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How-To-Do-It

Hands-on Activities that Relate Mendelian Genetics to Cell Division

Heather R. McKean
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What biology teacher hasn't engaged his or her students in the re-enactment of cell division with chromosomes contructed of materials ranging from pipe cleaners to peanuts? Students diligently work through the phases, putting to memory the sequence of events of each stage. Hopefully, they emerge from the activity with insight into differences and similarities between mitosis and meiosis. However, the greater significance of meiosis as the mechanism underlying Mendel's laws of segregation and independent assortment is rarely taught (Moll & Allen 1987). Teachers may make reference back to meiosis with the discussion of linked genes, but without a review of the process, it is likely to be a faded recollection.

Our objective was to design hands-on activities that would connect Mendelian laws with the physical process of cell division. The "Meiosis/Mitosis Game" concentrates on separation of genetic material during cell division and sexual fusion. This is followed by the "Genetics Game," where Mendelian genetics is tied to the process of meiosis.

Our instruments are inexpensive paper chromosomes that carry commonly taught genes (see Figures 1 to 3) on their surface. Though designed for college biology courses, they have been used without alteration by high school teachers.

Preparing the Chromosomes

Any learning tool that can go home with students stands some chance for out-of-class use and allows for homework. For this reason the chromosomes were made easy to duplicate. Three chromosome types are differentiated in three ways: by a number in the center of the chromosome, by size and by banding pattern. Each plate contains a different set of homologues. Figure 2 has three homologues, so that all three ABO alleles are represented.

Run a set of plates on both blue and pink paper for each student. Cut the chromosomes into rectangles of equal size for ease in storing. Mix the chromosomes before distribution to ensure a variety of genomes among your students. Make one-half of your students homozygous and one-half heterozygous for any given trait to ensure genetic variation in your population. Each student will need a double set of blue and pink homologues for all chromosome types, giving each a total of 12 cards (two identical sets, so that sister chromatids can be formed). Since three homologues are presented in Figure 2, the number duplicated can be reduced by one-third. Students write their names on the back of each chromosome.

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Meiosis-Mitosis Game

The students will use the cards to produce gametes (meiosis) and then combine them with a partner's gamete to simulate sexual fusion. This is followed by the process of mitosis. To avoid any conflict with the association of sexual fusion with human sexual intercourse, we have designed our activities around an imaginary species, "card animal," which has a diploid number of six. The following objectives should be met by the student in this activity:

1. The student will understand these terms: homologous chromosomes, sister chromatids, genome, diploid and haploid.
2. The student will understand how homologous chromosomes segregate and nonhomologous chromosomes assort independently during meiosis.
3. The student will be able to identify differences and similarities between meiosis and mitosis.

Preparation for the Game

This activity will probably take two to three hours. The students divide their packs of 12 cards into two identical sets before starting the game. The result is a blue 1, 2, 3 and pink 1, 2, 3 in each set. They place one set face down and away from them while the other set is laid in front of them. Work through questions 1 through 6 with the students as a group, making sure that everyone understands each step.

Materials Needed (Per Student)

1 duplicated set of chromosomes
6 paper clips
6 pieces of string (each 45 cm long)

Procedure

The students should read along with the teacher.

1. The following game is designed to learn the concepts behind meiosis and mitosis. Try to understand how the process works step by step. Talk

over each step with your partner and ask for help if you do not understand.

2. We will first go through the process called meiosis. Its purpose is to produce four gametes from a single cell. A gamete is a cell that contains half the genetic material of the parent cell. In humans, they are called sperm and eggs. Once the gametes are produced, join one of your gametes with one of your lab partner's gametes to form a zygote, a fertilized egg. This process is called sexual fusion. The zygote will then go through the process of mitosis in order to grow into a multicelled organism.

3. In this card game, each student will be a member of an imaginary species called "card animal." The diploid number of chromosomes in this animal is six. Each card represents one chromosome. Chromosomes are packets that contain DNA.

4. Card animals, like humans, form from the fusion of gametes from their parents, receiving equal amounts of genetic material from each. The genetic material contributed by each parent is called a genome. In the game, any combination of chromosomes 1, 2, 3, regardless of color, constitutes a genome. At the start of the game the pink cards represent the genome given by your mother and the blue, the genome from your father. Each genome contains three cards and represents the haploid number. Any two cards that are of the same kind but are from different parents are said to be homologous chromosomes, for example, a blue 1 and a pink 1.

5. Before a cell can divide, the chromosomes must duplicate so that each daughter cell receives a copy of each chromosome. Each replicate is called a sister chromatid and is identical to the other.

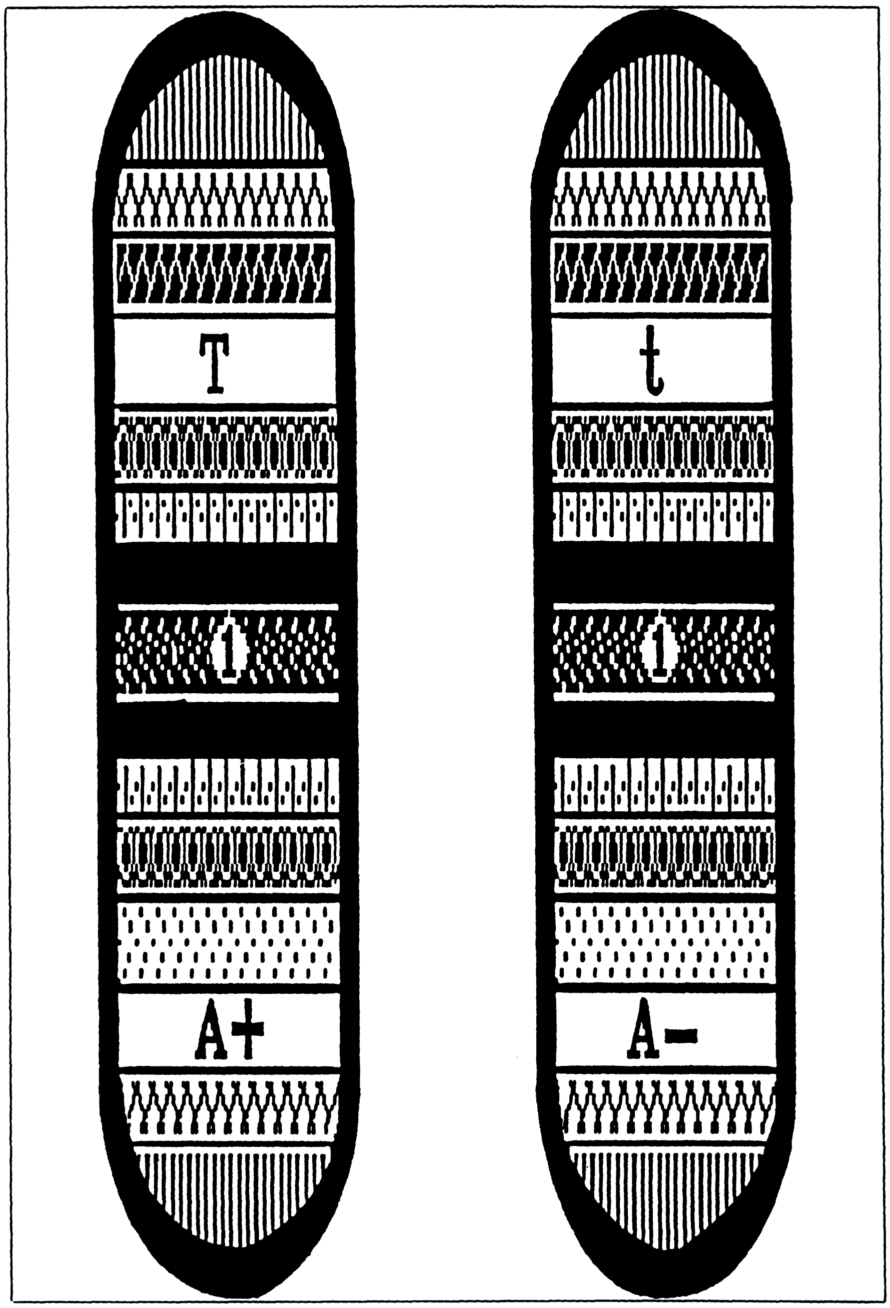

Figure 1. A pair of homologous chromosomes carrying the genes for tongue rolling (T = dominant tongue-rolling gene; t = recessive non-tongue-rolling gene) and for albinism (A− = dominant normal gene and A+ = recessive gene for albinism).

Meiosis

Step 1. Be sure your cards have been divided into two identical sets. One set should be face down and the other set should be spread out in front of you. Pretend these are the chromosomes of one of your cells which will give rise to gametes.

1. What is the diploid number of this cell? ______
2. How many chromosomes came from your mother? ______
3. How many chromosomes came from your father? ______
4. How many homologous pairs are in your cell? ______ Identify a single pair of homologues by writing the color and number of each chromosome in the blank. Example of homologous pair:
____
5. How many genomes are in your cell? ______ Identify a single genome by writing the color and number of each of its chromosomes in the blank. Example of a genome:
____

DNA Synthesis

Step 2: To simulate DNA replication, lay your second set of cards on top of the first set, matching cards that are identical. Clip the two cards (sister chromatids) together with a paper clip since they are physically attached until meiosis II.

6. Identify a single pair of sister chromatids by writing the color and number of each chromatid in the blank.

____

7. How many genomes are present in the cell now? ______

Meiosis I

Step 3. Line up homologous chromosomes on opposite sides of an imaginary line that begins in front of you and goes directly away from you. This is the equatorial plate. Lay a piece of string along the equatorial plate.

Step 4. Pull each member of a homologous pair in opposite directions away from the equatorial plate. (Do not separate sister chromatids which are joined by a paper clip.) Simulate the division into two cells by laying a second piece of string beside the first.

8. Identify the composition of the two daughter cells formed by writing the color and number of their chromosomes in the following blanks. For example: blue 1, pink 2, blue 3; pink 1, blue 2, pink 3

______________________________ , ______________________________

9. List the other three possible combinations below.

______________________________ , ______________________________

______________________________ , ______________________________

______________________________ , ______________________________

10. Can the two cells formed from meiosis I ever be identical? ______

11. How many homologous pairs are in each cell? ______

12. How many genomes are in each cell? ______

Meiosis II

Step 5: Lay down another piece of string representing the equatorial plate for each newly formed cell. Place the sister chromatids on opposite sides of it.

Step 6: Pull sister chromatids apart at the centromere (paper clip) and move them to opposite poles.

Step 7: Lay down a second piece of string between the two resulting cells.

13. How many gametes have you formed from meiosis? ______

14. How many homologous pairs are in each cell? ______

15. How many genomes are in each cell? ______

16. Where in the human female does this process take place? ______

17. Where in the human male does this process take place? ______

Sexual Fusion

Step 8: Choose a single gamete to combine with the gamete from your partner. You have now formed a zygote.

18. How many chromosomes are in your offspring? ______

19. How many genomes are in the cell? ______

20. How many homologous pairs are in the cell? ______

Mitosis

DNA Synthesis

Step 9: In order for this zygote to grow from a single cell to an adult, it must replicate by mitosis. Supplement your zygote with cards from your discarded gametes in order to form sister chromatids. (Remember that sister chromatids must be identical replicates.) Work with your partner through this step.

Cell Division

Step 10: Line up sister chromatids on the equatorial plate indicated by a single piece of string. In mitosis, homologous chromosomes do not line up! Separate sister chromatids by pulling them apart at their centromeres (paper clips) and move them to opposite poles. Form two cells by laying a second piece of string along the equatorial plate.

21. Are the two cells identical or different? ______
22. How many genomes are in each cell? ______
23. How many homologous pairs are in each cell? ______
24. Where in the human body does this process occur? ______

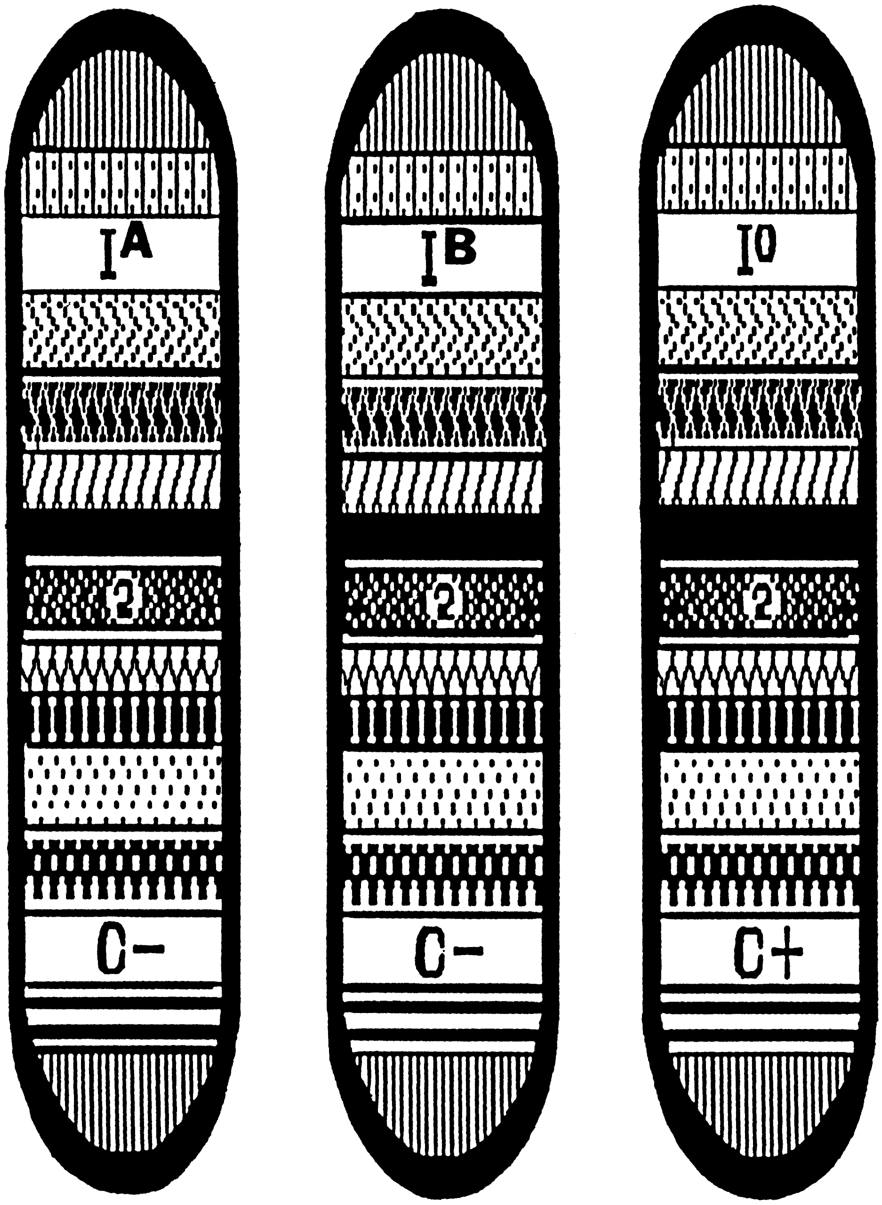

Figure 2. A triplet of homologous chromosomes carrying the genes for the ABO blood group (I^A = co-dominant A gene, I^B = co-dominant B gene and I^0 = recessive gene) and hair texture (C+ = curly hair gene and C− = straight hair gene).

Comparing Meiosis to Mitosis

Write A for meiosis, B for mitosis, C for both.

25. Which process has two cell divisions? ______
26. In which process do homologous chromosomes divide? ______
27. In which process do sister chromatids divide? ______
28. Which process produces four daughter cells? ______
29. Which process produces identical daughter cells? ______

Answers to Meiosis/Mitosis Game

(1) 6; (2) 3; (3) 3; (4) 3, Ex. blue 1 and pink 1; (5) 2, Ex. blue 1, blue 2, blue 3; (6) Ex. blue 1, blue 1; (7) 4; (8) blue 1, blue 2, blue 3; pink 1, pink 2, pink 3; (9A) blue 1, blue 2, pink 3; pink 1, pink 2, blue 3; (9B) blue 1, pink 2, pink 3; pink 1, blue 2, blue 3; (9C) blue 1, pink 2, blue 3; pink 1, blue 2, pink 3; (10) no; (11) 0 (homologous pairs split up in meiosis I); (12) 2; (13) 4; (14) 0; (15) 1; (16) ovaries; (17) testes; (18) 6; (19) 2; (20) 3; (21) identical; (22) 2; (23) 3; (24) everywhere but the sex cells; (25) A; (26) A; (27) C; (28) A; (29) B.

Genetics Activity

The following activity is designed to take place sequentially, but not immediately, to the meiosis/mitosis game. It is presumed that Mendelian genetics has been presented in traditional ways. Specifically, the student should understand dominance/recessiveness, codominance and incomplete dominance. The activity meets the following objectives:

1. The student will review meiosis and understand how it dictates the laws of segregation and independent assortment.
2. The student will understand the terms homozygous, heterozygous and alleles.
3. The student will understand how crossover separates linked genes.

Preparation for the Game

This activity may take two to three hours depending on the preparation and level of the class. The students should work in pairs. They will use the same set of cards and will need a copy of the meiosis game, since a review of that process will be made.

Materials Needed (Per Student)

1 duplicated set of chromosomes
6 paper clips
6 pieces of string (each 45 cm long)
scissors
tape

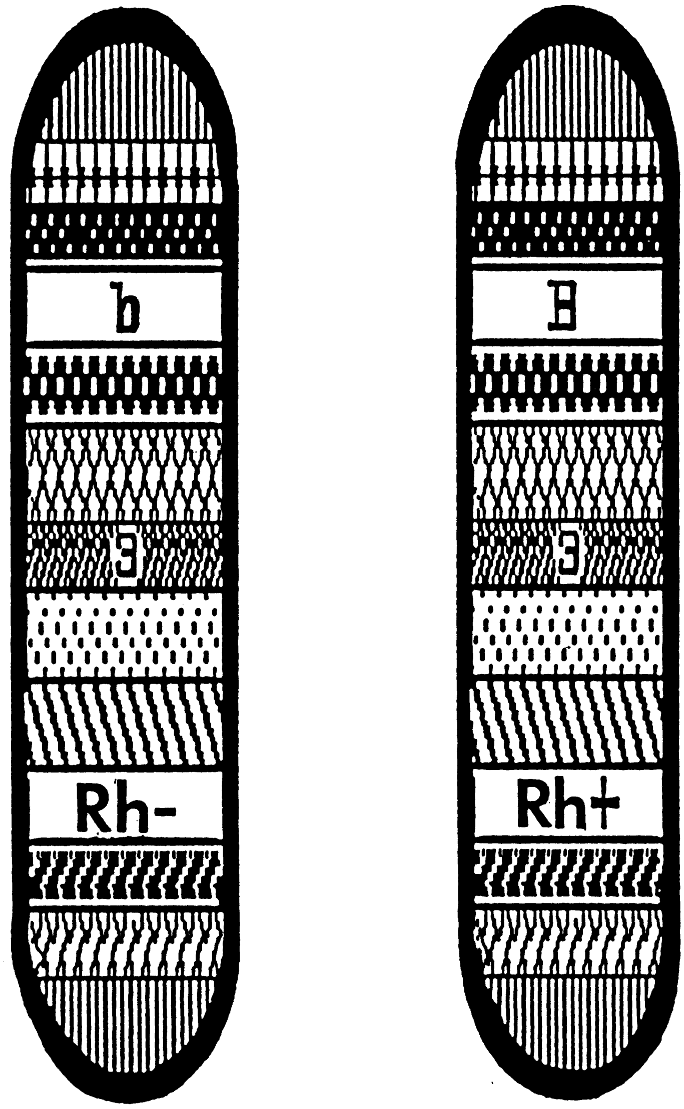

Figure 3. A pair of homologous chromosomes carrying the genes for eye color (B = brown gene and b = blue gene) and Rh blood type (Rh+ = Rh antigen gene and Rh− = Rh non-antigen gene).

Genetics Game

We will now use the card animal chromosomes to look at gene relationships and to show how meiosis increases variability. Diploid organisms have two genes for each physical trait, such as eye color or blood type. The genes are represented by symbols and are referred to as the genotype of the organism. The physical trait that is observed is called the phenotype.

Different forms of a gene that code for the phenotype are called alleles. For example, a person may have an allele for the production of brown pigment of the eye, as well as an allele for the production of blue pigment of the eye. In the case where the two different alleles make up the genotype, for example one blue allele and one brown allele, the individual is said to be heterozygous for that trait. If an individual has two alleles of the same type, for example two alleles for brown eyes, then it is called homozygous.

Gregor Mendel, the founder of modern genetics, discovered that alleles separate during meiosis and end up in different gametes. We now call this the law of segregation. This means that a heterozygous person for eye color can pass either the blue or the brown gene into a gamete but not both. His work also led to what is known as the law of independent assortment which predicts that different genes found on nonhomologous chromosomes will separate independently of each other during meiosis. Keep these two laws in mind throughout this activity.

Step 1: Divide your pack into two piles as you did in the meiosis game with a blue 1, 2, 3 and a pink 1, 2, 3 in each pile. Put one pile aside and concentrate on the remaining six cards.

Step 2: Each of the symbols on your chromosomes represents a gene. Alleles have similar symbols. Match up your six chromosomes into homologous pairs. For each of the following six traits, give your genotype and phenotype. Gene action is indicated in parentheses after each gene. Identify examples of dominance (dom.)/recessiveness (rec.), codominance (codom.) and incomplete dominance (incom.).

	My genotype	My phenotype
ABO blood group		
1. I = A antigen (codom.) I = B antigen (codom.) I = O nonantigen (rec.)	______ , ______ ;	____________
Albinism		
2. A− = normal gene (dom.) A+ = albino gene (rec.)	______ , ______ ;	____________
Eye color		
3. B = brown gene (dom.) b = blue gene (rec.)	______ , ______ ;	____________
Hair texture		
4. C+ = curly gene (incom.) C− = straight gene (incom.)	______ , ______ ;	____________
Rh blood type		
5. Rh+ = Rh+ antigen (dom.) Rh− = Rh− nonantigen (rec.)	______ , ______ ;	____________
Tongue rolling		
6. T = tongue-roller (dom.) t = non−tongue-roller (rec.)	______ , ______ ;	____________

7. For what traits are you homozygous? Circle your answer(s).

ABO blood group	Albinism	Eye color
Hair texture	Rh blood type	Tongue rolling

8. For what traits are you heterozygous? Circle your answer(s).

ABO blood group	Albinism	Eye color
Hair texture	Rh blood type	Tongue rolling

9. Identify pairs of linked genes, that is genes that are found on the same chromosome.

________ + ________ ;	________ + ________ ;	________ + ________
Chromosome 1	Chromosome 2	Chromosome 3

Step 3: Begin the process of meiosis with your cards using the directions in the Meiosis/Mitosis Game. Stop after lining up homologues on the equatorial plate. To simulate the process of crossover, which will have already occurred by this time in cell division, cut one of the sister chromatids at a site between its two genes. Make a second cut at the same site on one of the sister chromatids of the homologous chromosome. Reconstruct the chromatids by taping a pink arm to a blue arm and vice versa. Make sure each chromatid has two different kinds of genes. Repeat the process for the other homologous pairs. Continue meiosis until four gametes have formed.

10. Identify the resulting four gametes by writing their gene make-up in the blanks.

____________________ ____________________

____________________ ____________________

11. How many genes for a single trait are found in each gamete? ______

12. Give an example of Mendel's law of segregation using the traits in the game.

13. Give an example of Mendel's law of independent assortment using the traits in the game.

14. Do either of Mendel's laws apply to the process of mitosis? Explain your answer.

15. What mechanism separates linked genes during meiosis? ____________

16. Would any of the gametes have been the same if this mechanism were not at work? ______

17. What advantage does this mechanism give to sexually reproducing organisms? ____________

Step 4: Combine one of your gametes with a partner.

18. Identify the genotype and phenotype for each of the six traits of your offspring.

Trait	Genotype	Phenotype
ABO blood group	______ , ______ ;	____________
Albinism	______ , ______ ;	____________
Eye color	______ , ______ ;	____________
Hair texture	______ , ______ ;	____________
Rh blood type	______ , ______ ;	____________
Tongue rolling	______ , ______ ;	____________

19. If mitosis was the only mode of reproduction for an organism, would the genotype of the offspring be the same as the parent? ______