



MATERIALS AND RESOURCES

EACH GROUP

noodle chromosomes

TEACHER

index card, 3 in. × 5 in.

marker, Sharpie®

1 roll tape, masking

1 box toothpicks

Velcro® (hook and loop)

1 roll yarn

The Amazing Sperm Race

Modeling Meiosis and Determining Zygote Characteristics

ABOUT THIS LESSON

This activity involves an inexpensive, hands-on, and exciting way for students to experience how homologous chromosomes undergo meiosis to produce gametes. This activity culminates in a “race” to determine a zygote’s genotypic and phenotypic characteristics. This is an essential lesson because it provides a deep, rich context for past heredity content in the middle grades and sets the foundation for all future learning in genetics.

OBJECTIVES

Students will:

- Simulate the process of meiosis using pool noodle chromosomes
- Determine the phenotype and genotype of a zygote
- Compare and contrast mitosis and meiosis
- Articulate the steps of Meiosis I and II
- Analyze the impact that meiosis has on genetic variability in a population

LEVEL

Biology

COMMON CORE STATE STANDARDS**(LITERACY) RST.9-10.1**

Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

(LITERACY) RST.9-10.2

Determine the central ideas or conclusions of a text; trace the text’s explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

(LITERACY) RST.9-10.3

Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

(LITERACY) RST.9-10.4

Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9–10 texts and topics.

(LITERACY) RST.9-10.5

Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).

(LITERACY) RST.9-10.8

Assess the extent to which the reasoning and evidence in a text support the author’s claim or a recommendation for solving a scientific or technical problem.

NEXT GENERATION SCIENCE STANDARDS

DEVELOPING AND USING MODELS



PATTERNS



SYSTEMS AND SYSTEM MODELS



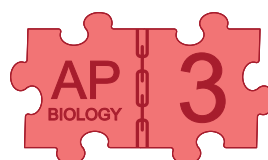
STRUCTURE AND FUNCTION



LS1: STRUCTURES AND PROCESSES



LS3: HEREDITY

CONNECTIONS TO AP*

- A.2** In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization.
- C.2** Biological systems have multiple processes that increase genetic variation.

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ASSESSMENTS

The following types of formative assessments are embedded in this lesson:

- Assessment of prior knowledge
- Class discussion after Meiosis I
- Class discussion after Meiosis II
- Assessment of the understanding of phases

The following additional assessments are located on our website:

- Lesson Quiz: The Amazing Sperm Race
- 2009 Biology Posttest, Free Response Question 1

REFERENCES

Barnhart, Kelsi, and Farrar, Jennifer (2011). “Chromonoodles: Jump Into the Gene Pool.” *The Science Teacher*. 78 (5): 34–39.

Locke, J., and McDemid, H. (2005). “Using pool noodles to teach mitosis and meiosis.” *Genetics* 170 (1): 5–6.

ACKNOWLEDGEMENTS

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TEACHING SUGGESTIONS

This activity is meant to be an introduction and facilitation of learning for the concepts of meiosis and the results of fertilization (genotype and phenotype). It can be completed in one 90-minute class period or split into two days if your class periods are shorter. If you do split it into two days, perform Part I and Part II on the first day and Part III on the second day.

Pool noodles can be found at local discount stores or pool supply stores. Because they are seasonal items, it is advisable to buy them during the summer season as they may not be available in your local stores during other times of the year. (Pool noodles can be bought year-round online, although slightly more expensive.) You will need to purchase 28 pool noodles (each cut in half to make 56 pieces) for this activity.

Alternatives to pool noodles include meter sticks that have been spray-painted, gray pipe insulation (found at the hardware store), wrapping paper cardboard tubes, paper towel tubes, and so on. The main point to remember is that you need something that is brightly colored, straight (stick like), and has a top portion that can be removed and exchanged during crossing-over.

This activity is designed for groups of four but can be modified to accommodate any class size. Extra students could possibly be used for:

- Reading the procedure to the class or group
- Acting as microtubules (using rope or string)
- Assisting the instructor to help groups choose cards (EGG, SECONDARY OOCYTE, and POLAR BODY) during Part II
- Keeping track of all the genotypes and phenotypes on the board after each trial

You are not limited to these suggestions but can modify and adjust according to your unique classroom. However, make sure that you rotate students with every single trial so that every student gets practice walking through the steps and gets to participate in the “race.”

Also included is an article on parthenogenesis (females reproducing without sperm) with higher-level questions that provide students an opportunity to not only apply what they have learned to a real-world context but, more importantly, allow them to predict future implications of this process on shark populations in the wild.

TEACHING SUGGESTIONS (CONTINUED)

PREPARATION OF MATERIALS

1. Cut the typical 4-ft pool noodle in half to make two “sister chromatids.” On each chromatid, make another cut approximately one third from the top. This small section will be exchanged through crossing-over during Prophase I.
Prior to crossing over, the cut sections of the chromatid can be held together by inserting two or three toothpicks around the hollow center of the bottom sections of each noodle. To make sure the toothpicks stay in the bottom portion, dip each toothpick into some glue prior to sticking it into the noodle.
2. The two sister chromatids can be temporarily connected by placing a small piece of hook and loop near the center of each chromatid, which will represent the centromere.
3. Use electrical tape or duct tape to create identical banding patterns on each sister chromatid pair. Brighter colors will produce better results. Use a permanent marker to write the allele type (H, h, A, a, X, Y) on the tape bands to indicate which allele of the gene it represents.

Listed here are the types and quantities of chromatids you will need:

- 14 noodles – H on the top, A on the bottom
- 14 noodles – h on the top, a on the bottom
- 14 noodles – X on the bottom
- 14 noodles – Y on the bottom

For Part II, use a marker to change the Y chromosomes into X chromosomes. This will allow you to start with an XX allele without purchasing more noodles. For Part III, you can mark out X and rewrite Y.

Alternatively, you might wish to purchase enough noodles to make seven more chromatids and label them with an X on the bottom specifically for use in Part I. If you choose this route, you may want to cut the Y chromosomes in half so that they are significantly smaller than the X chromosomes, as this is a more accurate representation of how the two sex chromosomes compare to each other.

4. Use the index cards to prepare labels for each group with the terms EGG, SECONDARY OOCYTE, and POLAR BODY. These labels will be used in both Part II and Part III.
5. Pick a location for the activity that provides a tremendous amount of room. This could be a field outside the school, gymnasium, lunchroom, or other similar area.
6. Set up seven circles (“cells”) using the spermatogenesis pattern in Figure 2 (i.e., start with one cell, which leads to two cells, which each lead to two more cells—for a total of four cells). You can use yarn, string, or even spray paint (if outside) to make your cells. Make the cells large enough to accommodate four students with noodles comfortably.
7. On the day of the activity, either randomly assign chromosomes or have the students select their own.

TEACHING SUGGESTIONS (CONTINUED)

SUGGESTED TEACHING PROCEDURE

Give the background information to students the day before the activity so they may read through it prior to coming to lab.

DAY 1: SPERMATOGENESIS AND OOGENESIS

- Hand every student a pair of chromatids and a copy of the activity. Review concepts from mitosis with your students that they should already have mastered. You can ask:
 - Show me a chromosome before the S-phase of the cell cycle.
 - Show me a chromosome after the S-phase of the cell cycle.
 - Show me a chromatid.
 - Show me a centromere.
 - Stand by another student that has the chromosome that is homologous to yours.
 - Point to a gene on your chromosome.
- Discuss with students the differences between *sexual* and *asexual* reproduction, and how sexual reproduction is more evolutionarily favorable.
- Discuss the *human reproductive cycle* with students. This can either be done in the classroom using a displayed slide of the cycle or, if you are outside the classroom, use a poster with the cycle drawn and labeled on it to review with the class.
Make sure that you point out how the diploid number is conserved due to meiosis, producing haploid gametes (23 chromosomes each) joining together in fertilization to produce a zygote that is diploid (46 chromosomes).
- Briefly describe the difference between *dominant* alleles and *recessive* alleles.
- Discuss the three traits to be studied in this activity: Huntington's disease, achondroplasia, and gender.
 - Huntington's disease* – a neurological disorder (affecting the brain) that causes neurons (nerve cells) to die off in certain parts of the brain.
 - Achondroplasia* – the most common form of dwarfism. You might explain that this is the disorder affecting the stars of the show, "Little People, Big World."
 - Gender* – male or female.
- Using the prepared chromatids, explain the concepts of genotype and phenotype.
 - Genotype* – genetic makeup, or what combination of dominant and recessive alleles are received from the gametes.
 - Phenotype* – describes the traits themselves, such as whether the zygote has Huntington's disease, achondroplasia, or is male or female
- Display Table 2 as a chart and discuss it with your students.
- Walk students through the steps of spermatogenesis (Step 1 through Step 23 of the Procedure). This attention is important so that the students go through steps correctly the first time. If you let them proceed on their own and they practice the steps of meiosis incorrectly, there is an increased chance of incorrect recall during future learning, such as genetics.
Clear any misconceptions and answer all questions throughout the process. It is also important that you let the activity be the learning process instead of explaining each step with a picture beforehand.

TEACHING SUGGESTIONS (CONTINUED)

9. After Meiosis I and Meiosis II, lead students in a discussion of the questions posed by Step 11, Step 22, and Step 23.
 - a. (Step 11) Discuss with your non-homologous partner about how the genetic makeup of the new cell you are in differs from the original cell.
 - i. Is the cell you are in diploid or haploid?
 - ii. Was the original mother cell diploid or haploid?
 - iii. Are the chromosomes you are holding still replicated chromosomes (two sister chromatids connected by a centromere) or single chromosomes?
 - b. (Step 22) Discuss with your non-homologous partner how the genetic makeup of your current cell differs from the previous cell.
 - i. Is the cell you are in diploid or haploid?
 - ii. Was the previous cell diploid or haploid?
 - iii. Are the chromosomes you are holding still replicated chromosomes or single chromosomes?
 - c. (Step 23) Discuss with your non-homologous partner about how the genetic makeup of the spermatid cell, the cell that you are in, differs from the genetic makeup of the secondary spermatocyte, the cell that you were in after Meiosis I.
 - i. Is the cell you are in diploid or haploid?
 - ii. Was the cell you just came from diploid or haploid?
10. After the process of spermatogenesis is completed once through with your help, let the students practice a few more times step by step until they feel comfortable with the process. It is important that they master these steps before going on to oogenesis.
11. Walk the students through the process of oogenesis step by step the first time, and then allow them to practice as they did in Part I. You will need your EGG, SECONDARY OOCYTE, and POLAR BODY cards for Part II. Make sure that you emphasize that in humans; a sperm will enter the secondary oocyte triggering the completion of Meiosis II (Step 12 through Step 21). The nuclei will not actually fuse until Meiosis II is over, at which time it is a diploid zygote. This fusion is simulated in Part III of this activity.
12. After Part I and Part II are complete, formatively assess your students' knowledge of specific phases by calling on specific groups and have them act out those phases, such as:
 - Show me Prophase I.
 - Show me Metaphase II.
 - Show me the results of Meiosis I.
 - Show me the results of Oogenesis.
 - Show me the results of Spermatogenesis.
13. Finish Day 1 with a class discussion of the differences between *mitosis* and *meiosis*. You might even have students walk through the phases of mitosis.

TEACHING SUGGESTIONS (CONTINUED)

DAY 2: FERTILIZATION FRENZY

1. Start the day with a quick review of *spermatogenesis* and *oogenesis*. Have all groups run through both processes before they are allowed to proceed.
2. Discuss with students that fertilization is the fusion of a sperm's chromosomes (haploid) with the egg's chromosomes (haploid) to make a diploid zygote.
3. Review with students the concepts of *genotype* and *phenotype*.
4. Review the procedure with students. Let them know that typically it is not the first sperm that reaches the egg but the first sperm to get inside the egg that fertilizes it. Monitor and adjust the “race” part to accommodate for the learners in each individual class period.

For instance, to allow for a more controlled environment (one in which the students are not running over each other and the egg), you can give the sperm a quick question that they must answer once they get to the egg, to determine who gets to fertilize the egg. For example: The first to correctly name the genotype and phenotype of the zygote if they were to fertilize the egg gets to be the “winning sperm.”

5. Repeat the “race” as many times as you can. There are eight trials listed in Table 3; however, you may choose to complete more or fewer depending on time.
6. Finish the activity by having students complete the Conclusion Questions. 🌟

ANSWER KEY

DATA AND OBSERVATIONS

Table 3. Fertilization Frenzy Data							
Trial	Cell Type (Sperm, Egg, or Polar Body)	Genotypes			Zygote		
		Yours	Parents	Egg	“Winning” Sperm	Genotype	Phenotype
1	Sperm	HaX	HhAaXX HhAaXY	HAX	hAY	HhAAXY	Male with both Huntington's and achondroplasia
2	Sperm	HAY	HhAaXX HhAaXY	haX	HaX	HhaaXX	Female with Huntington's but is of normal height
3	Egg	haX	HhAaXX HhAaXY	haX	haX	hhaaXX	Female that does not have Huntington's and is of normal height
4	Sperm	HAX	HhAaXX HhAaXY	HAX	haY	HhAaXY	Male with both Huntington's and achondroplasia
5	Sperm	hAY	HhAaXX HhAaXY	HAX	HAX	HHAAXX	Female with both Huntington's and achondroplasia
6	Sperm	haY	HhAaXX HhAaXY	haX	haY	hhaaXY	Male that does not have Huntington's and is of normal height
7	Sperm	hAX	HhAaXX HhAaXY	haX	HaY	HhaaXY	Male with Huntington's but is of normal height
8	Sperm	HaY	HhAaXX HhAaXY	haX	HaX	HhaaXX	Female with Huntington's but is or normal height

ANSWER KEY (CONTINUED)**CONCLUSION QUESTIONS**

1. Answers may vary.

Mitosis	Meiosis
One nuclear division	Two nuclear divisions
Produces daughter cells with the same amount of chromosomes as the mother cell	Produces daughter cells that have half the chromosomes as the mother cell
Produces two daughter cells	Produces four daughter cells
No crossing-over occurs between homologous chromosomes.	Crossing-over occurs between homologous chromosomes.
Chromosomes line up single file during Metaphase.	Homologous chromosomes line up on top of each other during Metaphase I and single file during Metaphase II.

2. An adult male undergoes spermatogenesis to make haploid sperm. An adult female undergoes oogenesis to make a haploid egg. They combine during a process called fertilization to produce a diploid zygote. The zygote undergoes mitosis (growth) to produce the adult male or female.

3. Answers may vary.

- Meiosis involves the separation of the homologous chromosomes and Meiosis II involves the separation of the sister chromatids.
- In Meiosis I the homologous chromosomes line up on top of each other during (Metaphase I), and during Meiosis II they line up single file (Metaphase II).
- Meiosis I involves crossing over, and Meiosis II does not.

4. A zygote's phenotype describes the traits themselves, such as whether the zygote has Huntington's disease or not, and the genotype is its genetic makeup (combination of dominant and recessive alleles (HH, Hh, or hh)).

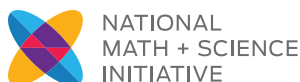
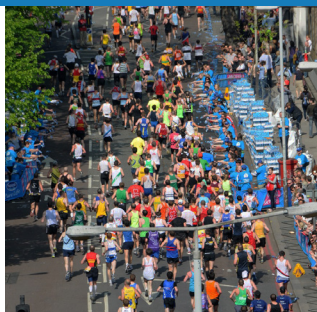
5. Answers may vary.

- Spermatogenesis and oogenesis both involve cells undergoing meiosis.
- Spermatogenesis occurs in the testes of males and oogenesis occurs in the ovaries of females.
- Spermatogenesis produces four haploid daughter cells (four spermatids or sperm) and oogenesis produces only one haploid egg with three polar bodies.

ANSWER KEY (CONTINUED)

6. The man's genotype is hhAaXY. Therefore, he only has the recessive alleles for Huntington's and achondroplasia. He is male, so his genotype for gender is XY. Therefore, he has the ability to make the following two types of sperm: hA and hY.
7. It would decrease the amount of sperm produced by 75%. It would decrease the variability of the possible zygote phenotypes produced due to the fact that instead of many different genotypes having the potential to be a part of the gamete, only one will have that opportunity.
8. Answers may vary
 - Crossing over in Prophase I produces a mixture of genes from both homologous chromosomes.
 - The way that the homologous chromosomes line up during Metaphase I is random.
 - The determination of which sperm fertilizes the egg is completely due to chance.
9. See Table 4.

Table 4. Genotype and Phenotype	
Genotype	Phenotype
HhAaXY	Male with both Huntington's and achondroplasia
hhAaXX	Woman that does not have either disorder
HHAaXX	Female with Huntington's but is of normal height
hhAaXY	Male that does not have Huntington's but does have achondroplasia



NATIONAL
MATH + SCIENCE
INITIATIVE

MATERIALS

noodle chromosomes

The Amazing Sperm Race

Modeling Meiosis and Determining Zygote Characteristics

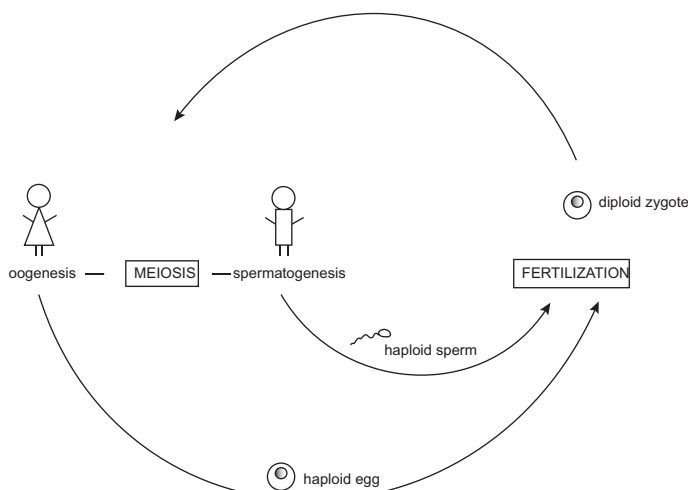
Sexual reproduction increases the genetic variability in populations. Many organisms can reproduce asexually (without a partner); however, the resulting offspring are genetic clones (identical genetic matches) of the parent. Asexual reproduction decreases the genetic variability in a population and therefore increases the probability that the population will lose certain genes due to natural selection.

Sexual reproduction involves chromosomes from the male parent (contained in the sperm) combining with the chromosomes from the female parent (contained in the egg), resulting in the formation of a **zygote**. The zygote then undergoes **mitosis**, or cell division, to grow into the adult form of the organism.

All human cells have 46 chromosomes except for the gametes (sperm and egg), which have 23 chromosomes. Gametes are **haploid** (n), which means they have half the number of chromosomes as a normal cell. The normal cell has the full complement of chromosomes (double that of the gametes) and is said to be **diploid** ($2n$). This preserves the chromosome number of each new human zygote.

Meiosis is the process that allows diploid cells to produce haploid cells. This process differs from mitosis, which allows a cell to produce two new cells that have the same number of chromosomes. There are two main phases in meiosis: *Meiosis I*, which involves the separation of the homologous chromosomes, and *Meiosis II*, which involves the separation of the sister chromatids. You may remember that a post S-phase chromosome contains two sister chromatids connected by a centromere.

Figure 1. Human reproductive cycle



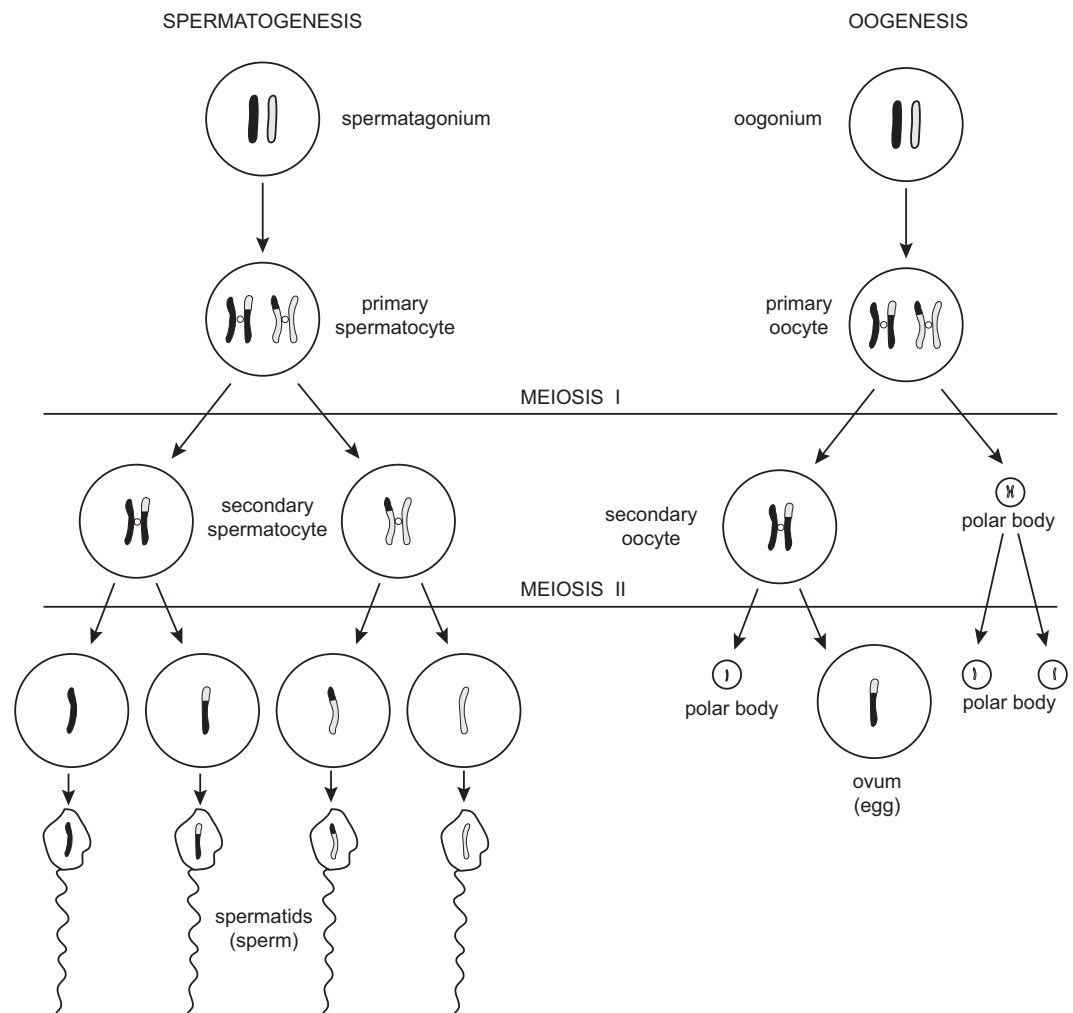
Without meiosis, a new zygote would have twice the number of chromosomes as its parents. Figure 1 shows the typical human reproductive cycle. The steps of meiosis are listed in Table 1.

Table 1. Steps of Meiosis	
Meiosis I	
Prophase I	<p>Chromatin condenses down into recognizable chromosomes. Homologous chromosomes pair up. Crossing-over occurs with corresponding segments on homologous chromosomes switch places. Similar to mitosis:</p> <ul style="list-style-type: none"> • Centrosomes begin to move toward the poles. • The nuclear membrane breaks down. • Nucleoli are dispersed. <p>Microtubules attach themselves to each homologous chromosome. Homologous chromosomes begin to move toward the equatorial plate.</p>
Metaphase I	<p>Homologous chromosomes align themselves on top of one another along the equatorial plate. The spindle apparatus is fully formed.</p>
Anaphase I	<p>Microtubules shorten and pull homologous chromosomes away from each other and toward opposite poles.</p>
Telophase I Cytokinesis	<p>Homologous chromosomes arrive at the poles. A cleavage furrow forms, resulting in the split of the cytoplasm (cytokinesis). This forms two daughter cells.</p>
Meiosis II	
Prophase II	<p>The spindle apparatus reforms. Chromosomes start traveling toward the equatorial plate.</p>
Metaphase II	<p>Chromosomes align themselves single-file, not on top of one another, along the equatorial plate. Microtubules are fully attached to each sister chromatid.</p>
Anaphase II	<p>Microtubules shorten, pulling the centromeres apart and thus pulling the sister chromatids apart and toward opposite poles. Each sister chromatid is now a single, individual chromosome.</p>
Telophase II Cytokinesis	<p>Cytokinesis occurs, finally producing four haploid cells (gametes). Nuclear membranes form around the chromosomes of the resulting daughter cells. Chromosomes begin to loosen into chromatin.</p>

In humans, meiosis occurs either in the testes (sperm production in males) or in the ovaries (egg production in females). Sperm production is called **spermatogenesis** and follows the exact process of meiosis as outlined previously. Therefore for every single diploid testes cell, there will be four sperm produced via meiosis.

Egg production is called **oogenesis** (pronounced “OH-a-genesis”) and follows a similar process; however, oogenesis only produces a single egg. This low production rate is due to unequal cytokinesis during both nuclear divisions in meiosis. Figure 2 illustrates both processes.

Figure 2. Spermatogenesis and oogenesis



Due to crossing-over in Prophase I, each resulting gamete potentially ends up with a variety of different combinations of genes. In humans, fertilization occurs when one sperm (*haploid*, carrying 23 chromosomes) fertilizes one egg (*haploid*, carrying 23 chromosomes) and makes a zygote (*diploid*, containing a total of 46 chromosomes).

Using the gametes that joined to form this zygote, we can determine what characteristics the offspring might have based on the combination of genes, or **alleles**, that are carried by the chromosomes on the gametes. This leads us to **genetics**, the study of heredity, or the study of which traits are passed from parents to offspring. We all inherit our traits from our parents, as shown in Figure 1.

On Chromosome 4, there are many genes. Two genes in particular code for two different genetic disorders, *Huntington's disease* and *achondroplasia*. Huntington's disease is a neurological disorder (affects the brain) that causes neurons (nerve cells) to die off in certain parts of the brain. Achondroplasia is the most common form of dwarfism.

Both disorders are caused by the presence of a *dominant* gene. These genes are dominant because if they are passed to the offspring during fertilization, the resulting baby will have whatever trait the dominant allele encodes. The other type of gene that might be passed is called a *recessive* allele, whose effect is masked by the dominant allele's presence.

Say that the zygote receives the dominant allele for Huntington's disease (H) from the sperm and a recessive allele (h) from the egg. The resulting zygote (Hh) would undergo mitosis to form a baby that has Huntington's disease. Again, it does not matter if the zygote gets one or two dominant alleles—the offspring will still have the disease. The only way for the offspring to avoid inheriting Huntington's disease is if both the sperm and the egg pass the recessive allele to the zygote (hh). Achondroplasia, also a dominant disorder, works the same way.

Of the 23 pairs of chromosomes, the final pair are called the **sex chromosomes** (X, Y). If the zygote receives an X chromosome from each parent, the offspring will be female (XX). If the zygote receives an X chromosome from the mother and a Y chromosome from the father, the offspring will be male (XY).

The zygote can be characterized by the genotype or the phenotype. A zygote's **phenotype** describes the traits themselves, such as whether the zygote has Huntington's disease, achondroplasia, or is male or female. The zygote's **genotype** is its genetic makeup, or what combination of dominant and recessive alleles it received from the gametes. Examples of these inherited traits are listed in Table 2.

Table 2. Traits, Genotypes, and Phenotypes

Trait	Genotype	Phenotype
Huntington's disease	HH Hh hh	Offspring has the disease Offspring has the disease Offspring does NOT have the disease
Achondroplasia	AA Aa aa	Offspring has the disorder Offspring has the disorder Offspring does NOT have the disorder
Gender	XX XY	Female Male

PURPOSE

This activity provides an opportunity for you to work collaboratively with your classmates to simulate the process of meiosis both through spermatogenesis (sperm production) and oogenesis (egg production). You will also practice determining genotypes and phenotypes using a fertilization activity.

SAFETY ALERT!

- » Noodles can be cut using a serrated knife or a utility knife. Please use caution when cutting the noodles.

PROCEDURE

Each member of your four-student group should be holding a replicated chromosome (two sister chromatids connected by a centromere). In the following simulations, we will examine three different traits: Huntington’s disease, achondroplasia, and gender.

Each member of your group will have a homologous “pair” represented by using the same color of noodle. This means that you both code for the same traits. You might have different alleles (dominant or recessive) but the trait is still the same.

Two members of your group will have chromosomes containing the genes for both Huntington’s disease and achondroplasia (found on Chromosome 4). One student will have all dominant traits (H, A) and the other will have all recessive traits (h, a). These two students should have the same color of noodle.

The other two students will represent the sex chromosomes (X, Y). These students should have different colors of noodle than the Chromosomes 4 pair. Remember that males are encoded XY and females are encoded XX. For Part I, you will only use the X and Y alleles; for Part II, you will use XX instead.

All four group members should stand within the largest circle. You should see two smaller circles directly in front of you. You will be simulating spermatogenesis in Part I. During spermatogenesis, one diploid testes cell undergoes meiosis to produce four haploid sperm cells.

PROCEDURE (CONTINUED)**PART I: SPRIGHTLY SPERMATOGENESIS**

The members of your group will now simulate Meiosis I.

PROPHASE I

1. Inside the larger circle (primary spermatocyte), stand by your homologous pair.
2. You and your homologue will now simulate crossing over. While standing shoulder-to-shoulder, exchange genetic information (the tops of the inside chromatids). The tops should be held in with toothpicks.
3. Examine your chromatids. All four members of your group should be holding one chromatid that has alleles from only one homologue and one chromatid that is a mixture of alleles from both homologous chromosomes. Your group is now ready for Metaphase I.

METAPHASE I

4. You and your fellow homologous chromosomes should line up in the middle of the circle, facing each other. This arrangement is much like the metaphase of mitosis but instead of all of the chromosomes lining up single-file along the equatorial plate, the homologous chromosomes will face each other.
It is not important which of you line up on which side. Do this randomly because when cells go through Metaphase I of Meiosis I, homologous chromosomes line up randomly as well. In fact, there are 2^{23} different ways that our 23 homologous chromosomes can line up. That is 8,388,608 different combinations!
5. At this point, you should be facing your homologous partner and standing shoulder-to-shoulder with a member of another chromosome (this is your non-homologous partner). You are now ready to split.

ANAPHASE I

6. You will now split from your homologous partner and start traveling toward opposite ends of the cell. Take two steps away from each other and stop. You are now done with Anaphase I.

PROCEDURE (CONTINUED)**TELOPHASE I AND CYTOKINESIS**

7. All members should now continue traveling until they are at opposite poles of the cell. At this point, you are in Telophase I and Cytokinesis will begin. Remember that in animal cells this involves the formation of a cleavage furrow and results in two new daughter cells (secondary spermatocytes). Simulate this event by moving the yarn between you to mimic the cleavage furrow.
8. To simulate the end of Meiosis I, you and your non-homologous partner should travel to one of the new cells in front of you.
9. Discuss with your non-homologous partner about how the genetic makeup of the new cell you are in differs from the original cell.
 - a. Is the cell you are in diploid or haploid?
 - b. Was the original mother cell diploid or haploid?
 - c. Are the chromosomes you are holding still replicated chromosomes (two sister chromatids connected by a centromere) or single chromosomes?

You are now ready for Meiosis II, which highly mimics the actions of mitosis.

PROPHASE II

10. In Prophase II, the non-homologous chromosomes begin to travel to the center of the cell. Simulate this movement with your non-homologous partner.

METAPHASE II

11. In Metaphase II, the chromosomes line up single-file along the equatorial plate. To simulate this step, stand facing your non-homologous partner with your chromosomes facing each other. Make sure that your chromosomes are held horizontally, i.e., parallel to the floor.

ANAPHASE II

12. Just as in the anaphase of mitosis, the chromatids will be pulled toward opposite poles of the cell. To simulate this, both you and your partner should unhook the chromatids at the centromere and start to move them away from their sister.
13. When your arms are fully extended, lay them both on the ground. Be careful not to hit your non-homologous partner's head on the way down.

PROCEDURE (CONTINUED)

TELOPHASE II AND CYTOKINESIS

14. In Telophase II, the chromatids arrive at the poles. To simulate this, stand next to one of the chromatid pairs lying on the ground. Your non-homologous pair partner should be standing at the other pair.
15. Both you and your partner should pick up the chromatids and move toward opposite poles of the cell.
16. Cytokinesis can now occur. To simulate this, both you and your partner should travel to one of the two smaller cells you see in front of you.
17. Discuss with your non-homologous partner how the genetic makeup of your current cell differs from the previous cell.
 - a. Is the cell you are in diploid or haploid?
 - b. Was the previous cell diploid or haploid?
 - c. Are the chromosomes you are holding still replicated chromosomes or single chromosomes?
18. Discuss with your non-homologous partner about how the genetic makeup of the spermatid cell, the cell that you are in, differs from the genetic makeup of the secondary spermatocyte, the cell that you were in after Meiosis I.
 - a. Is the cell you are in diploid or haploid?
 - b. Was the cell you just came from diploid or haploid?

Congratulations! You have just completed meiosis. At this point, you have produced four new daughter cells (called *spermatids* or *sperm*).

PROCEDURE (CONTINUED)**PART II: ENVIOUS EGG (OOGENESIS)**

Egg formation is a little different than spermatogenesis. In oogenesis, only one egg is made. Now take a closer look at the formation of the egg.

1. The original cell (primary oocyte) will develop during Meiosis I into a polar body and a secondary oocyte. Repeat Step 1 through Step 9 from Part I.
2. To determine the fate of the daughter cells from Meiosis I, your teacher will have each of the daughter cells draw one of two cards, either SECONDARY OOCYTE or POLAR BODY.

Recall from Figure 2 that the secondary oocyte has the potential to become the *ovum* (egg). *Polar bodies* are meiotic daughter cells created during egg formation that will not form into eggs (ovum) due to the fact that much of their cytoplasmic contents were “taken” by the cell destined to become the ovum. You will assume the identity of the cards that you select. Return your cards to your teacher

Important: In humans, a sperm will enter the secondary oocyte, triggering the completion of Meiosis II (Step 10 to Step 18). The nuclei will not actually fuse until Meiosis II is complete, at which time it is a diploid zygote. This will be simulated in Part III of this activity.

3. Repeat Step 10 through Step 18 (Meiosis II) from Part I.
4. The daughter cells of the secondary oocyte will draw cards again. This time, the cards will be either EGG or POLAR BODY. The cell that chooses the EGG card will become the ovum. The other three cells, all of which chose POLAR BODY cards, will now degenerate (sit down).

PROCEDURE (CONTINUED)**PART III: FERTILIZATION FRENZY**

1. Your teacher will assign one group to undergo oogenesis and the other groups to undergo spermatogenesis, and direct you to your positions in the activity area.

The groups that are assigned to undergo spermatogenesis will follow the directions from Part I. The group assigned to undergo oogenesis will undergo Meiosis I from Part II and then stop.

2. All of the sperm will run to the secondary oocyte, and the first one to get there (determined by your teacher) will get to stand just inside the secondary oocyte. This will trigger Meiosis II to begin. Simulate this as you did in Part II.
3. Once one of the daughter cells of the secondary oocyte has been determined (the one that chose the EGG card), then the egg's chromosomes and the sperm's chromosomes will fuse (fertilize). The cell now becomes a diploid zygote. To simulate this:
 - a. The two students in the zygote will stand next to each other.
 - b. One student will hold both of the Chromosome 4 chromatids (the one that contains the genes for Huntington's disease and achondroplasia) and the other student will hold the two sex chromosomes.
4. While viewing the zygote, have everyone fill out the rest of the information for that trial in Table 3: your genotype, genotypes of the original parents, genotype of the egg, genotype of the winning sperm, genotype of the zygote, and phenotype of the zygote.
5. Your teacher will lead you through several races. The "oogenesis" group will switch with another group every time so that different groups get to go through the egg-making process.

DATA AND OBSERVATIONS

Table 3. Fertilization Frenzy Data								
Trial	Cell Type (Sperm, Egg, or Polar Body)	Genotypes				"Winning" Sperm	Zygote	
		Yours	Parents	Egg			Genotype	Phenotype
1								
2								
3								
4								
5								
6								
7								
8								

CONCLUSION QUESTIONS

1. Explain the difference between *mitosis* and *meiosis*.
2. Explain the reproductive cycle of a human in terms of haploid and diploid cells.
3. Contrast Meiosis I and Meiosis II.
4. Explain the relationship between *phenotype* and *genotype*.
5. Compare and contrast *spermatogenesis* and *oogenesis*.

CONCLUSION QUESTIONS (CONTINUED)

- Using your data from Table 3, what effect do you think crossing over has on the overall phenotype of the zygote?
- If spermatogenesis underwent a meiotic division like oogenesis, predict any changes in the outcomes of Part III.
- Explain several ways in which the variability of the potential zygote's phenotype is increased during meiosis.
- Complete the information in Table 4. 🧬

Table 4. Genotype and Phenotype	
Genotype	Phenotype
HhAaXY	
	Woman that does not have either disorder
HHaaXX	
hhAaXY	