosomes side-by-side in the center of the cell. Connected pairs of autosomes should be together and connected pairs of sex chromosomes should be together. Each side-by-side pair forms a tetrad, a paired chromosome structure comprised of four chromatids. This represents the alignment of tetrads during metaphase I of meiosis (see Figure 21 on page S-13).

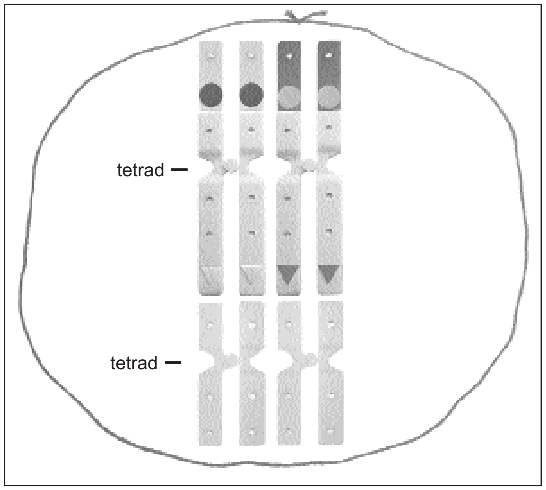

Figure 21: Step 6

7. Crossing-over takes place during prophase I of meiosis. Two non-sister chromatids within a tetrad become close enough to overlap each other and exchange similar pieces of genetic information. Crossing-over is one of several mechanisms that help ensure genetic variability within a species. To model crossing-over, exchange the chromosome fragments on the adjacent non-sister chromatids of the autosome tetrad (Figure 22).

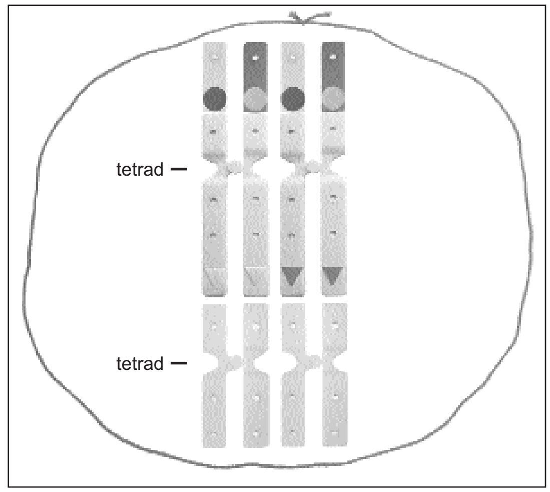

Figure 22: Step 7

8. Place the other loop of string beside the loop containing the chromosomes. Keeping each pair of chromosomes connected, place one pair of chromosomes from each of the two tetrads in the second loop. This represents the first cellular division in meiosis, which occurs during anaphase I, telophase I, and cytokinesis of meiosis I. You should now have a model of two daughter cells, each containing one connected pair of autosomes with fragments and one connected pair of sex chromosomes.

9. As the two daughter cells enter meiosis II, the chromosomes do not go through replication again. Instead, the paired chromosomes in each move toward the center of the cell, with their centromeres aligned. Place the chromosome pairs end-to-end in the center of each cell, with the centromeres aligned. This represents metaphase II.

10. Separate the connected pairs of chromosomes in each cell at their centromere and move one chromosome from each pair in the cell toward the opposite sides of the cell. This represents the separation of chromosomes during anaphase II of meiosis.

11. Lift one loop "membrane" and cross it over itself to create a figure eight. Repeat this procedure with the other loop. For each figure eight, place one chromosome from each of the unconnected pairs into each side of the figure eight (the new daughter cells). This represents the division of two cells into four cells during telophase II and cytokinesis of meiosis II. You should now have four gametes, each with one autosome and one sex chromosome (see Figure 23 on page S-14).

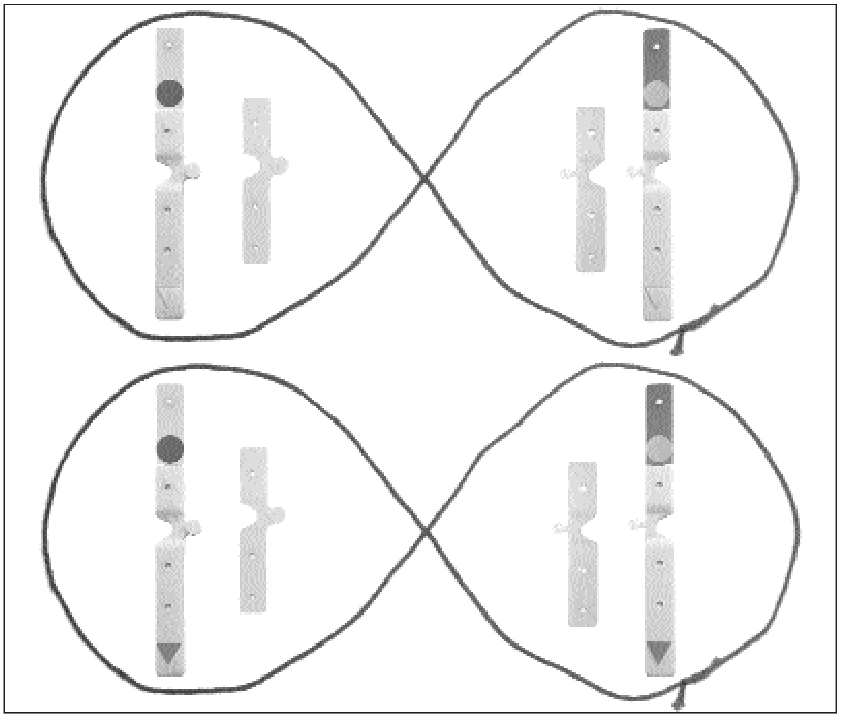

Figure 23: Step 11

Questions

1. Why did the modeling of the process of crossing-over include sex chromosomes?

2. Examine each of the autosomes in the four gametes that you have modeled and compare them with the drawing of your original autosome pair. How many are different from the original autosome pair? How are they different?

3. Take two gametes from your model and simulate fertilization by pairing up the autosomes and the sex chromosomes from the two gametes. Does the new fertilized cell have chromosomes and alleles identical to those of the original cell? If not, explain how and why it is different.

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