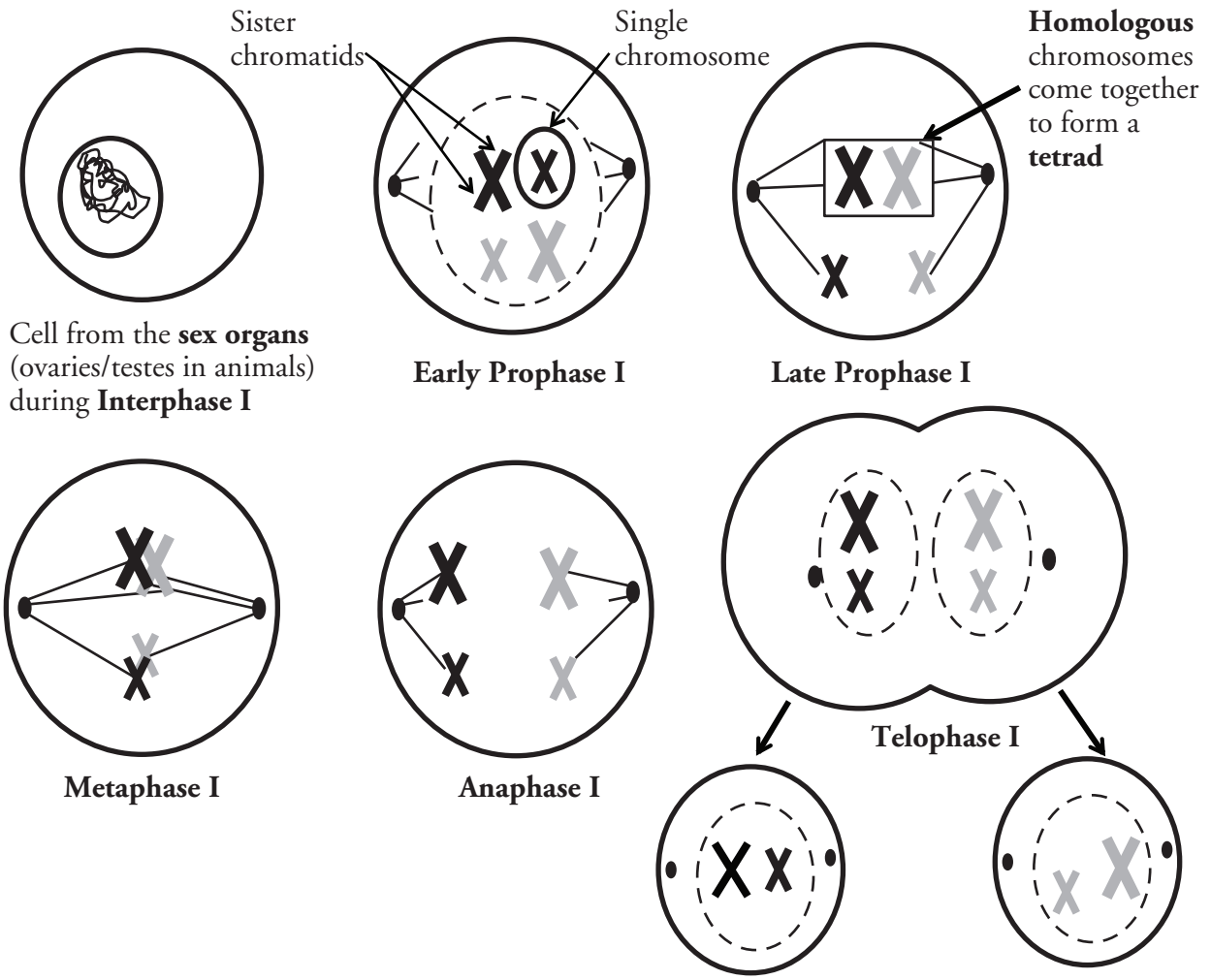
Meiosis

How does sexual reproduction lead to genetic variation?

Why?

Cells reproduce through mitosis to make exact copies of the original cell. This is done for growth and repair. Sexually-reproducing organisms have a second form of cell division that produces reproductive cells with half the number of chromosomes. This process is called **meiosis**, and without it, humans, oak trees, beetles, and all other sexually-reproducing organisms would be vastly different than they are today.

Model 1 – Meiosis I



1. According to Model 1, in what type of organs are the cells that enter meiosis I found?

   Sex organs (ovaries and testes).

2. Considering what you already know about mitosis in cells, what event must take place during interphase before a cell proceeds to division?

   DNA replication.

3. What two structures make up a single replicated chromosome?

   Sister chromatids.

4. In Model 1, how many replicated chromosomes does the cell contain during prophase?

   Four.

Read This!

Alleles are alternative forms of the same gene. For example, gene A may contain the information for fur color. One allele "A" may result in white fur, while the alternative allele "a" may result in black fur. **Homologous chromosomes** are chromosomes that contain the same genes, although each chromosome in the homologous pair may have different alleles.

5. At which stage in meiosis I do the pairs of homologous chromosomes come together?

   Late prophase I.

6. Once the chromosomes have formed a pair, what are they called?

   Tetrads.

7. At the end of meiosis I, two cells have been produced. How many replicated chromosomes are in each of these cells?

   Two.

8. Cells with a full set of chromosomes are referred to as **diploid** or **2n**, whereas cells with half the chromosomes are **haploid** or **n**. At which stage(s) of meiosis I are the cells diploid and at which stage(s) are they haploid?

   Diploid = prophase, metaphase, and anaphase

   Haploid = telophase after the cell has split.

9. Which of the statements below correctly describes the relationship between the cells at the end of telophase I and the original cell?

   a. The new cells have one copy of all of the genetic information in the original cell.

   b. The new cells have two copies of all of the genetic information in the original cell.

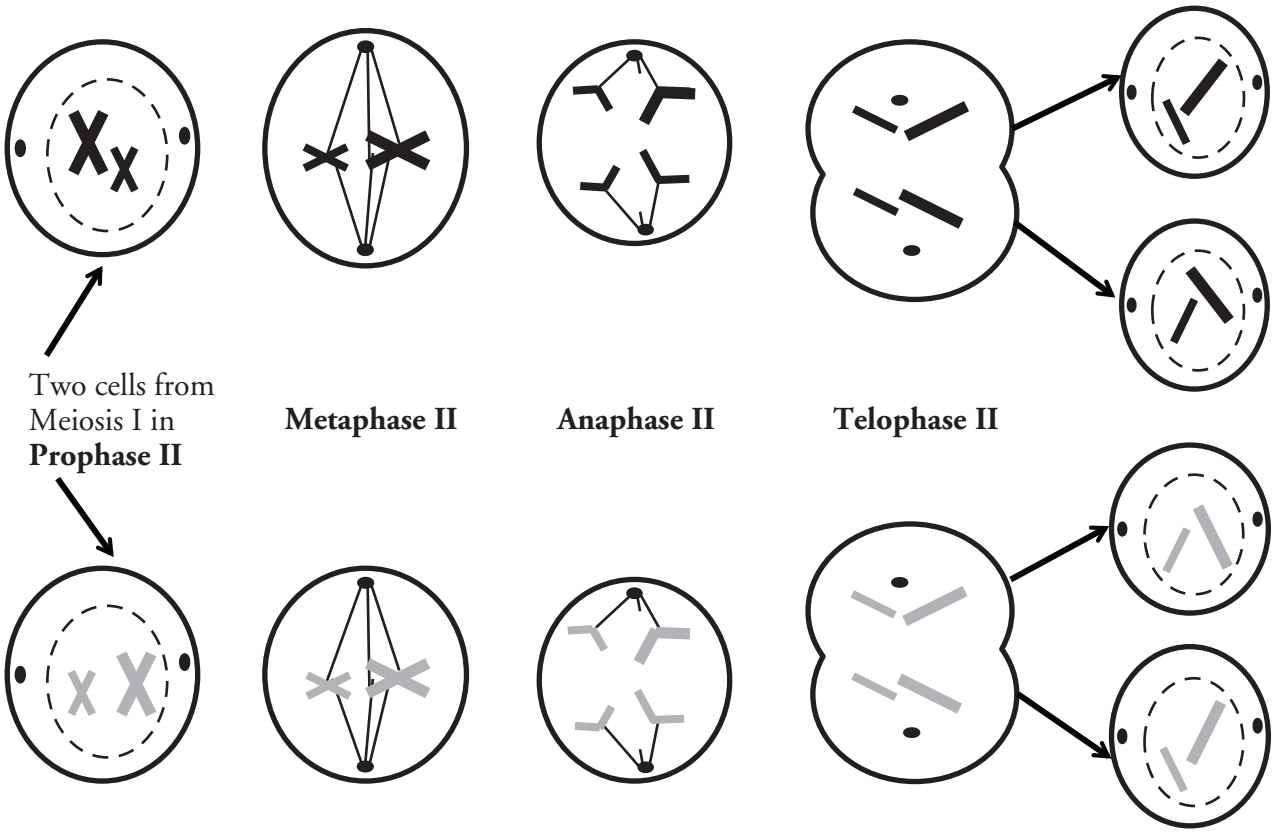
   c. The new cells have one copy of half of the genetic information in the original cell.

   (*d.*) The new cells have two copies of half of the genetic information in the original cell.

10. Considering the genetic makeup of the homologous pairs, will the cells at the end of telophase I be genetically identical to each other?

    No, they will not be genetically identical to each other because the homologous pairs separated and the alleles on each homologous pair are not necessarily identical.

Model 2 – Meiosis II



11. According to Model 2, where did each of the cells come from that started meiosis II?

    Meiosis I.

12. In meiosis I, during anaphase I, which structures separated—homologous chromosomes or sister chromatids?

    Homologous chromosomes separated.

13. In meiosis II, during anaphase II, which structures separated—homologous chromosomes or sister chromatids?

    Sister chromatids.

14. At the end of the meiosis II are four daughter cells. Are they haploid or diploid? Explain your answer in a complete sentence.

    The cells are still haploid. They each contain one chromosome (sister chromatid) from each homologous pair. Each chromosome contains a complete set of genes.

15. Which of the statements below correctly describes the relationship between the cells at the end of meiosis II and the original cell?

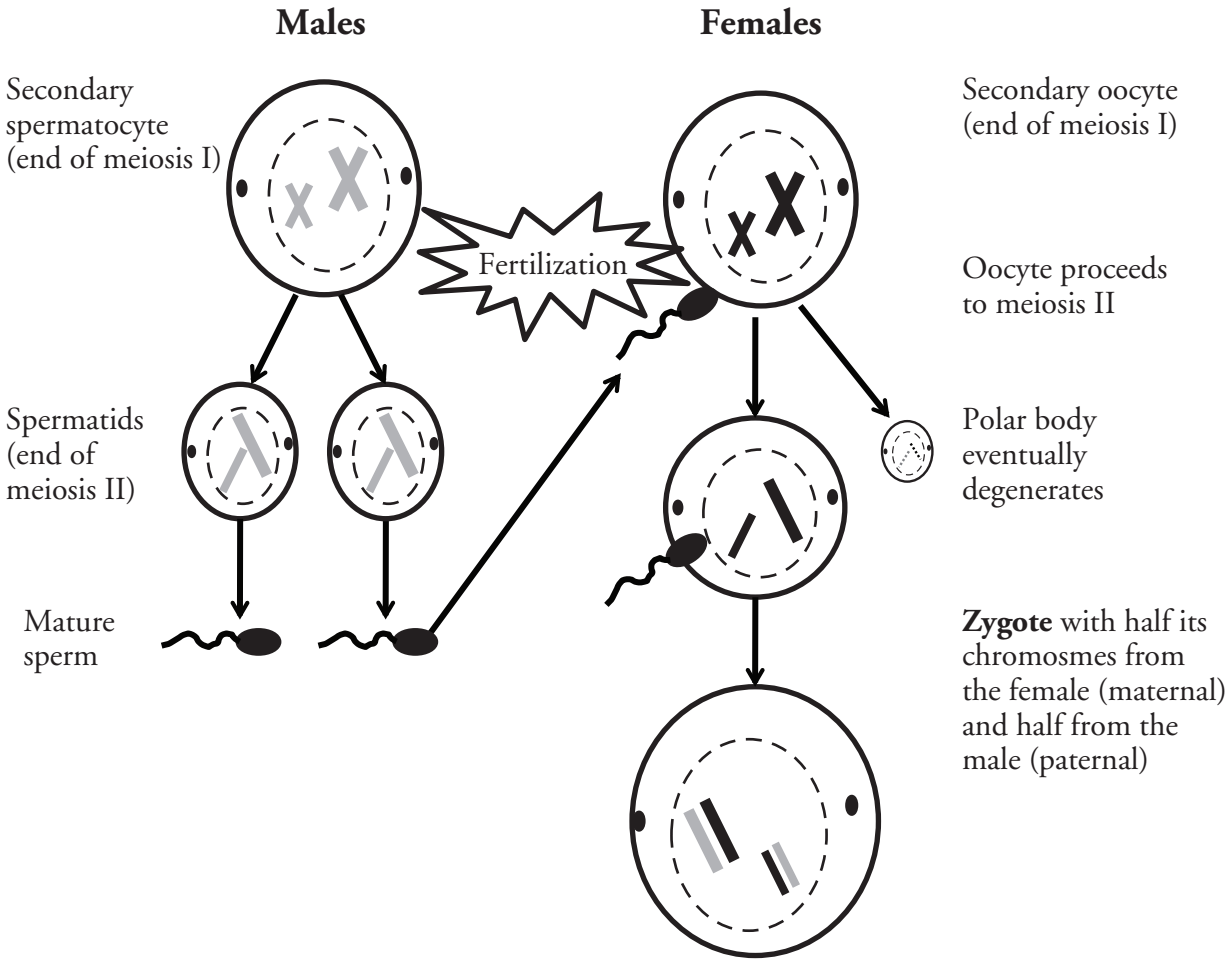
    a. The new cells have one copy of all of the genetic information in the original cell.

    b. The new cells have two copies of all of the genetic information in the original cell.

    (*c.*) The new cells have one copy of half of the genetic information in the original cell.

    d. The new cells have two copies of half of the genetic information in the original cell.

Model 3 – Gametogenesis and Fertilization (Human)



16. According to Model 3, what is the name given to the cells produced at the end of meiosis I in males?

    Secondary spermatocyte.

17. What is the name given to the cells produced at the end of meiosis I in females?

    Secondary oocyte.

18. Refer to Model 3.

    a. At the end of meiosis II in males, what cells are produced?

    Spematids.

    b. What do these cells (from the previous question) eventually become?

    Mature sperm.

19. Before fertilization, what happens to the secondary oocyte?

    Proceeds to meiosis II.

20. During fertilization which two cells come together? Be specific in your answer.

    Mature sperm and secondary oocyte.

21. During meiosis II, the secondary oocyte divides unevenly, with one cell (the ovum) receiving half of the chromosomes and nearly all the cytoplasm and organelles, while the other cell, the polar body, is much smaller and eventually degenerates. With your group, propose an explanation to explain why the secondary oocyte divides in this way.

    The ovum will receive more organelles, such as mitochondria for making energy, which will provide the zygote with all of its cytoplasm and organelles (note that the sperm contains only scant cytoplasm, a few mitochondria and haploid chromosomes), but nuclear division is necessary to produce the correct number of chromosomes in the oocyte.

22. What is the **ploidy** of the zygote produced by fertilization—haploid or diploid?

    Diploid.

23. What would the ploidy of the zygote be if egg and sperm were produced by mitosis rather than meiosis? How would this affect the ploidy of each successive generation?

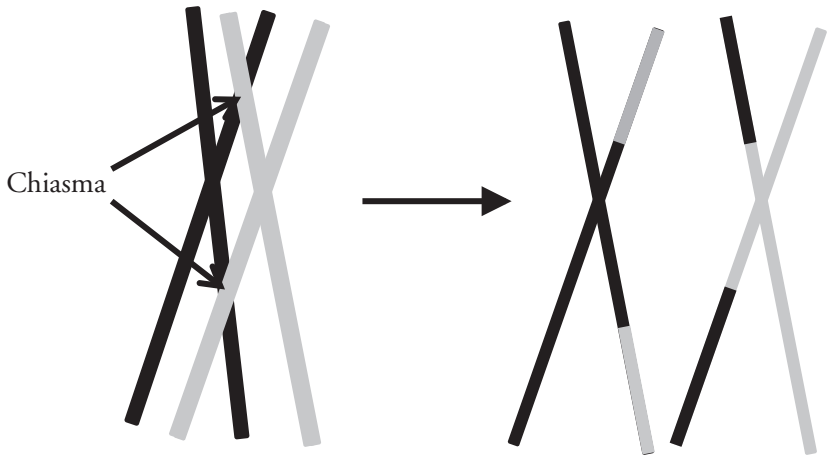
    If the egg and sperm were produced by mitosis, each would be diploid, so the zygote would be tetraploid (four sets of chromosomes). If this tetraploid organism produced tetraploid egg and sperm, the next generation would be octoploid (eight sets of chromosomes), and this doubling would continue with each generation.

24. With your group write a statement to explain the origin of the chromosomes found in the zygote. Your statement must include the term *homologous pair*.

    The homologous pairs of chromosomes found in the zygote have come from each parent. One half of each pair is maternal and the other half is paternal.

Extension Questions

Model 4 – Crossover of DNA in Chromosomes



Homologous pair of chromosomes (tetrad) during Prophase I

Recombinant chromatids

25. At which stage of meiosis are the chromosomes in Model 4?

    Prophase I.

26. When the chromosomes come together as homologous pairs, the arms of the sister chromatids may cross over.

    a. What are these crossover points called?

    The crossover points are chiasma.

    b. Describe what happens to the chromatids during crossover.

    Sections of the homologous pair switch places on the chromatids.

27. What phrase is used to describe the chromatids after crossing over takes place and the homologous chromosomes separate?

    Recombinant chromatids.

28. Compare the recombinant chromatids with the original pair.

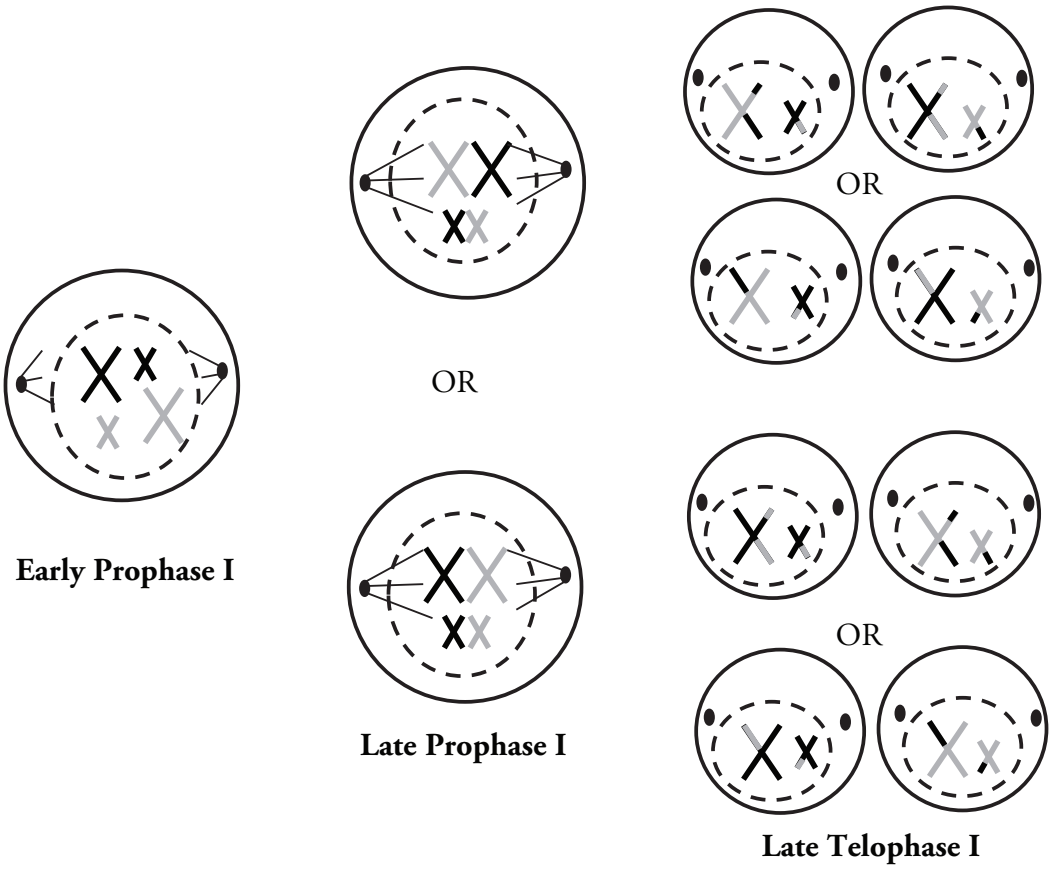
    a. Are the genes on a recombinant chromatid the same as the original chromatid?

    Yes, each chromosome in the homologous pair contains the same genes in the same place on the chromosome, so a switch between chromosomes would not affect the genes present.

    b. Are the alleles on a recombinant chromatid the same as the original chromatid?

    No, the chromosomes in the homologous pair can have different alleles for each gene, so a switch in a portion of the chromosome would affect the information in that chromatid.

Model 5 – Genetic Variation



Early Prophase I

Late Prophase I

Late Telophase I

29. Model 5 is a condensed version of meiosis I. Notice the two possible arrangements of chromosomes in late prophase I. Considering what you know about DNA replication and meiosis, is either arrangement equally likely during the formation of tetrads in late prophase I? Explain.

    DNA replication occurs randomly within the nucleus of a cell. When the homologous chromosomes come together as tetrads, they are just as likely to line up on one side of the cell as another.

30. If there were three sets of homologous chromosomes in the cell in Model 5, how many possible arrangements would there be for the tetrads in late prophase I?

    2 x 2 x 2 = 8 possible arrangements.

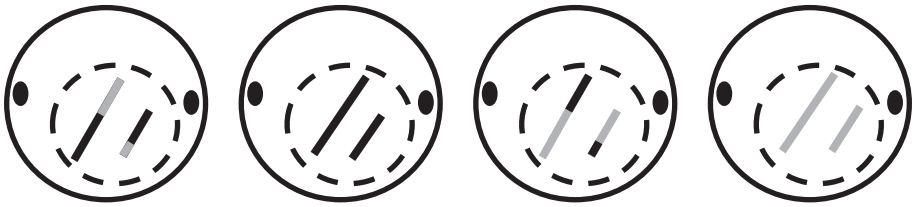
Read This!

When homologous chromosome pairs align on the spindle during metaphase I the orientation of one pair is independent of the orientation of any other pair. This is known as **independent assortment**. Humans have 46 chromosomes, arranged as 23 pairs. During metaphase I each pair lines up independently, which results in 2^{23} **possible combinations.**

31. With your group, calculate the number of possible genetic combinations due to independent assortment.

    2^{23} = 8,388,608

32. As a group, choose one set of daughter cells in late telophase I from Model 5. Imagine that those cells now undergo meiosis II. Draw at least four resulting haploid cells that could result.



33. Meiosis and sexual reproduction each lead to variation in the genetic make-up of every person. With your group, explain how meiotic events, as well as the random fertilization of eggs and sperm, together lead to this genetic variation.

Independent assortment leads to multiple different maternal and paternal gene combinations being produced in the cells at the end of meiosis I. Chiasma formation between homologous pairs of chromosomes leads to blocks of genes being swapped between nonsister chromatids during separation at anaphase I. This leads to allele combinations on the chromosomes being shuffled, and further varies the chromosomes that end up in egg and sperm after meiosis II. Random fertilization of eggs and sperm means that when zygotes are formed, the gene combination will be different each time, even if they come from the same two parents.

Teacher Resources – Meiosis

Learning Objectives

1. Explain the stages of meiosis and how haploid cells are produced for reproduction.
2. Explain how fertilization restores the diploid number and how meiosis maintains the diploid number across generations.

Prerequisites

1. Students should be familiar with all the events that occur at each stage of mitosis and interphase.
2. Students should have an understanding of vocabulary from mitosis and genetics, such as chromosome, chromatid, genes, and alleles.

Assessment Questions

1. If an organism contains 10 chromosomes in its body cells, how many chromosomes will be in the spermatid cells?

   a. 5 *b.* 10 *c.* 20

2. If an organism contains 10 chromosomes in its body cells, how many chromosomes will be in the zygote?

   a. 5 *b.* 10 *c.* 20

3. How many daughter cells are produced from one parent cell during the process of meiosis?

Assessment Target Responses

1. *a.*
2. *b.*
3. *Four cells.*

Teacher Tips

- It will be important to emphasize that no further DNA replication takes place between meiosis I and II but nuclear division occurs twice. Similarly, in this activity the process of oogenesis is abbreviated and the production of the three polar bodies and one ovum is not emphasized.
- Many concepts in this activity can be named by various terms. For example, the term "tetrad" is sometimes interchanged with "bivalent." If the text for your course uses different vocabulary, this should be made clear to the students before starting this activity.
- The Flinn Scientific laboratory kit, *Allele's Crossing Over to the Other Side,* Catalog No. FB1792, is a hands-on simulation using beads (alleles) and chenille wires (chromosomes) to create a unique gene sequence that students then crossover to complete the phases of meiosis.

Notes