Meiosis – Key to Gamete Formation

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Student Objectives:

<u>A student will be able to</u>:
1. Define meiosis and describe where it occurs within the body.
2. Identify, demonstrate and explain what is occurring (where chromosomes are located) at each stage of meiosis I and II.
3. Identify and explain the difference between a chromosome, chromatid, sister chromatids, and homologous pair.
4. Compare and contrast mitosis and meiosis. Be able to list the number of divisions, resulting daughter cells and whether daughter cells are haploid or diploid for each type of cell division.
5. Define and demonstrate the process of spermatogenesis including where it occurs and the number of resulting sperm cells.
6. Define and demonstrate the process of oogenesis including where it occurs and the number and type of resulting cells.
7. Identify the following structures on a microscope slide or picture: seminiferous tubule, interstitial cell, spermatid, primary follicle, Graffian follicle, and secondary follicle.
8. Define nondisjunction and describe how, when, and where it occurs.

Introduction

Each individual produced through sexual reproduction is genetically different from all other members of its species. Although each offspring will resemble its parents in many characteristics, the offspring will also vary in appearance from both of them. A knowledge of the principles of inheritance helps explain the similarities and differences observed in members of all species.

In this lab we will explore the details of meiosis with Brad and Jaci, a recently married couple. We will determine how this cell division produces the gametes (sex cells), each containing half the genetic information for a human (**haploid**). The gametes then combine during fertilization and produce a cell containing a whole set of genetic information (**diploid**). We will also evaluate some potential problems that could occur during gamete production and the consequence of each for a developing child.

Part 1: Gender of the Parents

Each species has a characteristic number of **chromosomes**: for example, an onion has 16 chromosomes, the fruit fly *Drosophila* has 8 chromosomes, and humans have 46 chromosomes. Located along each chromosome are **genes**, the carriers of hereditary traits. Alternate forms of the same gene are called **alleles**. The symbol for a **dominant** allele is usually an upper case letter (A, B, H, etc.), while the symbol for a **recessive** allele is usually a lower case letter (a, b, h, etc.). When both alleles are present, the dominant allele expresses itself while the recessive allele remains "hidden." For example, in humans the hairline gene has the allele for widow's peak in the hairline (W), which is dominant to the allele for straight hairline (w). This implies that if a person had the combination of (Ww) as their **genotype** (genes), their **phenotype** (physical trait) would express the dominant trait, having a widow's peak.

For this activity, work in groups of two. Each group will receive two bags that contain both pipe cleaners and pasta pieces. Humans have twenty three pairs of chromosomes and thousands of genes to represent many different traits, but we will only be looking at a few different traits for this exercise. You should find a total of **16 chromosomes** in each bag.

Before opening the bag you can determine what your gender is by looking to see if you have four pink (female) pipe cleaners or if you have two pink and two blue (male) pipe cleaners.

Questions:

1. What do the pipe cleaners represent in this activity? ______________________
2. What do the pasta pieces represent in this activity? __________________________
3. How many pairs of chromosomes do humans have? ___________

Part 2: Traits of the Parents & Interphase

1. Take the chromosomes out of the bag making sure not to mix them up with your partner's. The following chromosomes should be in your bag:

Number	Pipe Cleaner Color	Size	Brad's Pasta Pieces	Jaci's Pasta Pieces
2	black	short	C	C
2	black	short	S	C
2	black	long	F bottom, R top	F bottom, r top
2	black	long	f bottom, R top	f bottom, R top
2	green	short	no pasta pieces	no pasta pieces
2	green	short	no pasta pieces	no pasta pieces
2	pink		H	H
2	pink (Jaci only)			h
2	blue (Brad only)		no pasta pieces	

2. The chromosomes need to double during interphase. Match up chromosomes that are the same size and color and have the exact same letters of the alphabet (pay attention to lowercase and uppercase letters). Twist matched chromosomes together in the middle to form an "X" shape (your lab teacher will show you how). You have just made duplicated chromosomes.

Each individual pipe cleaner represents a **chromosome** when by itself; when it is twisted into an X with another pipe cleaner, each individual pipe cleaner represents a **sister chromatid** and the entire X (two pipe cleaners) represents a **duplicated chromosome**. In duplicated chromosomes, both sides of the X contain the exact same genetic information (same genes and same alleles in the same locations). **Homologous chromosomes** carry the same genes in the same locations but may have different alleles. For example, Brad's duplicated short, black chromosome with "Cs" and duplicated short, black chromosome with "Ss" are homologous chromosomes. The pink/blue pairs are **sex chromosomes** (XX - female, XY - male) because they determine the sex of the child in addition to other traits.

Which chromosome does the pink pipe cleaner represent? (X or Y) ___________

The blue pipe cleaner? (X or Y) ___________

In this lab, the letters on the pasta pieces represent the following alleles, genotypes, and phenotypes:

F = freckles f = no freckles FF - freckles Ff - freckles ff - no freckles

R = red hair r = hair not red RR - red hair Rr - red hair rr - hair not red

S = straight hair C = curly hair SS - straight hair SC - wavy hair CC - curly hair

Chromosome #21 (green)
One pipe cleaner = 1 two pipe cleaners = 2 no pipe cleaners = 0

For sex chromosomes ONLY (chromosome #23)
Pink = X blue = Y XX - girl XY - boy

H = normal h = hemophiliac boys: X^HY = normal, X^hY = hemophiliac
girls: X^HX^H = normal, X^HX^h = normal (carrier), X^hX^h = hemophiliac

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Hair Coloring: long black pipe cleaners (top)

This trait is inherited simply with a single gene that has dominant and recessive alleles.

R = red hair r = hair not red RR - red hair Rr - red hair rr - hair not red

Use Jaci's (mother's) chromosomes.

Look at the homologous chromosomes for hair coloring, and focus on the "r" or "R". What letter do you see on the first duplicated chromosome (write the letter once, no need to duplicate information)? ___________ What letter do you see on the second chromosome? ____________ What is the genotype (letters of the alleles from the previous two blanks) for the mother's hair color? ____________ Mother's phenotype (actual trait you see)? ____________

What is the genotype for the father's hair color? ___________ phenotype? _____________

Freckles: long black pipe cleaners (bottom)

This trait is inherited simply with a single gene that has dominant and recessive alleles.

F = freckles f = no freckles FF - freckles Ff - freckles ff - no freckles

What is the genotype for the mother's freckles? ____________ phenotype? ___________

What is the genotype for the father's freckles? ____________ phenotype? ____________

Hair Texture (incomplete dominance): short black pipe cleaners

Hair texture is a trait that demonstrates incomplete dominance in Caucasians. In incomplete dominance an intermediate phenotype can occur. The genotype SC produces neither curly nor straight hair; instead SC produces an intermediate hair texture, wavy.

S = straight hair C = curly hair SS - straight hair SC - wavy hair CC - curly hair

What is the genotype for the mother's hair texture? ___________ phenotype? ____________

What is the genotype for the father's hair texture? ___________ phenotype? _____________

Hemophilia (sex-linked trait on X chromosome): pink and blue pipe cleaners

This means that the trait for hemophilia is on the X chromosome. The trait has dominant and recessive alleles, but they are located on the X chromosome. The result is that the Y chromosome does not contain this allele.

Pink = X   blue = Y   XX - girl   XY - boy

H = normal   h = hemophiliac   boys: X^HY = normal, X^hY = hemophiliac
girls: X^HX^H = normal, X^HX^h = normal (carrier), X^hX^h = hemophiliac

What is the mother's genotype for hemophilia? ____________ phenotype? ____________

What is the father's genotype for hemophilia? ____________ phenotype? ____________

Can a father ever be a carrier? ____________

Part 3: The Process of Meiosis or Making Sperm and Secondary Oocytes

The process of meiosis is very similar to mitosis in many ways. The general stages that occur, prophase, metaphase, anaphase and telophase, are the same. Cytokinesis follows all divisions in both processes. Interphase occurs prior to prophase of mitosis and prior to prophase I of meiosis. Interkinesis, a resting period, occurs between telophase I and prophase II of meiosis. No replication of DNA occurs during this phase since the purpose of meiosis is to reduce the chromosome number by one half; replication would only undo all the work that the cell has just accomplished. The number of cellular divisions differs. In mitosis only one cell division occurs following the duplication of the cell's DNA. In meiosis the process involves two separate cell divisions. You will observe other differences between the two processes as you complete this section.

In the following activity you will work as a pair to simulate the stages of meiosis occurring in the gamete production of Brad and Jaci using the pipe cleaners and pasta pieces from above. Before you begin, your instructor will show you the simplified stages of meiosis. After watching your instructor, move your pipe cleaners through all the simplified stages of meiosis.

1. Use the diagram of meiosis (text Figure 7.23, p. 158-9) to help you model each phase of meiosis with your pipe cleaners. **First, both lab partners should complete the steps below, working together, for Brad (father).** Your lab teacher will demonstrate how to use the figure to model Prophase I and Metaphase I.
2. Be careful during Prophase I. After you have paired the homologous chromosomes, you will need to use the long black chromosomes to demonstrate crossing over. What are the alleles on the long black chromosomes at the beginning of Prophase I, prior to crossing-over? (label chromosomes below with letters that show where the pasta pieces are located)

   X   X

   Take the F freckles pasta piece at the bottom of one long black pipe cleaner and exchange it with the f freckles pasta piece at the bottom of one of the other long black pipe cleaners. This is crossing-over. During **crossing-over** genetic information is exchanged between non-sister chromatids. What are the alleles on the long black chromosomes after crossing-over has occurred? (label chromosomes below with letters that show where the pasta pieces are located)

   X   X

   Why is it important that genetic information be exchanged between non-sister chromatids?

3a. Be careful during Metaphase I. The position of the homologous chromosomes as each is lined up at the metaphase plate is random. This is called **random alignment** of chromosomes.

3b. **Illustration of independent assortment.** For Brad only - Do not do step 3b for Jaci. Could you have lined up the homologous chromosomes another way during this step that would have given you different pasta pieces on each side of the cell? ________ Draw the way you lined up the chromosomes for Brad on the left side below using X's for the chromosomes and letters placed next to them to represent the pasta pieces. On the right, draw an alternative way the chromosomes could have lined up.

	Brad's Chromosomes		Alternate Chromosomes for Brad	
Long Black	X	X	X	X
Short Black	X	X	X	X
Green	X	X	X	X
Blue/Pink	________	________	________	________

4. Continue with the remaining phases of meiosis.

5. When the meiosis is complete, record the allele combination for each resulting gamete in Table 1. DO NOT TAKE APART BRAD'S CHROMOSOMES. YOU WILL USE THEM LATER.

Table 1. Chromosomes of Brad's Resulting Gametes

	Chromosomes and Alleles Present			
Chromosome & Gene	**Gamete 1**	**Gamete 2**	**Gamete 3**	**Gamete 4**
Long black, top, hair color (R, r)				
Long black, bottom, freckles (F, f)				
Short black, hair texture (C, S)				
Green, chromosome 21 (0, 1, 2)				
Pink/blue, sex chromosome 23, hemophilia (X^H, X^h, Y)				

List the gender and trait information that Brad contributed to each of the following gametes.

Gamete 1 ________________________ Gamete 2 ________________________

Gamete 3 ________________________ Gamete 4 ________________________

Are all 4 of Brad's gametes the same? _______ Why or why not (hint: which phase of meiosis allows you to get different combinations of alleles (letters) in the gametes)? ________________________________

____

How does this similarity/difference in gametes relate to similarities/differences in brothers and sisters?

____

____

6. Repeat steps 1-4 for Jaci. Record her results in Table 2

Table 2. Chromosomes of Jaci's Resulting Gametes

	Chromosomes and Alleles Present			
Chromosome & Gene	**Gamete 1**	**Gamete 2**	**Gamete 3**	**Gamete 4**
Long black, top, hair color (R, r)				
Long black, bottom, freckles (F, f)				
Short black, hair texture (C, S)				
Green, chromosome 21 (0, 1, 2)				
Pink/blue, sex chromosome 23, hemophilia (X^H, X^h, Y)				

- You will use the gametes in Tables 2 and 4 to determine the genetic traits of Jaci and Brad's baby during the next lab. Meiosis in Jaci can produce four daughter cells as seen in the table above, but three of these cells will not survive (see oogenesis for more detail).

7. Fill in the table below and answer the questions by comparing the processes of mitosis and meiosis. Refer to text Figures 7.23 and 7.25 (p. 161) for help.

Table 3. Comparison of Resulting Products of Mitosis and Meiosis

	Mitosis	**Meiosis**
Number of Cell Divisions	1	2
Number of Resulting Daughter Cells	2	
Number of Chromosomes in Daughter Cells [haploid (n) or diploid (2n)]		

1. Fill in the table below.

Comparison of Mitosis, Meiosis I and Meiosis II

	Mitosis	Meiosis I	Meiosis II
Event that occurs during prophase	___________		___________
Structures that line up during metaphase			
Structures that separate during anaphase			

2. Now look back at the table. Which division, Meiosis I or Meiosis II, is most similar to Mitosis? ____________________ Which is least similar? ____________________

   Why? ____

   ____

   ____

   ____

Part 4: Processes of Gametogenesis – Meiosis in Action

The body utilizes meiosis to create gametes, the haploid sex cells. Formation of these sex cells through meiosis is called **gametogenesis**. Gametogenesis only occurs in two locations, the testes of males (spermatogenesis) and the ovary of females (oogenesis). In males, spermatogenesis produces sperm, and in females, oogenesis produces secondary oocytes. The purpose of gametogenesis is to produce sex cells containing only half the genetic information needed. When gametes combine in fertilization, the resulting cell then contains a complete set of genetic information, half from each gamete.

Spermatogenesis

In the previous meiosis activity, you modeled the production of Brad's sperm cells. Their production takes place within the tightly coiled **seminiferous tubules**, which are packaged within the testes of a male. If a cross section is taken of one of these seminiferous tubules, it will reveal numerous cells called **spermatogonia (Germinal cells)** surrounding the outer inside surface. These diploid cells undergo mitosis to create two new identical cells, one will stay in the outer inner surface and the second will continue to undergo cell division, carry out meiosis and form four immature haploid sperm cells each called a **spermatid**. As the cell is undergoing the two division of meiosis it is slowly pushed toward the middle of the tubule. In the end, the four spermatids are located in the middle of the tubule from where they will be transported to a location for further development. Text Figure 30.12, p. 660 is a visual depiction of the process.

Oogenesis

For Jaci you modeled oogenesis. Within each of her ovaries, there are tens of thousands of cells called **oogonia**. These starting cells, unlike the spermatogonia do not undergo mitosis to constantly replace themselves. Instead, Jaci was born with all of the oogonia she will ever have. Prior to birth the process of meiosis begins in all oogonia. They undergo meiosis I but stop during prophase I as **primary oocytes**. Then when a woman reaches puberty, on average one of these cells matures each month completing meiosis I and starting meiosis II. The cell is again halted at metaphase II. This cell, now called a **secondary oocyte,** is then released from the ovary in an event called ovulation. Once it is released it may have the opportunity to be located and penetrated by a sperm cell. It is only when the secondary oocyte is penetrated by a sperm cell that it is able to complete meiosis II. At the end of meiosis there are four cells, but they are not equal sizes. Instead there are one large egg cell or **ovum** and three small cells called polar bodies, which are a mechanism for removing half the nuclear material during each division of meiosis.

As the primary oocyte is maturing inside the ovary it is surrounded by a group of cells called follicular cells, which provide needed nutrients. As the cell gets larger the follicular cells increase and their secretions begin to accumulate creating a fluid filled cavity around the oocyte. Prior to ovulation the secondary oocyte and its surrounding follicular cells is termed a **Graafian follicle (mature follicle)** because of its large size and fluid filled cavity. Text Figure 30.16, p. 662 is a visual depiction of the process of oogenesis.

In the following activity you will use slides to gain a better understanding of spermatogenesis and oogenesis.

1. Obtain a microscope, a cross section of an ovary slide, and a cross section of testis slide.
2. Once the microscope has been properly set-up, view the ovary slide by focusing using the scanning, low power and high power objectives.
3. When focused on high power closely observe. Identify smaller, primary follicles, larger secondary follicles, and a Graafian follicle. **On the lab practical you will have to identify these parts when looking through a microscope.**
4. When observation of the ovary is complete, remove the slide and place the testis slide on the stage. Focus using the scanning, low power and high power objectives.
5. Once focused on high power observe closely. Identify the seminiferous tubules and interstitial cells. Also locate immature spermatids in the center of each tubule. **On the lab practical you will have to identify these parts when looking through a microscope.**

Part 5: Nondisjunction – When Division is Not Complete

We have demonstrated that the meiotic event that occurred in Brad and Jaci's gametogenesis produced normal sperm and secondary oocytes each containing a complete, haploid set (n=23) of chromosomes. But, things do not always go smoothly. At times homologous chromosomes or sister chromatids fail to separate completely during anaphase I or II. This failure to separate is referred to as **nondisjunction**.

1-3. Using Brad's chromosomes from Part 3 of the lab, use the diagram of meiosis (text Figure 7.23, p. 158-9) to help you model each phase of meiosis with your pipe cleaners.

4. Be careful when you reach Anaphase II. A mistake, nondisjunction, occurs here in one of the cells. Select one cell going through Anaphase II. Show nondisjunction by moving both of the green pipe cleaners to the same side of this cell. When this cell finishes dividing, one daughter cell will end up with two of these pipe cleaners, and the other will end up with none. The two chromosomes represented by the green pipe cleaners have not separated properly. For the other cell going through Anaphase II, proceed normally, with one green pipe cleaner moving to each side of the cell.
5. Continue with the rest of meiosis.
6. Fill in the table below with Brad's new gametes.

Table 4. Chromosomes of Brad's Resulting Gametes after Nondisjunction

	Chromosomes and Alleles Present			
Chromosome & Gene	**Gamete 1**	**Gamete 2**	**Gamete 3**	**Gamete 4**
Long black, top, hair color (R, r)				
Long black, bottom, freckles (F, f)				
Short black, hair texture (C, S)				
Green, chromosome 21 (0, 1, 2)				
Pink/blue, sex chromosome 23, hemophilia (X^H, X^h, Y)				

There are many syndromes which can result following the fertilization of a gamete containing an abnormal chromosomal number as the result of nondisjunction. The nondisjunction event that took place in Part 5 involved chromosome 21. When the gamete that contains an **extra chromosome 21** fuses with a normal gamete, the result will be a baby with **Down syndrome** (3 copies of chromosome 21).

Which gamete number(s), if used when Jaci and Brad's baby is created, will cause Down syndrome?

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