PEER-LED TEAM LEARNING
INTRODUCTORY BIOLOGY

MODULE 10: MEIOSIS AND GAMETOGENESIS

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I. Introduction

Most cells in our bodies have nuclei with 46 chromosomes organized in 23 **homologous pairs**. Because there are two chromosomes of each type, the cells are called **diploid** and 2N = 46. If mothers and fathers each passed 46 chromosomes to their offspring in reproducing, the children in the new generation would have 92 chromosomes apiece. In the following generation it would be 184. Obviously, the increase does not occur; normal people in each generation have the same 2N = 46.

To produce a new individual (a **zygote**, initially) with 46 chromosomes, an egg and sperm each contribute half the total, or 23, when fertilization occurs. Both sperm and eggs, called **gametes**, develop from body cells in which the full 46 chromosomes are present. These body cells, located in the testes and ovaries, undergo special cell divisions, which reduce the number of chromosomes in half. The special cell divisions, two for each cell, make up a process called **meiosis**. Cells that have completed meiosis then differentiate to become gametes.

The general objective of this laboratory is to learn how meiosis occurs in forming eggs and sperm to carry genetic information from one generation to the next.

B. Benchmarks.

1. Demonstrate an understanding of the terminology of cellular genetic structure using diagrams.
2. Demonstrate the process of meiosis by using models or drawing chromosomes on cell outlines.
3. Compare the processes of mitosis and meiosis by: a. drawing diagrams with explanations of the processes, and b. comparing the genetic makeup in parent and daughter cells.
4. For spermatogenesis and oogenesis: a) compare and contrast b) label diagrams of the processes; c) relate the structures of the two gametes to their functions in producing a zygote.
5. Explain the processes of fertilization and cleavage using diagrams and models.

Prepare for your workshop by reading your textbook (Campbell, 4th Edition, Chapter 12; Audesirk, et al., 6th Edition, Chapter 11) and completing the Pre-Workshop activities below. Show your work on the pages of this handout.

II. Pre-Workshop Activities

<u>Activity 1. Genetics of the Cell</u>
Do this activity with a round robin. The following student may suggest changes to the answer made by the prior student. Answer the following questions by referring to Fig. 10.1.

1. For the cell in Fig. 10.1, 2N = __________ ?

2. How many chromosomes are represented?____ How many homologous pairs?_______

3. a. Indicate by number (#) which chromosomes form homologous pairs.

b. What two types of evidence indicate which chromosomes are paired?

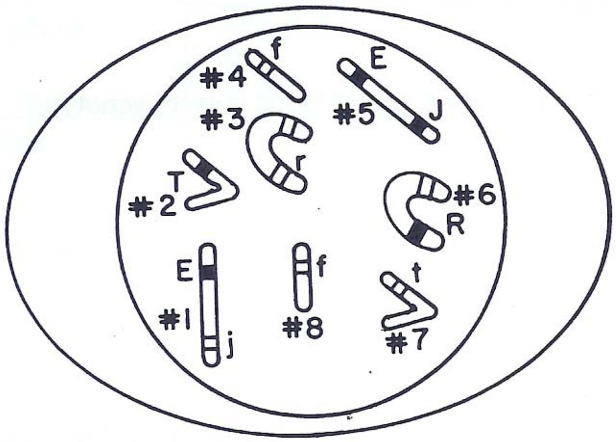


Figure 10.1 ______________________________
(title)

4. a. How many **different** genes are represented?__________
   b. How many **different** alleles?_____________

5. a. What genes appear in the homozygous condition?________________
   b. Which in the heterozygous state?_______________________

6. a. Which gene has a locus on the same chromosome as the **E/e** gene?__________
   b. Describe the position of that locus relative to the **E/e** gene. _____________________
____

7. Give a title for Fig. 10.1.

8. Write the genotype for the cell in Fig. 10.1. Be sure to follow the rules spelled out in your lab guide.
____ .

9. This cell is part of an organism whose father's sperm carried the following alleles: **EfjTr**. What alleles were carried by its mother's egg? _______________________________ .

10. The gene that is shown and not labeled is called the **M/m** gene. Label its alleles in Fig. 10.1.

Activity 2. Meiosis & Fertilization Concepts

Give a brief definition for each of the concepts below. On this list, make a series mini-concept maps (each with two concepts and a connector) by connecting each concept to at least one other.

meiosis gametogenesis gametes

spermatogenesis	oogenesis	haploid
1st meiotic division (M 1)	2nd meiotic division (M-2)	diploid
cleavage	zygote	sperm penetration
tetrad	1st polar body	2nd polar body fertilization
	Independent Assortment	unequal division
double chromosome	sister chromatids	synapsis

<u>Activity 3. Key events in Meiosis</u>

Using your book or lecture notes make simple drawings of the following 4 stages of meiosis and label them using the associated terms. Draw a cell in which 2N = 4. Below the drawing use a few words to describe what is happening in that stage and what the products of each division (M1 and M2) are.

1. metaphase I: sister chromatids, double chromosomes, synapsis, tetrad, homologous chromosomes, kinetochore,

2. anaphase I: sister chromatids, double chromosomes, kinetochore, spindle fibers, centrosomes

3. metaphase II: centromere, metaphase plate, sister chromatids, kinetochore,

4. anaphase II: chromosomes, spindle fibers, centrosomes

______________ ______________ ______________	______________ ______________ ______________	______________ ______________ ______________	______________ ______________ ______________

III. Workshop Activities

Activity 1. Review of the Pre-Workshop Activities

Jigsaw with pairs

1. Student pairs spend 5 minutes reviewing answers to the pre-workshop questions.
2. Pairs of students may raise questions about items that they can't agree on or both had trouble with.
3. The peer leader will ask pairs to answer selected questions from the pre-workshop that might be difficult or confusing.

Activity 2. Model the Cell

Pairs and jigsaw. Your pair should do two problems as directed by the peer leader. At the end, provide solutions to the other workshop members and ask for comments or corrections. Draw a large cell outline with a large nucleus on the board and add the components as described below to provide a solution.

1. A daughter cell with 2N = 4 at the end of cell division. The cell has two genes represented, one on each type of chromosome. For one gene (A/a) the cell is heterozygous. For the other gene (T/t) it is homozygous for **t**.

2. A diploid cell is entering prophase with 2N = 6. The cell has 4 genes (A/a, F/f, G/g and T/t). Each chromosome has at least one of the genes on it. Represent 2 of the genes as heterozygous, and 2 as homozygous.

3. A cell with 2N = 4 is in late prophase. Its chromosomes each have one gene represented. Choose symbols for the alleles, decide if the cells are heterozygous or homozygous for the gene. Represent the alleles on the chromosomes.

4. A diploid cell 2N = 6 early in the G-2 phase. Represent 3 genes so each chromosome has at least one gene.

5. Devise you own model problem and write it out. Exchange problems with another pair of students. When you have solved the problem, share the results with the group.

Activity 3. Using Models to Review Mitosis

Pairs followed by round robin. Pairs complete the simulation and then a large cell outline should be placed on board. Individual students, in turn, add elements to check the results of their simulation. The Learning exercises in this and the following activity use simulations to provide you with a concrete experience in distributing chromosomes to daughter cells as it would happen in mitosis and meiosis. *You will need scissors for this activity.*

1. Cut out four chromosomes of each size, two with cross-hatched genes and two without, and lay them on a flat surface so that they are easy to handle in the simulations. Place them on the large cell nucleus in the arrangement indicated.

2. Label the genes and alleles so the cell for this simulation is heterozygous for by genes.

3. Find the template at the end of the workshop handout. In the template, the large cell on the left is called the ____________________ ? The two smaller cells on the right are called _________________________ ? Label them. Use them in the following steps.

4. Using the chromosome strips, construct a parent cell on the left side of your template so that 2N = 4 in the state it would appear prior to DNA replication. Make sure it heterozygous for both the genes.

5. Now simulate what happens when DNA replication occurs in the S phase by changing the chromosomes on your model.

6. In the doubled state, each strip of a pair is called a ______________ . Compare the strips you joined together to make doubled chromosomes. Should they be similar or different? ______________ Why? _________________ .

7. In sequence, place the chromosomes in the appropriate position for each stage of mitosis on the large cell outline.

8. Finally distribute the chromosomes from the parent cell into the daughter cells.

9. Compare the two daughter cells you produced. Are their genes similar or different? __________ Explain why? ____ .

10. Each daughter cell has how many chromosomes? ________ Single or double? _________

Activity 4. Meiosis Simulation

Pairs and jigsaw. Each pair does the entire simulation and then share with the whole group in a round robin manner.

1. Where does meiosis occur in males and females?

2. Name the products of meiosis and their functions.

First Meiotic Division (M-1)

3. On your template, reconstruct a diploid parent cell with 2N=4 exactly as you represented it in the mitosis review. Record the results in Fig 10.2.
4. Simulate the first meiotic division (M-1) by distributing the chromosomes from the parent cell into the 2 daughter cells on your template. Draw the results in Figure 10.2.
5. How much DNA does each daughter cell have compared to the parent cell? ________________
6. Are the two daughter cells identical genetically? (Do they have all the same alleles?) Explain. ____
7. Record the genotype for each cell in Fig 10.2.
8. Rebuild the parent cell you started with by replacing the chromosomes on the template outline.
9. The distribution of double chromosomes to daughter cells is random. Can you figure out a new way of distributing the chromosomes so the daughter cells have a different combination of alleles from the ones you drew in Fig 10.2? Do the simulation and record your results in Fig 10.3.
10. An important point to be learned from this last step is that the way chromosomes of one homologous pair are distributed to daughter cells in M-1 does not influence where members of the second pair end up. They assort independently of one another, so different combinations are possible. This is the idea in the **Law of** __________________________.
11. Give titles to Figs 2.2 and 2.3.

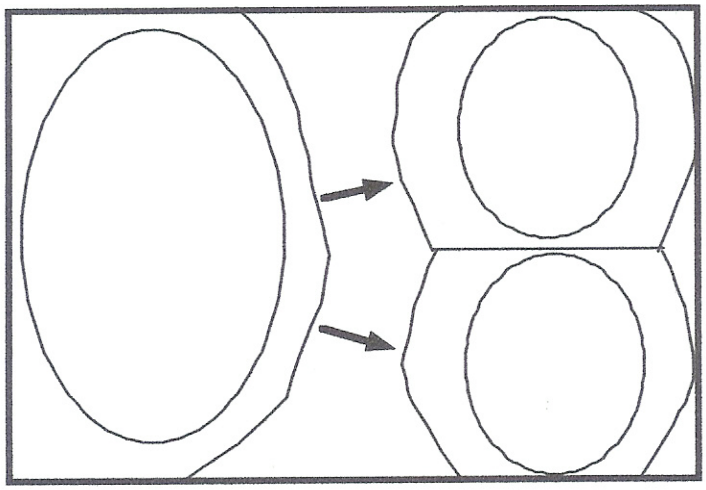


Figure 10.2. Meiosis I : version A

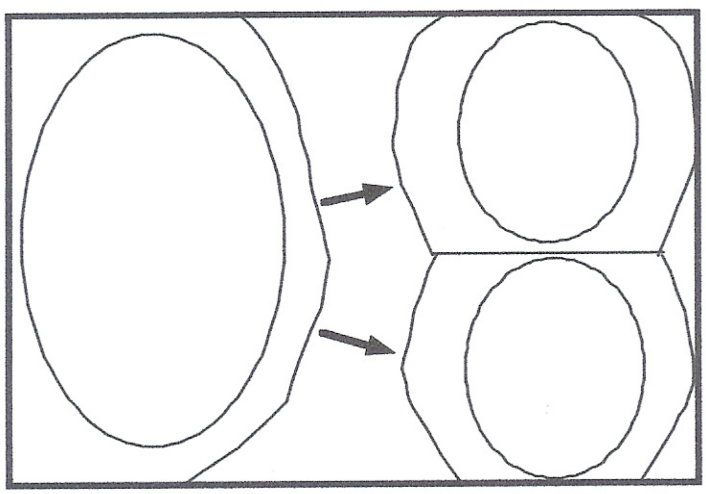


Figure 10.3. Meiosis I: version B

Second Meiotic Division (M-2)

1. Take the chromosomes from the top daughter cell on your template and place them on the parent cell after removing all other chromosomes. This now becomes the parent cell for the second meiotic (M-2) division. Draw it in Fig 10.4.

2. Simulate the M-2 division by moving strips to the daughter cells on the template. Record your results in Fig 10.4.

3. How much DNA does each daughter cell have compared to the parent cell? Compared to the original parent cell in Fig 10.2? ____

4. Are these daughter cells from the second division:

a. genetically identical to one another? Explain.

b. genetically identical to the parent cell? Explain.

5. Give a title to Fig 10.4.

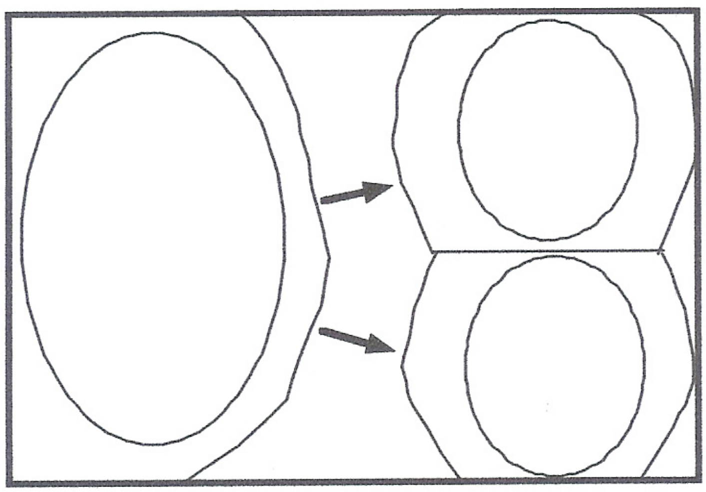


Figure 10.4. Meiosis II

<u>Activity 5. Meiosis Summary and Comparison</u>

1.Complete Table 10.1 to summarize information you have learned doing the simulation.

Table 10.1. Meiosis Summary

Cell's Genetic Makeup	**Parent cell just prior to M-1**	**Daughter cells after M-1**	**Daughter cells after M-2**
No. of chromosomes			
Single or double chromosomes			
Total no. of chromosomes			
No. of homologous pairs of chromosomes			
Haploid or diploid			

2. Multiple matching. Team competition. Divide the workshop into two teams. Each team completes as many of the 12 items in the time permitted and writes answers on a piece of paper that will be submitted to the peer leader. At the end of the competition period, the teams alternate in sharing answers for the questions. Two points are awarded for a correct and complete answer; one or no points if the answer is

incorrect or incomplete. The other team may correct/complete the answer of the first team and try for one point. If the suggested change is wrong, the second team loses a point.

Each of the numbered statements below applies to one or more of the 8 processes (a-h) in the following list. After the statement, give the letter for each process to which the statement applies. Note that some statements may apply to two or more processes. The first item is done as an example.

a) cytokinesis
b) fertilization
c) meiosis - 1
d) meiosis - 2
e) mitosis
f) oogenesis
g) spermatogenesis
h) sperm penetration

1. Synapsis forms tetrads during prophase: *c, f, g.*

2. A second polar body is extruded from the cell.

3. The centromeres break and sister chromatids migrate to opposite poles.

4. One gamete enters the cytoplasm of another, different gamete.

5. The cytoplasm begins to pinch in at the equator of the cell.

6. The daughter cells from the division are about equal in size.

7. A spindle forms.

8. A new diploid cell forms from the union of two haploid cells.

9. The daughter cells have half as much DNA as the parent cell, but carry all the alleles of the parent.

10. The daughter cells are genetically identical to one another but not to the parent cell.

11. The daughter cells are genetically different from one another and from the parent cell.

12. Four gametes are formed from one parent cell by this process.

Activity 6. Applications of Mitosis and Meiosis in Gametogenesis

Round robin done with an overhead transparency or large version of the figures drawn on the board or newsprint tablet. Each student, in turn, will add items to the diagram. Other students may tactfully suggest modifications.

The process you have just learned about is an important part of gametogenesis, or the development of gametes (eggs and sperm). In the testes of breeding males, one version of gametogenesis, called **spermatogenesis**, occurs producing millions of sperm each day in breeding males. Each meiotic sequence (two divisions) produces four tiny cells that will become spermatozoa. In the ovaries of females, meiosis occurs as well, but the timing and details are somewhat different. One important difference is that only one egg (**ovum**) is produced in each meiotic sequence. In this section of the workshop you will apply your knowledge of meiosis to the differing processes of **spermatogenesis** and **oogenesis**.

Spermatogenesis in Males

1. Figure 10.5 provides graphic outlines of cells in the stages of spermatogenesis. The cell at the top is shown in its prophase only. You will be adding the chromosomes to the other cells as directed in the following steps.

2. At the top of Fig. 10.5 is a stem cell located in the testis. Label it. Is it diploid or haploid? (Circle one) .

3. Stem cells periodically undergo <u>mitosis</u> and of the daughter cells, one (**B**) becomes a primary spermatocyte, which will begin meiosis to form sperm, and the other (**C**) is a new stem cell. Add labels in Fig 10.5.

4. Distribute the chromosomes from the original stem cell into daughter cells **B** and **C** in Fig 2.5. Remember this is <u>mitosis</u>.

5. Before the primary spermatocyte can undergo meiotic division, it must go through the normal cell cycle including the S phase in which it replicates its single chromosomes, making them double chromosomes. In the cell outline marked **D** show the chromosomes of the cell after its S phase as it is entering Meiosis 1. Add one gene to each chromosome so that the cell is heterozygous for the two genes.

6. The first meiotic division occurs dividing cell **D** into two daughter cells **e** and **f**, called secondary spermatocytes. Show the chromosomes of these daughter cells with their alleles. Are the daughter cells genetically identical? _____ Haploid or diploid?_________

7. The second meiotic division occurs just as you've learned it, producing a total of four spermatids (**g, g', h, h'**). Show the genetic material and label the arrows. Explain the use of the labels with "primes".
____ .

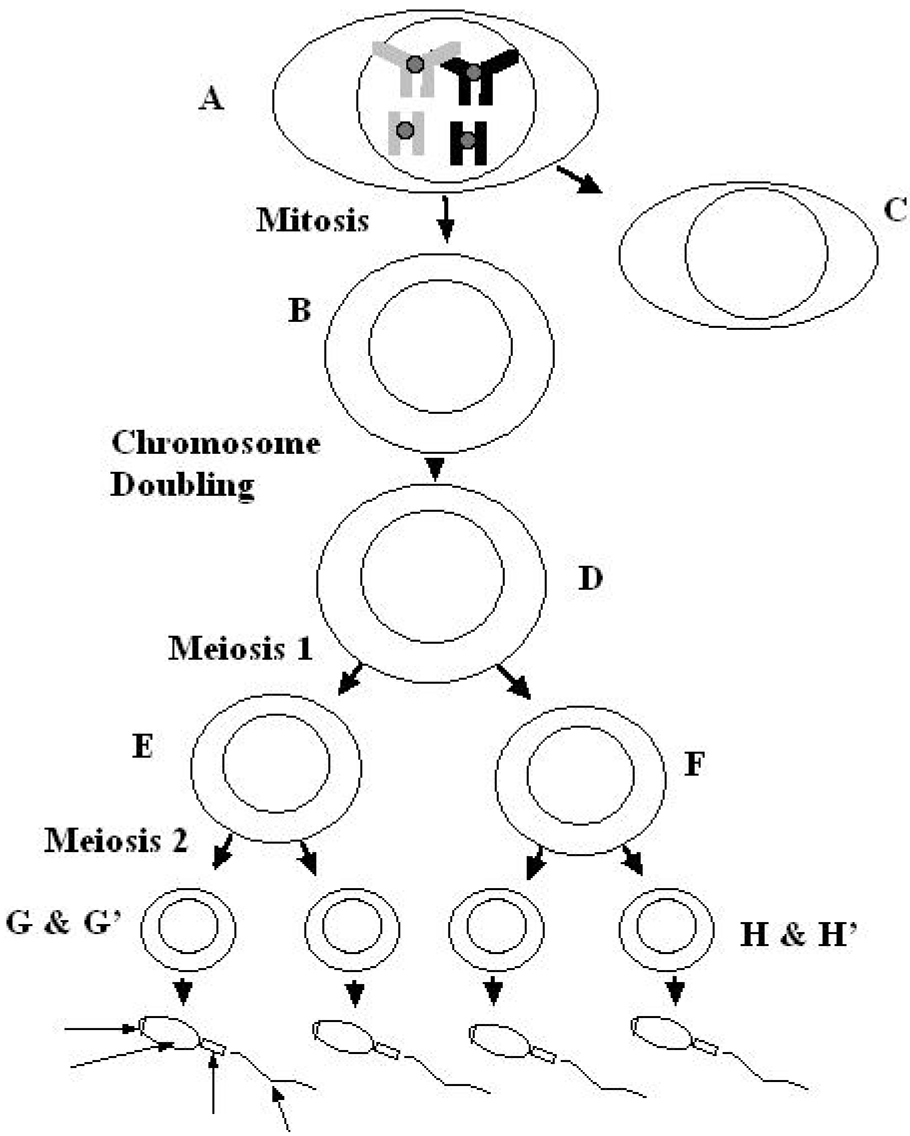


Figure 10.5. ____

8. Before the spermatids can function as gametes, they must undergo some important changes in a process called **differentiation**. The change converts the cells to a new functional form called **spermatozoa**.

9. Find and label the large **head** which contains the genetic material. Near the front of the head is an **acrosome** filled with enzymes to help the sperm chemically cut its way into the egg. Shown to the right of the head is a **midpiece** filled with mitochondria, which produce the energy needed by the sperm as it moves through surrounding fluids toward the egg. Finally the **tail** is the elongated strand which whips rapidly back and forth propelling the sperm. Label the arrows indicating parts of the sperm in Fig 10.5.

10. Label Fig. 10.5. Following spermatogenesis where are the sperm stored and what is the eventual fate of them? ____ .

Oogenesis in Females

1. Figure 10.6 provides graphic outlines of cells in the stages of oogenesis. The cell at the top is shown in its prophase only. You will be adding the chromosomes to the other cells as directed in the following steps.

2. At the top of Fig. 10.6 we show a stem cell dividing by mitosis to produce a primary oocyte (**C)** and another stem cell (**B**). Label them and fill in the genetic material so each chromosome has one gene and the cell is heterozygous for its genes.

3. Prior to meiosis, chromosome doubling occurs during the S phase of the cell cycle. Show the cell at **D** as it would appear in prophase of meiosis 1. Fill in the genetic material for this cell, including all the alleles.

4. Notice that as the first meiotic division is beginning, the nucleus of the cell is near the cell membrane, not in the center of the cell. The division is *unequal* because one cell gets most of the cytoplasm, while the other, called a **polar body**, gets only half of the genetic material. Add the genetic material to the unequal daughter cells of the first division. Label the first polar body. It will eventually degenerate and not participate in reproduction.

5. The remaining cell is a secondary oocyte. Is it haploid or diploid?__________________ This cell awaits the penetration of a sperm to undergo the second division. From Fig 10.6, how would you describe the second division in terms of the resulting daughter cells? __________________ The products are a **second polar body** and **ovum**. Label the cells after the second division and show the genetic material in each.

6. Suggest the reasons for unequal divisions in oogenesis? ________________________

7. Review and compare the production of eggs and sperm, and their final forms. What can these differences tell you about the different functions of the two types of gametes? Each student can add one item for the comparison.

Comparing the structures and functions of sperm and ova.

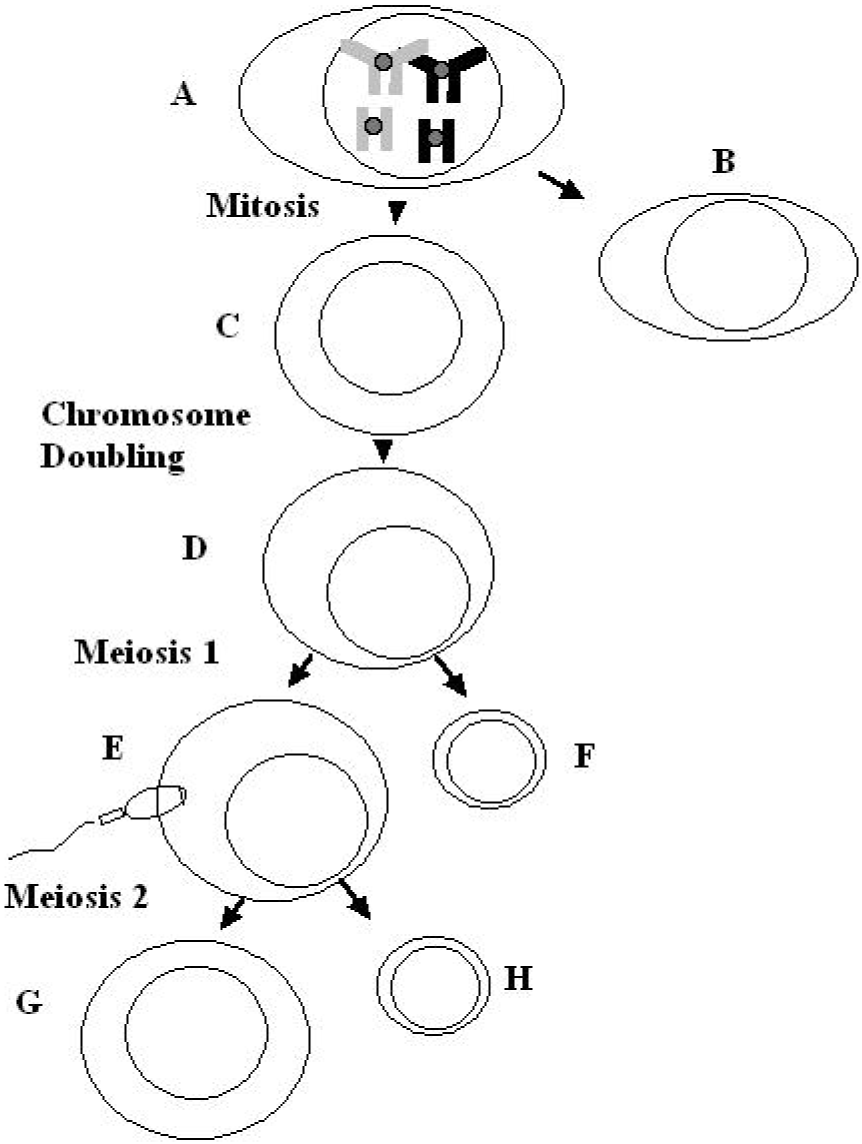


Figure 10.6. ____

Activity 7. Fertilization and Cleavage
Continue the round robin using a diagram or transparency of Fig 10.7.

1. The cell in Figure 10.7 was formed when an egg nucleus and a sperm nucleus came together. Use it to answer the following questions.

2. The specific name for the cell in Fig 10.7 is a ____________ . Is it haploid or diploid?

3. It is formed by an event called ____________________ , when the egg and sperm nuclei unite.

4. For this cell to begin developing into a multi-cellular organism, what process must occur next?____________________________________

5. If the egg carried the dominant allele for the G/g gene, but the recessive allele for the T/t gene, what was the genotype of the sperm? _______________ . Draw the egg and sperm above the cell showing their genetic makeup.

6. Based on chromosomes structure and number only, what period of interphase is the cell in as it is drawn in Fig 10.7? How can you tell?____.

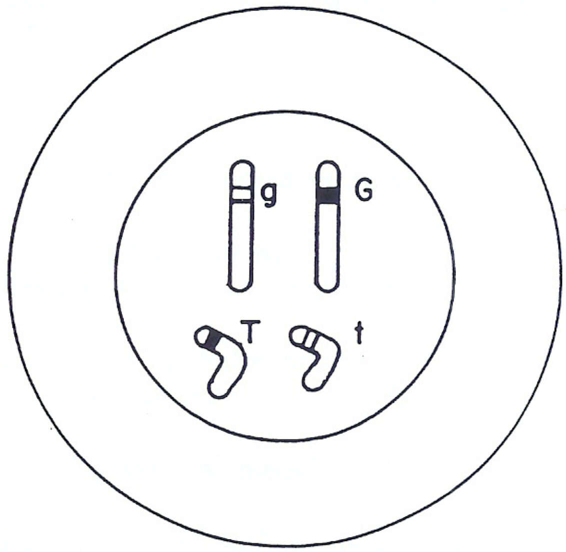


Figure 10.7. Fertilization

7. Shortly after fertilization, the new cell in Figure 10.7 will replicate its chromosomes in preparation for **cleavage**. In cleavage, repeated <u>mitotic</u> divisions transform the zygote into a multicellular ball.

8. Using your template, arrange chromosome models to represent the zygote in Fig. 10.7. Now double those chromosomes in preparation for mitotic cell division. Show the results in a small drawing.

9. Simulate the first cleavage by moving chromosome models to the daughter cells on your template. Add the daughter cells to your drawing from #7. Fill genotypes for all three cells.

10. Are the daughter cells produced in the previous step genetically identical or not? Explain.
____

11. Now label the genes of the zygote in Figure 10.7, showing the genetic makeup after the sperm and egg nuclei combine.

12. Give a title to Fig 10.7.

IV. Post-Workshop Activities: The following exercises are provided for you to complete after the workshop. They allow you to test your own mastery of the material separate from the collaborative work done in the meeting. They afford extra practice with the skills and ways of thinking about the material used in the workshops. We suggest you share the work of the exercises and compare your answers with other students.

Activity 1. Genetics of the Cell

Answer the following questions by referring to Figure 10.8.

1. For the cell in Figure 10.8, 2N = __________ ?

2. How many chromosomes are represented? How many homologous pairs?

3. a. Indicate by number (#) which chromosomes form homologous pairs.

   b. What two types of evidence indicate which chromosomes form pairs?

4. a. How many different **genes** are represented?

   b. How many different **alleles**?

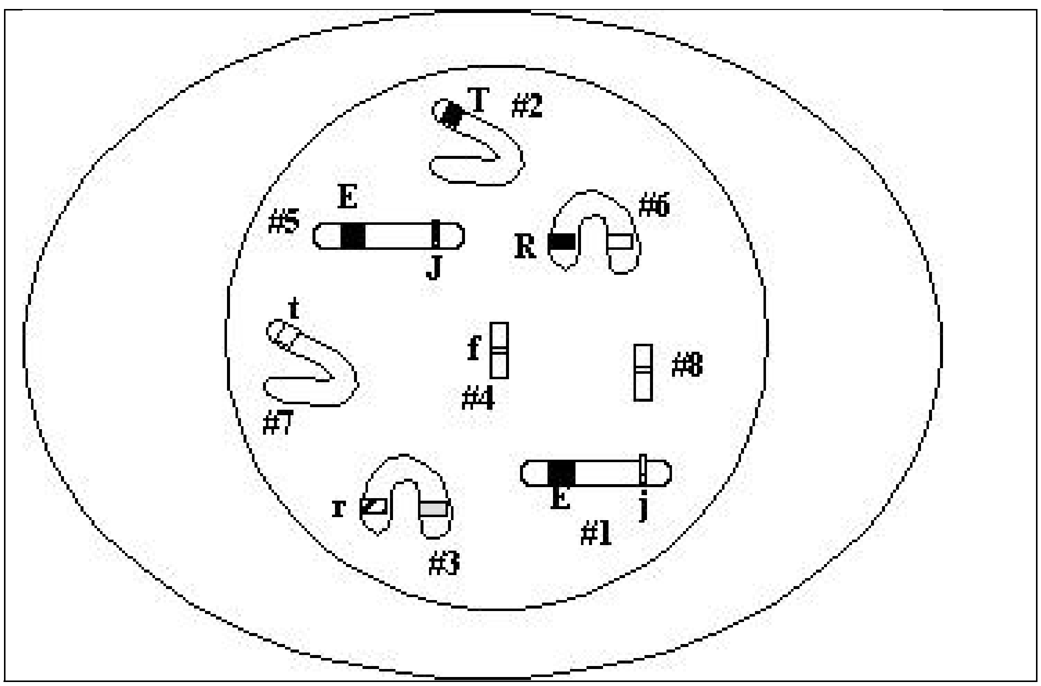


Figure 10.8 ____

5. What genes appear in the homozygous condition? Which in the heterozygous state?

6. a. Which gene has a locus on the same chromosome as the **E/e** gene?

   b. Describe the position of that locus relative to the **E/e** gene.

7. Prepare a title for Fig. 10.8.

8. Write the genotype for the cell in Fig. 10.8. Be sure to follow the rules presented earlier.

9. This cell is part of an organism whose father's sperm carried the following alleles: **EfjTr**. What alleles were carried by its mother's egg?

10. The gene that is shown and not labeled is called the **M/m** gene. Determine one way to label its alleles in Fig 10.8. What are some other possibilities?

11. Draw a cell with 4 chromosomes that has the genotype AABbCc. Use a blackboard or newsprint so the results are visible to all workshop participants.

12. How would you describe the cell in the prior question using the terms homozygous and heterozygous?

Activity 2. Key stages of Meiosis

Identify four stages of meiosis I and II that you think are critical in understanding the process and use your template and chromosome models to simulate them. For each stage you set up, make a simple stick drawing from it showing the chromosomes in the proper configuration. It works best if you put a least one gene on each chromosome and show the cell as heterozygous for the genes. Now add arrows that show what the chromosomes do in completing the key stages or going to the next stage.

1	2	3	4

Activity 3. Scholarly Definitions

Evaluate the definitions in # 1 – 10. Circle any items that are incorrect and change the words to make them correct. Write TRUE if all information is already correct.

1. Polar body: a tiny cell produced by both M-1 and M-2 divisions in spermatogenesis; contains one-half the parent cell's DNA, but little of its cytoplasm; develops further to form a gamete.

2. Cleavage: includes mitosis plus cytokinesis; results in daughter cells which differ genetically; if repeated several times can transform a zygote into a multicellular ball; one of the earliest stages in development of a multicellular organism.

3. Law of Independent Assortment: talks about distribution of alleles in formation of gametes; indicates that alleles on different chromosomes tend to be inherited together as pairs; applies only to genes located on different chromosomes.

4. Diploid: the condition of gametes only; the remainder of our cells are haploid; have two alleles for each gene; twice as many alleles present as compared to the haploid condition.

5. Meiosis-2: produces a polar body in oogenesis; the formation of tetrads occurs in prophase; centromeres break and chromatids migrate in anaphase; daughter cells from the division are genetically identical.

6. Oogenesis: means the origin of an ovum or egg; occurs in the ovaries before ovulation;   occurs through two mitotic divisions; produces one egg for each cell that starts the process.

7. Meiosis-1: occurs in oogenesis but not spermatogenesis; reduces the number of chromosomes to make the daughter cells haploid;   breaks in the centromeres occur at the start of anaphase; produces a polar body in oogenesis.

8. Gametes: eggs and sperm; haploid; produced in ovaries and testes; one is mobile while the other stores food for early development; coming together involves sperm penetration and fertilization.

9. Spermatogenesis: occurs in the epididymis; four sperm are produced for each cell that begins the process; involves two meiotic divisions; two polar bodies are produced; is exactly the same as oogenesis; products of the process are haploid cells.

10. Fertilization: the coming together of two diploid gametes to form a haploid zygote; occurs before sperm penetration; happens in the oviducts of the female; involves the physical union of the genetic material of the gametes.

Activity 4. Mitosis vs. Meiosis

Answer the questions that follow to check your understanding of how mitosis and meiosis compare.

1. Contrast the behavior of chromosomes in the following stages of mitosis and meiosis:

a. prophase M-1 vs. prophase of mitosis

b. anaphase M-1 vs. anaphase of mitosis

c. anaphase M-2 vs. anaphase of mitosis

d. anaphase M-2 vs. anaphase of M-1

2. The daughter cells of the first meiotic division have half as much genetic material as the parent cell. The same is true after a mitotic division. There is a big difference, however. What is it?

3. True or false?: The daughter cells following the first meiotic division are genetically identical (carry the same alleles). Explain your answer.

4. When does the replication of chromosomes occur for meiosis as compared to mitosis?

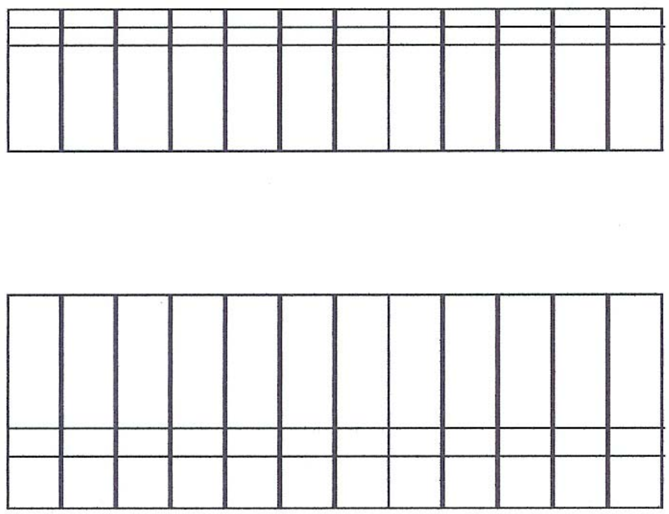
5. What is the number of chromosomes for human cells in each of the following stages? Indicate if they are single or double chromosomes.

a. prophase of mitosis

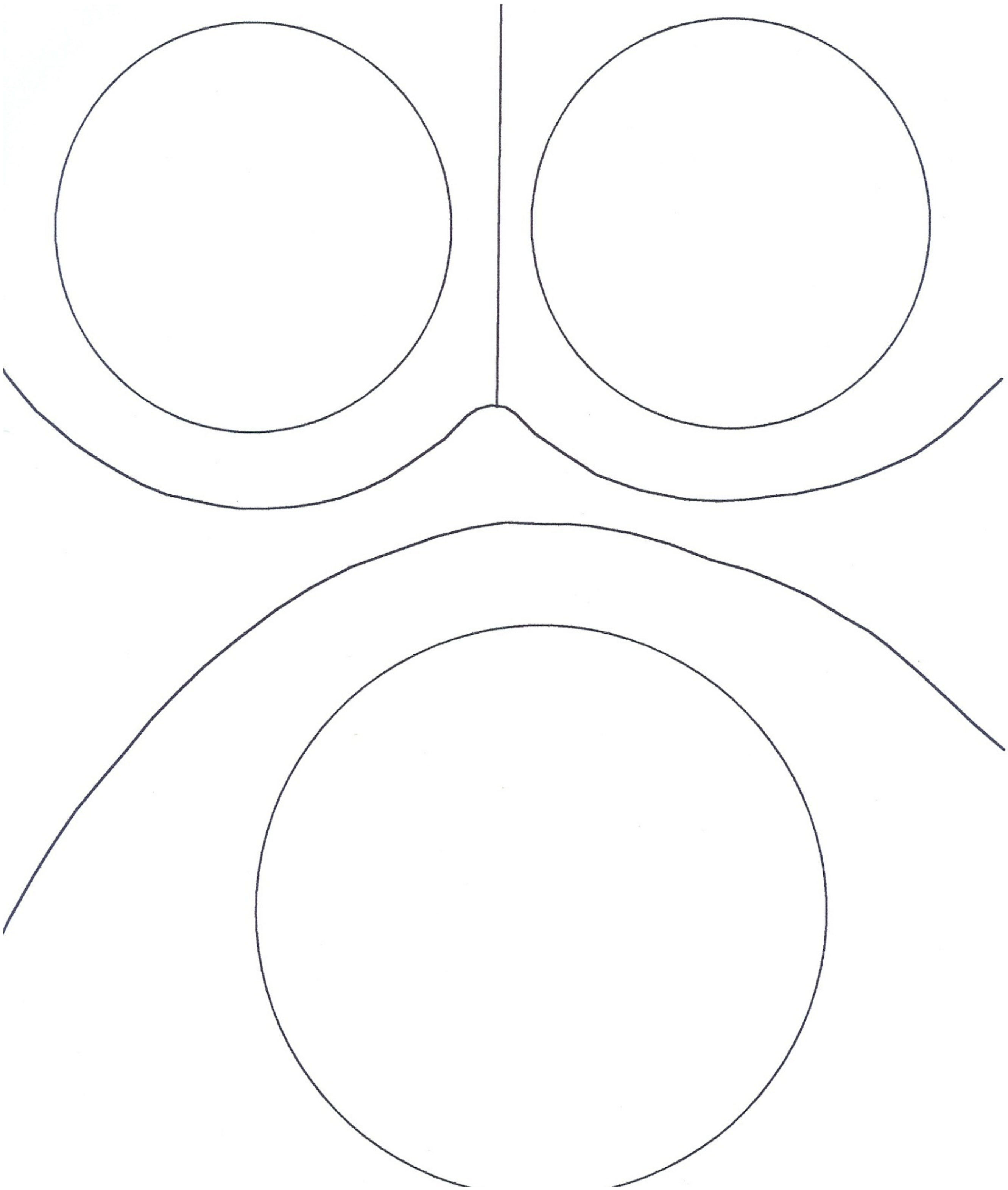
b. telophase of mitosis after cytokinesis

c. telophase of meiosis 1 after cytokinesis

d. telophase of meiosis 2 after cytokinesis



Chromosome Models. Cut out the chromosomes and label as required in each activity.



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