1. Today’s lab requires you to understand a bit of vocabulary. Briefly draw or explain the following terms.

- Chromosome:

- Gene:

- Allele:

- Haploid (1n):

- Diploid (2n):

- Gamete (1n):

- Zygote (2n):

- Testes:

- Ovary:

- Spermatogenesis:

- Oogenesis:
2. A. Draw chromosomes: For each of the following phases of meiosis, draw out the chromosomes from an organism that has 3 different types of chromosomes (n=3). The chromosomes need to be drawn so that you can see if they are duplicated (made up of 2 sister chromatids) or not, and the three types should be represented by three different lengths of chromosomes.

Hint: if it has three types of chromosomes, it has 6 chromosomes in a diploid cell (2n=6). The cells in Metaphase I and Metaphase II have been drawn for you.

2. B. Circle the correct answers in the boxes: for each stage listed, indicate if the cell is haploid or diploid and whether chromosomes are made up of sister chromatids or not.

3. In humans, both mitosis and meiosis start with one diploid cell. How are the cells ultimately produced by the processes different? (in number of cells, in numbers of chromosomes and in genetic diversity)
Lab 4: Meiosis and Vertebrate Reproduction

LAB SYNOPSIS:
• Meiosis will be modeled using pop-beads.
• The genetic diversity of gametes will be modeled using pop-beads
  o Crossing Over and Independent Assortment.
• The genetic diversity of offspring via random fertilization will be modeled using pop-beads.
• We will watch a video exploring the advantages of sexual reproduction.
• We will overview male and female reproductive systems and the process hormonal control of ovulation/menstruation.

OBJECTIVES: After successfully completing this lab, a student will be able to:
• List the main phase of meiosis, including the major events of each phase.
• Explain events that lead to genetic variation of gametes.
• Identify the main structures of the human reproductive systems.
• Explain the process that is used to synchronize the ovarian and uterine cycles.
• Briefly describe the process of fertilization and development that take place in humans.

Part I: Meiosis

Overview:
You started out life as a zygote, your first diploid cell resulting from the fertilization of your mother’s haploid egg cell by your father’s haploid sperm cell (fig. 1). Your zygote then proceeded to undergo many many cell cycles to ultimately produce the ~20,000,000,000,000 cells that make up your body. Recall, the cell cycle is the sequence of phases that occurs as a cell divides (one parent cell becomes two genetically identical daughter cells via interphase → mitosis → cytokinesis).

Meiosis is the process of making haploid cells (sperm or egg). Today’s lab will help demonstrate the process of meiosis; One diploid cell will go through 2 cell divisions to produce 4 haploid cells. These 4 haploid cells are genetically different from each other due to crossing over and independent assortment.

Interphase → Meiosis I → Cytokinesis I → Meiosis II → Cytokinesis II

Exercise 1A: Modeling Interphase Prior to Meiosis with Pop Beads

To understand the mechanism of meiosis, we are going to model the each of the phases using pop beads to represent chromosomes. Parts of this will look a lot like the process of mitosis. To help highlight differences, look for * below.

Gonads- Testes for males, ovaries for females; contain the germ cells that will undergo meiosis.
Germ Cells- The cells that will go through meiosis to form sperm or eggs.
Somatic Cells- Cells in your body that do not undergo meiosis. Ex. liver, skin, bone, etc.
Procedure: constructing chromosomes using pop beads. Since you will be exchanging chromosomes with other groups to model fertilization, make sure you construct your chromosomes exactly as in fig. 2.

1. Using figure 2 as a guide, construct chromosomes for a pretend cell containing 4 chromosomes (2 red chromosomes originally inherited from its mother and 2 yellow chromosomes from its father). This is a diploid cell.

**Diploid cell-** A cell containing 2 sets of chromosomes. One set from mom, one set from dad.

Diploid cells contain homologous pairs of chromosomes.

**Homologous chromosomes-** are similar in size, the order of genes and centromere position (represented here by the white magnetic links).

Homologous chromosomes are not however identical because one was inherited from mom and the other from dad.

### Sets and Pairs

For figure 2 understand:

Which set of chromosomes were inherited from the father?

Which set of chromosomes were inherited from the mother?

Which chromosomes are homologous pairs?

Confirm your understanding of this before continuing.

**Interphase-** Phase of the cell cycle when the cell does not appear to be doing much.

Just like mitosis, germ cells undergo the 3 parts of interphase; Gap 1, Synthesis phase & Gap 2.

- **Gap 1 (G₁)-** Phase in which the cell grows and functions normally.
- **Synthesis phase (S-phase)-** Phase in which the cell duplicates its DNA. During the S-phase of interphase each chromosome goes through the process of DNA replication. Following DNA replication, each chromosome is composed of 2 identical sister chromatids attached at the centromere.

Procedure cont.

2. Although in real cells you cannot see individual chromosomes, to demonstrate the results of the S-phase, construct exact copies of each of your chromosomes and link them via their magnets.

Note: Following the S-phase, you still have 4 chromosomes, but each chromosome is made up of two sister chromatids. Fig. 3.

Label each of the following in figure 3. Chromosome, Sister Chromatid, Centromere & Homologues.

- **Gap 2 (G₂)-** Phase in which the cell resumes its growth in preparation for meiosis.
**Exercise 1B: Meiosis I and Crossing-Over. Modeling Using Pop-Beads**

*Meiosis I (The Reduction Phase)* Phase of the meiosis that separates the homologous pairs. (Recall in mitosis, we separated sister chromatids). One diploid cell will form two haploid cells.

**Prophase I**- chromosomes become visible under the light microscope. Also during prophase I, the nucleolus disappears and the nuclear envelope breaks down. Microtubules extend from centrioles at either pole of the cell forming the spindle apparatus.

3. Use figure 4 to guide you through the process. Fig. 4A represents prophase. Your moving of the chromosomes with your hands is equivalent to the work the spindle microtubules are doing.

* Prophase I cont.- Synapsis and Crossing-over. (this does not happen during mitosis)
* Synapsis- homologous chromosomes pair up
* Crossing-over- The process in which genetic material is exchanged between two homologous chromosomes.

Exercise 3 below covers the process of crossing-over in detail. You may choose to wait to cross over till then.

* Metaphase I- homologous pairs line up in the middle of the cell (along the metaphase plate).

4. Line chromosomes up double-file so homologous chromosomes are facing either side of the cell (Fig. 4B).

* Independent Assortment- homologous pairs line up and assort chromosomes originally inherited from mom vs. from dad randomly. (See below)

* Anaphase I- homologous chromosomes separate and begin to move to either side of the cell.

5. Separate homologs and pull them to either side of the cell (Fig. 4C).

* Telophase I- homologous chromosomes are pulled all the way to either side of the cell.

6. Pull chromosomes further away from one another (Fig. 4D).

**Cytokinesis I**- This is the process of cell division, dividing one cell into two new daughter cells. Following cytokinesis the nuclear envelope reforms around the chromosomes, the chromosomes de-condense and the nucleolus reforms.

7. Pull chromosomes yet further away from each other. Note: each “new cell” does not have identical chromosomes to each other (Fig. 4E).

Haploid cells- Cells containing 1 set of chromosomes.
Haploid cells do not contain homologous pairs of chromosomes. Pairs separated during meiosis I.

Note from figure 4E. Following meiosis I, homologous chromosomes have been separated, but each of the two chromosome is still made up of 2 sister chromatids. Meiosis II is the process of separating the sister chromatids. Meiosis II is very similar to mitosis.
**Exercise 1C: Meiosis II. Modeling Using Pop-Beads**

**Meiosis II**- Phase of the meiosis that separates the sister chromatids. (Recall in mitosis, we also separated sister chromatids). Two haploid cells will form four haploid cells.

- **Prophase II**- chromosomes become visible under the light microscope. (Fig. 5A)
- **Metaphase II**- chromosomes line up single-file in the middle of the cell (along the metaphase plate). (Fig. 5B)
- **Anaphase II**- sister chromatids separate and begin to move to either side of the cell. (Fig. 5C)
- **Telophase II**- sister chromatids, now considered individual chromosomes, are pulled all the way to either side of the cell. (Fig. 5D)

**Cytokinesis II**- This is the process of cell division, dividing each cell into a total of 4 new daughter cells. Following cytokinesis the nuclear envelope reforms around the chromosomes, the chromosomes de-condense and the nucleolus reforms. (Fig. 5E)

Note: Following cytokinesis II each cell is genetically different from each other.

Practice the phases of the cell cycle again without the aid of the figures.

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Gametogenesis- Differentiation and development of the 4 cells resulting from meiosis into the gametes (either sperm or egg).
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If this were a human germ cell;

How many total chromosomes are their prior to the meiotic cell cycle? _______

How many sets of chromosomes would there be prior to meiosis I? _______

How many chromosomes would there be in each set prior to meiosis I? _______

How many sets of chromosomes would there be in each cell after meiosis I? _______

How many chromosomes would be in each set after meiosis I? _______

Would chromosomes be composed of sister chromatids before meiosis II? _____

Would chromosomes be composed of sister chromatids after meiosis II? _____

How many chromosomes would be in each of the 4 cells after meiosis II? _______
Exercise 2: Genetic Diversity of Gametes

There are two events that lead to the genetic diversity seen in the final 4 haploid cells at the end of meiosis; crossing over and independent assortment. In the following exercise, we will use pieces of tape to track genes as they go through the process of meiosis.

Procedure:

1. Using labeling tape, identify 3 genes on your “dad’s” yellow chromosomes precisely as follows: Genes are represented by individual beads on the pop-beads. You will also need to label mom’s red chromosomes (not shown in figure).

   ![Figure 6. Dad’s Yellow Chromosomes](image)

   **Step 1: Assigning Alleles**
   - **Gene 1** codes for β-hemoglobin (part of the protein that carries oxygen in your red blood cells). Normal β-hemoglobin can be represented by *s* while the sickle cell anemia trait will be represented by *S*.
   - **Gene 2** codes for hair color. Black hair will be represented by *B* while red hair will be represented by *b*.
   - **Gene 3** codes for being able to roll your tongue. Being able to roll your tongue will be represented by *R* and not being able to roll your tongue will be represented by *r*.

   You need to determine what form of genes 1, 2 & 3 are found in dad’s yellow chromosomes and in mom’s red chromosomes. Do this randomly. For each gene, roll the die, if it comes up even (2, 4 or 6), write the uppercase letter form of the gene (*S*, *B*, or *R*). If it comes up odd (1, 3 or 5) write the lowercase form of the gene (*s*, *b*, or *r*). Indicate your results in the table below.

<table>
<thead>
<tr>
<th>Gene</th>
<th>Dad’s yellow chromosomes</th>
<th>Mom’s red chromosomes</th>
<th>Alleles differ or are identical?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   **Allele**- Different forms of the same gene at a specific position on both homologous chromosomes.

   Note in the table which of the alleles for genes 1, 2 or 3 differ between mom’s and dad’s chromosomes, and which alleles are identical.

2. Using the data from the table, label with tape dad’s 2 yellow and mom’s 2 red chromosomes. Remember you are modeling the whole process of meiosis, so you will need to duplicate this procedure starting with DNA replication during the S-Phase. After you should have 4 chromosomes each made up of two identical sister chromatids (yes you will need to put tape on those as well). See fig. 3 above.

3. You are ready to model the process of meiosis in separating genes. You will need to model two events: crossing over during prophase I and the independent assortment of chromosomes during metaphase I.

   a. **Crossing over**: To model crossing over, which is the process that results from the breaking and swapping of DNA strands between homologous chromosomes, you will need to pair your chromosomes...
Pairing up of chromosomes happens during prophase I: Place your long red chromosome next to the long yellow and the short red next to the short yellow (fig. 4A). With your two long chromosomes lined up next to each other, start at end of the long arm. Crossing over is somewhat random, so roll the die; if it is a 6 then break apart the joints on both the red and yellow chromatids that are right next to each other and swap the chromosome tips. If the die rolls a number other than 6 then do not swap the beads at this joint. Either way, after finishing this first joint, move down to the joint between the second and third beads and roll the die again. If the roll is a 6 then cross-over at this joint and then keep moving on through all the other joints. Every time you roll a 6, you should break open the joint and cross over. After you have finished with the long chromosome go through the short chromosome, checking for cross over at each of its joints.

b. Independent Assortment: After checking for crossing over on both the chromosomes, it is time to set up the chromosomes for metaphase I. Notice that the process of crossing over forces the two chromosomes of the same type to be next to each other. These chromosomes, called homologous chromosomes, now will line up for Metaphase I in pairs. To determine which chromosome goes on each side, we will once again allow chance to dictate. To set up the long chromosomes, roll the die; if the number is a 1, 2, or 3 then the chromosome with the most red beads will be on the left. If the number is a 4, 5, or 6 then the chromosome with the most yellow will be on the left. Now repeat this for the short chromosome (1, 2, 3 = red on left; 4, 5, 6 = yellow on left).

4. Now go through the rest of meiosis until you have produced 4 haploid cells (fig. 4&5). These cells will develop into gametes. Each gamete needs to find another gamete to fuse with so that they can make a new diploid cell called a zygote! Notice that the gametes are haploid (only one of each type of chromosome), and that each gamete is “genetically” different from the other gametes.

Recall: Before meiosis the one diploid cell had 2 copies of each gene. See your table above.
Note: After meiosis, due to the separation of homologous pairs, the resulting 4 haploid cells only have 1 copy of each gene. And, that due to crossing over and independent assortment, these genes have been randomly segregated.

Record the results for the four cells following meiosis: Recall these 4 cells will develop into gametes.

<table>
<thead>
<tr>
<th>Gene 1</th>
<th>Gene 2</th>
<th>Gene 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamete #1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamete #2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamete #3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamete #4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Exercise 4: Random Fertilization

Crossing over and independent assortment result in diversity of the gametes produced. Random fertilization results in an additional degree of variation in the resulting offspring that any two individuals can produce.

As you will see in the video shown during today’s lab, picking mates is often anything but random; for now though, we will randomly select gametes to fuse together to produce a zygote. This process is clearly more complicated than we will be modeling today but we are really just looking for the genetics of what is going on.

Procedure:
1. Pick a random sperm: Group your 4 separate gametes in front of you. Now roll the die twice, add the numbers together and starting from the left, count through the gametes one at a time until you reach the number you rolled. Give this sperm to another lab group. You will also need to obtain another group’s random sperm.

2. Fertilize a random egg: Use the die again to randomly determine which of your remaining 3 gametes to fertilize. Record the set of alleles found in your new offspring in the table below and then collect the information from each of the other groups. If there is a group that cannot find a “mate”, you many need to select another one of your gametes to give to them. If this happens, just randomly chose one of your remaining gametes to use for fertilization.

*Fertilization reestablishes the diploid (2n) condition.

Record your fertilization results and those from other groups below.

<table>
<thead>
<tr>
<th>Group</th>
<th>Alleles for gene 1</th>
<th>Alleles for gene 2</th>
<th>Alleles for gene 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Example</td>
<td>S S</td>
<td>b b</td>
<td>R r</td>
</tr>
<tr>
<td>#1 (your group’s egg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* What will be the result of the genes inherited by the Example above? SS, bb, & Rr. Will it have sickle cell anemia or not? Will it have black hair or red hair? Will it be able to roll its tongue or not? These questions and many more will be explored in next week’s lab, “Genetics”.

**Exercise 4: Why Sex?**

**Video:** Why Sex. (2002). Runtime ~60 min.

“In evolutionary terms, sex is more important than life itself. Sex fuels evolutionary change by adding variation to the gene pool. The drive to pass on our genes has shaped not only our bodies, minds, and lives, but the rich and complex fabric of human culture.”

In this exercise, you will watch a video that asks the question, why do organisms have sex? This video also presents several new concepts related to evolution, including the idea of evolution through sexual selection and the hypothesis that human intelligence is at least partially the result of sexual selection.

Read these questions prior to watching the video and answer them during the video.

1. What is the reproductive strategy for almost every animal?

2. Was black spot disease in minnows more likely to infect asexual or sexual reproducers? Why?
3. What is the Red Queen idea?

4. What is a benefit of sexual reproduction?

5. Give some examples of ornamentation found on males in the animal kingdom.

6. How did the peacock offspring fathered by males with small trains compare to those fathered by males with large trains?

7. Why do you think it is important that the traits used in sexual selection indicate the fitness of the mates?

8. What is a benefit of monogamy?

9. What brought about the gender role reversal in Jacana birds?

10. How do female chimpanzees reduce the killing of their young?

11. In the video they introduce the field of evolutionary psychology. One of these psychologists while talking about olfaction says that the smell is not in the molecule we smell but in the brain that does the smelling. What does he mean by this? Do you agree?

12. What is so unusual about the baby that the human couple has? Why do you think this is uncommon in the rest of the natural world?
Part II: Vertebrate Reproduction (Humans)  

Note: this may be assigned as homework

Overview:

Sexual reproduction (formation of gametes via meiosis & random fertilization) results in a huge amount of diversity in offspring. Evolution via the process of natural selection has favored this type of reproduction in most plants, fungi, protists and animals. In these exercises we will focus on the structure/function of sexual reproductive systems in human.

We will then see how the events of the menstrual (or uterine) cycle are controlled by events occurring in the ovary during the ovarian cycle. The process of development from fertilization of a human egg can take a single cell (the zygote) and through mitosis generate an incredibly complex individual organism - a human baby.

Exercise 1: Male Reproductive Anatomy

In this exercise, we will use models and pictures to help us understand the structures of the male reproductive system and how they relate to fertility. In particular, we will look at the organization and structure of the testis and the path that sperm travels from until it exits the penis.

Procedure:

1. Get a copy of an unlabeled diagram of the male and female reproductive system.

2. Go through the diagram with the model of male anatomy and fill in the labels of the following structures: epididymis, ejaculatory duct, penis, prostate, scrotum, seminal vesicle, testis, urethra, urinary bladder, vas deferens. (Include any completed figures into your lab manual).

3. Find the picture of the testes. Try to identify the tubes that are the site of sperm production and see if you can identify cells in the various phases of meiosis and sperm production.

Exercise 2: Female Reproductive Anatomy

In this exercise, we will use models and pictures to help us understand the structures of the female reproductive system and how they relate to fertility. In particular, we will look at the organization and structure of the ovary and see how ovary cells change as they prepare for ovulation. We will also examine the different structures responsible for taking care of the egg after ovulation.

Procedure:

1. Get a copy of an unlabeled diagram of the female reproductive system.

2. Go through the diagram with the model of female anatomy and fill in the labels of the following structures: cervix, clitoris, fallopian tube, labia, ovary, urethra, urinary bladder, uterus, vagina. (Include any completed figures into your lab manual).

3. Find the ovary picture and look for:

   a. Primordial follicles: small cells usually around the outer edge of the ovary.
b. **Maturing follicle:** the egg cell is developing and the follicle grows to include a fluid filled chamber; meiosis I finishes in the cell that will become the egg.

c. **Corpus luteum:** after releasing the secondary oocyte from the ovary, much of the follicle remains in the ovary releasing hormones.

**Exercise 3: Ovulation and Menstruation**

In this exercise, you will look at the cycling hormones that drive changes in the **ovary** and **uterus** that lead to **ovulation** and **menstruation**. As you will see, these changes effectively tie together events in the ovary and the uterus to ensure that both organs cycle together.

Figure 7 shows changes in body temperature and hormone levels during a woman’s menstrual cycle. Answer the following based on the figure.

**Figure 7.** Menstrual Cycle (FSH- Follicle Stimulating Hormone. LH- Luteinizing Hormone)
Questions:

1. Looking at the graphs, which hormones rise mostly before ovulation (day 14)?

2. Which hormone rises mostly after ovulation?

3. Imagine that you work for a company that produces fertility-testing devices. Your boss, who is not a biologist, says he wants to build a machine that measures hormone levels and can predict when a woman will be most fertile. He wants you to decide which hormone(s) (you can pick one or two) would be the best indicator that ovulation is coming. What do you tell him, and why?

4. For each of the following hormones, draw arrows to indicate how they affect each other. For stimulation use an arrow with a plus and for repression use an arrow with a minus.

   FSH  LH

   ESTROGEN  PROGESTERONE

5. Look at the bottom panel of figure 7. How do estrogen and progesterone affect the uterus?