# Mitosis, Meiosis and Fertilization -- Teacher Preparation Notes

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## Teaching Points[2]

- Each cell has DNA molecules which contain genes and are organized in chromosomes.
- 46 chromosomes = 23 pairs of homologous chromosomes in each human cell[3]
- For each pair of homologous chromosomes, both chromosomes contain the same genes which code for the same proteins and influence the same characteristics. However, the two copies of each gene may be different in the two homologous chromosomes (e.g. the alleles for normal vs. defective enzyme for producing melanin, resulting in normal skin color vs. albinism).

- There are two types of cell division, mitosis and meiosis. Cells are produced by mitosis (almost all cells), meiosis (sperm and eggs), or fertilization (zygote).
- Some similarities between mitosis and meiosis are:
  - Before mitosis or meiosis the DNA is replicated to form two copies of the original DNA.
  - At the beginning of mitosis or meiosis the replicated DNA is condensed into sister chromatids in each chromosome .
  - At the end of each cell division, cytokinesis forms two daughter cells.

- The purpose of mitosis is to produce new cells for growth, development and repair.
- Mitosis separates sister chromatids → complete sets of chromosomes at opposite ends of cell, so each daughter cell receives a complete set of chromosomes with exactly the same genes as the original cell.

- The purpose of meiosis is to produce haploid eggs and sperm (23 chromosomes in humans), so fertilization can produce a diploid zygote (fertilized egg with 46 chromosomes in humans).
- Meiosis consists of two cell divisions. Meiosis I separates pairs of homologous chromosomes and Meiosis II separates sister chromatids → 23 chromosomes in each egg or sperm.
- Different eggs or sperm from the same person have different genetic makeup.
- When a sperm fertilizes an egg, the resulting zygote receives one copy of each gene from the mother and one from the father. Thus, each person receives half of his/her genes from his/her mother and half from his/her father.
- Understanding meiosis and fertilization provides the basis for understanding genetics. (This idea is developed further in the next activity, "Genetics").

- If there is a mistake in meiosis and the zygote does not have exactly the correct number of chromosomes, this results in abnormalities such as Down Syndrome or, more frequently, death of the embryo.

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[1] These teacher preparation notes, the related student handout, and additional hands-on, minds-on biology activities are available at http://serendip.brynmawr.edu/sci_edu/waldron.

[2] Most of the information provided for humans applies to other animals, although chromosome numbers differ for different animals. There are significant differences for other eukaryotes and even greater differences for prokaryotes.

[3] There are a few exceptions (e.g. gametes, which are mentioned in the student handout, and red blood cells, which are not mentioned).

## Instructional Suggestions

Students should know what a cell is and understand basic information about the functions of DNA and proteins before beginning this activity. For this purpose, you may want to use "Understanding the Functions of Proteins and DNA" (available at http://serendip.brynmawr.edu/exchange/bioactivities/) which includes learning activities to help students understand the molecular and genetic basis of lactose intolerance, albinism, sickle cell anemia, and hemophilia. The introduction to the current mitosis, meiosis and fertilization activity discusses genes that influence sickle cell anemia, albinism, the ability to detect odors and one form of dwarfism, as well as the effect of having an extra chromosome 21 in each cell (Down Syndrome). You may want to use an introductory discussion of these conditions to motivate student interest in learning about mitosis and meiosis.

We recommend using one 50 minute class period to cover the introductory review of chromosomes and genes (pages 1-2 in the student handout) and the section on mitosis (pages 2-5, with an additional question on the top of page 6). After completing the introduction to mitosis (pages 2-4) and before beginning the mitosis modeling activity (page 5), we recommend showing two short videos available at http://iknow.net/cell_div_education.html. Specifically, we recommend that you first show "Plant Cell Mitosis" which has clear diagrams and then show "Live Animal Mitosis" which has good video of an actual cell undergoing mitosis with helpful explanations. These videos also demonstrate cytokinesis and how this differs between plant and animal cells.

We recommend using a second 50 minute class period for meiosis and fertilization (pages 6-11). During your discussion of questions 5 and 6 on pages 8-9 concerning the differences and similarities between mitosis and meiosis, you may want your students to view the animation comparing mitosis and meiosis available at http://www.pbs.org/wgbh/nova/baby/divide.html#.

Alternatively, you may want to use four class periods, with the first class period for the introductory section of the student handout (pages 1-2) and the additional introductory material suggested in the first paragraph of this section. Then, complete the section on mitosis (pages 2-6) in a second class period, the section on meiosis (pages 6-9) in a third class period, and the sections on meiosis and fertilization and Down syndrome (pages 9-11) in a fourth class period. Additional suggestions for an expanded learning sequence using this hands-on activity are provided in "Mitosis, Meiosis and Fertilization -- Concepts and Learning Activities", available at http://serendip.brynmawr.edu/exchange/bioactivities/.

This activity uses model chromosomes (see pages 3-6). Students should carry out the demonstrations with model chromosomes on a lab table or similar large flat surface, so they can more easily see the processes and outcomes. If students have difficulty recognizing which chromosomes are in the different cells at the end of mitosis or meiosis I or II, you may want to provide pieces of string or yarn for students to use as cell membranes.

To prevent student confusion, remind students to check the figures on page 3 or page 7 of the student handout as they model mitosis and meiosis, respectively. Also, in our experience, it is crucial to circulate among student groups continuously and provide considerable input.

We have focused our activity on understanding the processes of mitosis and meiosis and have limited technical terminology to the terms that are most important for understanding these processes. Students often have difficulty understanding the difference between chromosomes and chromatids, so we have made a special effort to clarify this distinction (e.g. on page 3 and question 3 on page 4). If you want to incorporate additional terminology, you can revise the

Word document for the student handout; for example, you can incorporate the names of the phases of mitosis in the questions on page 4.

Caution for Mac users: If you want to use the word version of the student handout, please check that the diagrams display properly, as shown in the PDF version.

Many students have difficulty understanding and distinguishing the concepts of DNA, genes and chromosomes. In this activity, almost all the student questions ask about the **A/a** and **D/d** alleles. We have included the **R** and **S** alleles on the model chromosomes with the **A/a** alleles to counteract the tendency for some students to assume that each chromosome has only a single gene. One analogy that may be helpful is to compare each gene to a recipe which gives instructions about how to combine the right components to make a protein (comparable to a recipe for a soup, salad or cake). Each chromosome has hundreds of these recipes for different proteins, so you could compare each chromosome to a chapter in a cookbook. All the chromosomes together are like a cookbook which provides recipes for all the different proteins our bodies need to make (or all the different dishes a person would want to cook). Different alleles of a gene produce different versions of the same protein, which is comparable to different versions of a recipe (e.g. brownie recipes with different numbers of eggs produce brownies with different textures). We think this analogy is useful, but you should be aware that the explanation of the effects of trisomy at the end of the protocol uses the analogy differently and treats the whole genome as one recipe.

If you would like to have a key with the answers to the questions in the student handout, please send a message to iwaldron@sas.upenn.edu.

## Preparing the Model Chromosomes

You will need 8 model chromosomes for each pair of student groups (2-4 students in each group) (see charts on pages 4 and 6). You can use sockosomes, chromonoodles **or** posterboard models. The sockosomes provide three-dimensional models that look like metaphase chromosomes in karyotypes and they are small enough for easy classroom use and storage. Sockosomes are relatively time-consuming to make, although this can be a good time investment if you will be using the sockosomes year after year. The chromonoodles provide three-dimensional model chromosomes that are relatively easy to make, but they are relatively large so each student group will need a relatively large surface to work on (>= 30" by 30", e.g. a lab table or desks pushed together). The posterboard models may be the easiest to make, but are not durable and not as engaging for students.

**Sockosomes**

**Supplies:**

--Small or medium children's crew socks (no more than half of any one color; even number of pairs of each color sock; eight pairs of socks for two groups of 2-4 students each (see chart on page 4); avoid black and dark blue socks typically found in packs of boys socks). To make the two different chromosomes different sizes, turn the cuffs of half of them down inside to make half the sockosomes smaller

-- Fiber fill

-- Self-stick squares or circles of hook-and-loop fasteners (Velcro); if you are making more than 36 sockosomes it may be more cost effective to purchase a roll of self-stick hook-and-loop tape and cut it into 1/2 " pieces.

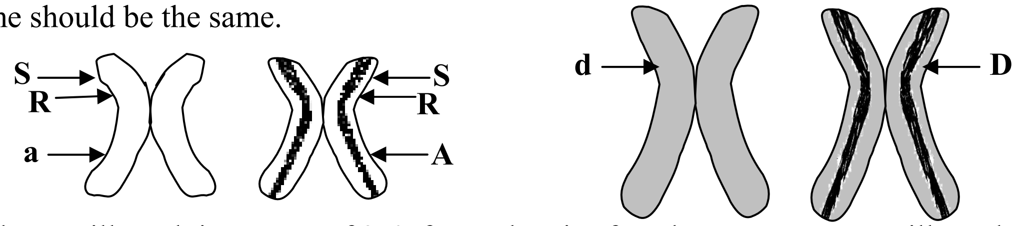
-- Needle and thread

-- 1" wide masking tape and permanent markers (e.g. Sharpies)

**Making the Sockosomes:**

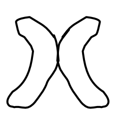
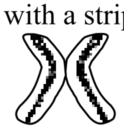
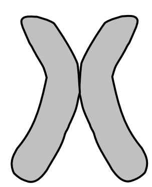
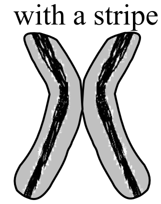
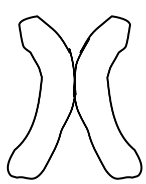
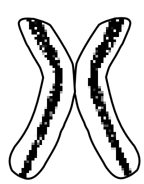
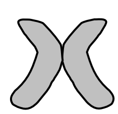
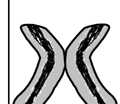
1. Attach and secure with staples or by sewing one part of a piece of self-stick hook-and-loop

tape (the fuzzy part) to the heel of one sock, and attach the other part (the part with hooks) to the heel of the other sock.
2. Fill each sock with fiber fill, and sew the end of each sock closed (sewing works much better than gluing for this step). This is the step at which you make half of each color shorter by folding the cuff down inside of the sock before stuffing.
3. Stick the socks together at the heels. You now have a chromosome with two chromatids, where each sock represents a chromatid. Note that a <u>sockosome refers to the pair of socks attached</u> by hook-and-loop tape, not the individual socks.
4. Pairs of homologous chromosomes will be represented by two sockosomes of the same color, one with a stripe marked along the length of each sock with a permanent marker (representing the potentially different alleles on the two homologous chromosomes). Add a ring of tape around each sock in each sockosome to represent an allele of each of the genes as shown and explained further below. The tape stays on best if it goes completely around the sock, overlapping at the ends. Obviously, for each gene the allele labeled on both socks in a single sockosome should be the same.




Your students will work in groups of 2-4; for each pair of student groups, you will need eight sockosomes (see the chart below). Get two pairs of homologous sockosomes which are the same size, but different colors, and label them with the alleles for skin pigmentation (**A** for pigmented skin or **a** for the albino allele) plus the **R** and **S** alleles (for normal hemoglobin and normal smell receptor protein). Then, get another two pairs of homologous sockosomes (both the same size, but different colors) and label them with the alleles for dwarfism versus normal height (**D** and **d**). The sockosomes with **A, R**, and **S** genes represent human chromosome 11. The sockosomes with the **D** gene represent human chromosome 4 (which is longer than chromosome 11). Therefore, if half of your socks are short and half long, then all of the short socks should be labeled with an **A** or **a**, **R** and **S**, and all of the long socks should be labeled with a **D** or **d**.

**Eight Sockosomes Needed for Two Groups of 2-4 Students Each**

| | | | | |
|---|---|---|---|---|
| **Mitosis & Meoisis Activities -- Group 1** | **a** (and **R, S**) sockosome in solid color 1  | **A** (and **R**, **S**) sockosome in solid color 1 but with a stripe  | **d** sockosome in solid color 2  | **D** sockosome in solid color 2 but with a stripe  |
| **Mitosis & Meoisis Activities -- Group 2** | **d** sockosome in solid color 3*  | **D** sockosome in solid color 3* but with a stripe  | **a** (and **R, S**) sockosome in solid color 4*  | **A** (and **R**, **S**) sockosome in solid color 4* but with a stripe  |

*Solid color 3 can be the same as solid color 1, and solid color 4 can be the same as solid color 2. The specific colors used can vary for different sets of sockosomes.

These same sockosomes can be used for these two groups of students to model meiosis followed by fertilization (in the activity on pages 9-10 of the student handout), but for this activity one group should have all the **a** and **A** sockosomes, and the other group should have all the **d** and **D** sockosomes. The pair of sockosomes in one color will represent the mother's chromosomes, and the pair of sockosomes in the other color will represent the father's chromosomes. The different colors for the mother's and father's sockosomes represent the fact that, although the labeled alleles are the same for the mother's and father's chromosomes, there are many genes on each chromosome and the mother's and father's chromosomes will have different alleles for many of these genes.

**Chromonoodles** (adapted from "Chromonoodles: Jump into the Gene Pool" by Farrar and Barnhart, The Science Teacher, Summer 2011, **78**:34-39

**Supplies:**

For two groups of 2-4 students each:

- -- 2 swim noodles (the smallest diameter available), two different colors (you will need 52" of each color)
  Note: You may need to purchase these swim noodles during the summer.
- -- 8" self-stick hook-and-loop tape (Velcro), cut into 1" pieces.

-- 1" wide masking tape

-- permanent marker (e.g. Sharpy)

**Making the Chromonoodles:**

To make 8 chromonoodles for two groups of 2-4 students each:

1. Cut each swim noodle into eight pieces, two pairs that are 8" long and two pairs that are 5" (using a utility or serrated kitchen knife or a band saw). For each pair of pieces, stick opposite sides of the hook-and-loop tape on the pieces of swim noodle (about one-third of the way from one end), so the two pieces of swim noodle can be attached as sister chromatids. You now have eight model chromosomes, each with two chromatids, where each piece of swim noodle represents a chromatid.

Note: A chromonoodle refers to the pair of swim noodle pieces attached by hook-and-loop tape, not the individual pieces.

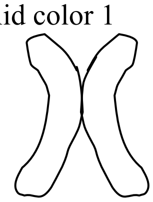
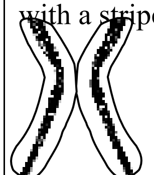
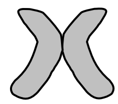
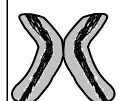
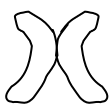
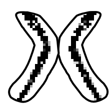
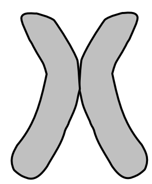
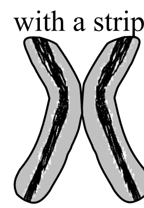
2. Pairs of homologous chromosomes are represented by two chromonoodles of the same color and length. For each pair of homologous chromosomes, use a permanent marker to make a long stripe down both chromatids of one of these chromosomes; this stripe will represent the differences in alleles from the other homologous chromosome.
3. Add a ring of tape around each noodle piece in each chromonoodle to represent an allele of each of the genes as shown in the figure below; the tape stays on best if it goes completely around the noodle, overlapping at the ends. Use the instructions below and on the next page to label the alleles.

```
        8" Chromonoodles                      5" Chromonoodles

 ___________________________________     ___________________
(___|S|_____|R|___________|a|_____)     (__________|d|____)
                   *                              *
 ___________________________________     ___________________
(___|S|_____|R|___________|a|_____)     (__________|d|____)


 ___________________________________     ___________________
(___|S|_____|R|___________|A|_____)     (__________|D|____)
                   *                              *
 ___________________________________     ___________________
(___|S|_____|R|___________|A|_____)     (__________|D|____)
```

Each * represents a hook-and-loop tape attachment in the centromere region.

Your students will work in groups of 2-4; for each pair of student groups, you will need eight chromonoodles (see the chart below). Get four 8" chromonoodles (one striped and one unstriped for color 1 and one striped and one unstriped for color 2) and use the figure on the previous page and the chart below to label them with the alleles for skin pigmentation (**A** for pigmented skin or **a** for the albino allele) plus the **R** and **S** alleles (for normal hemoglobin and normal smell receptor protein). Then, get four of the 5" chromonoodles and use the chart below to label them with the alleles for dwarfism versus normal height (**D** and **d**). (Note: The relative lengths of the chromonoodles are a matter of practical convenience and do not reflect the actual relative lengths of the shorter human chromosome 11 which has the **A, R**, and **S** genes and the longer chromosome 4 which has the **D** gene.)

**Eight Chromonoodles Needed for Two Groups of 2-4 Students Each** (The chromonoodles will not have the shapes shown here but will look more like the figure on the previous page.)

| | | | | |
|---|---|---|---|---|
| **Mitosis & Meoisis Activities -- Group 1** | **a** (and **R, S**) chromonoodle in solid color 1  | **A** (and **R**, **S**) chromonoodle in solid color 1 but with a stripe  | **d** chromonoodle in solid color 2  | **D** chromonoodle in solid color 2 but with a stripe  |
| **Mitosis & Meoisis Activities -- Group 2** | **d** chromonoodle in solid color 1  | **D** chromonoodle in solid color 1 but with a stripe  | **a** (and **R, S**) chromonoodle in solid color 2  | **A** (and **R**, **S**) chromonoodle in solid color 2 but with a stripe  |

These same chromonoodles can be used for these two groups of students to model meiosis followed by fertilization (in the activity on pages 9-10 of the student handout), but for this activity one group should have all the **a** and **A** chromonoodles, and the other group should have all the **d** and **D** chromonoodles. The pair of chromonoodles in one color will represent the mother's chromosomes, and the pair of chromonoodles in the other color will represent the father's chromosomes. The different colors for the mother's and father's chromonoodles represent the fact that, although the labeled alleles are the same for the mother's and father's chromosomes, there are many genes on each chromosome and the mother's and father's chromosomes will have different alleles for many of these genes.

**Posterboard models**: If you do not have the time and/or budget to prepare sockosomes or chromonoodles, you can use posterboard models of the chromosomes made from posterboard or card stock available from stationery stores. You can use the pattern on the last page of these Teacher Preparation Notes to cut out individual chromatids. To attach the sister chromatids, put poster tack on top of the centromere of one sister chromatid and then press the centromere of the other sister chromatid onto the poster tack. Follow the instructions for sockosomes beginning with step 4 on page 4 in order to make the right number of model chromosomes with the right labels for the activities.

## Background and Supplementary Information

The rate of cell replacement by mitosis varies for different circumstances and different types of cells. The rate of cell division and replacement is greater when an injury has occurred, and cells that are routinely exposed to injury (e.g. skin cells or epithelial cells that line the lumen of the stomach and small intestine) are replaced within days or a couple of weeks. In contrast, nerve cells and muscle cells can last a lifetime. Mammalian red blood cells are a special case since they have no nucleus or mitochondria (which maximizes the amount of hemoglobin and thus oxygen that each red blood cell transports); this is the primary reason that red blood cells only survive about four months. New red blood cells are produced by mitosis and differentiation of stem cells in the red bone marrow.

The Teacher Preparation Notes for our "Genetics" activity (available at http://serendip.brynmawr.edu/sci_edu/waldron/) provide additional information on sickle cell anemia, albinism and vitiligo (another condition in which lack of melanin pigment results in pale skin). Our activity, "From Gene to Protein -- Transcription and Translation" (available at http://serendip.brynmawr.edu/sci_edu/waldron/) provides additional information on sickle cell hemoglobin and sickle cell anemia. For additional information on the inherited conditions discussed in this activity, search OMIM (Online Mendelian Inheritance in Man, http://www.ncbi.nlm.nih.gov/omim/) for 603903 (sickle cell anemia), 606952 (albinism) or 100800 (achondroplasia dwarfism).

(Continued on next page)

Down syndrome (trisomy 21) is genetic, but usually not inherited since it is often caused by meiotic non-disjunction, typically in the formation of an egg. The conditions listed in the table below are also genetic, but not inherited.

Mistakes in Mitosis, Meiosis and Fertilization - What are the effects on human reproduction?

| **Mistake** | **Results in** | **E.g.** | **Pregnancy outcome** | **Outcome after birth** |
|---|---|---|---|---|
| Fertilization by more than one sperm | Polyploidy | Triploidy | Almost always fatal in utero; -- > ~15% of miscarriages | Fatal within a month |
| | | Tetraploidy | Fatal in utero; -- > ~5% of miscarriages | |
| Meiotic non-disjunction | Aneuploidy | Autosomal trisomy | Generally fatal in utero, but trisomy 8, 13 and 18 sometimes survive until birth and trisomy 21 can survive into adulthood; trisomies -- > ~1/3 of miscarriages | Trisomy 8, 13 or 18 severely disabled and do not survive to adulthood; trisomy 21 can survive to adulthood, although heart defects and leukemia relatively common; degree of mental retardation variable |
| | | 45XO = Turner syndrome | 99% die in utero; but only viable monosomy* | Infertile, normal IQ |
| | | 47XXY = Kleinfelter syndrome | Majority die in utero, but some survive into adulthood* | Very low fertility and learning disabilities common |
| Mitotic non-disjunction | If occurs very early in embryonic development, can result in polyploidy or aneuploidy or mosaic | Kleinfelter syndrome mosaic can have similar symptoms, but some cells have normal chromosome makeup | | |

Primary source: Michael Cummings, 2006, Human Heredity

*In each cell all but one X chromosome is inactivated, so variation in the number of X chromosomes does not produce as severe abnormalities. (A small part of each X chromosome is not inactivated, which explains why abnormal numbers of X chromosomes result in some abnormalities.)

## Additional, Alternative and Supplementary Activities

We recommend that this activity be followed by our **Genetics** activity (available at http://serendip.brynmawr.edu/sci_edu/waldron/), so your students will develop a better understanding of how meiosis and fertilization provide the basis for understanding inheritance. This concept is developed in both "Section IV - Analyzing Meiosis and Fertilization to Understand Genetics" (pages 9-10 in the student handout for this Mitosis, Meiosis and Fertilization activity) and "Inheritance of Albinism" (pages 1-2 in the student handout for the Genetics activity). The Inheritance of Albinism version uses model chromosomes to demonstrate how meiosis and fertilization provide the basis for understanding Punnett squares. These two sections provide useful reinforcement, unless the Mitosis, Meiosis and Fertilization activity is followed immediately by the Genetics activity, in which case you may want to omit Section IV of the Mitosis, Meiosis and Fertilization activity.

A mitosis and meiosis card sort activity to reinforce understanding of the processes of mitosis and meiosis and a mitosis, meiosis and fertilization taboo game to reinforce learning of relevant vocabulary are both available at http://serendip.brynmawr.edu/exchange/bioactivities/.

"Chromonoodles: Jump into the Gene Pool" by Farrar and Barnhart, The Science Teacher, Summer 2011, **78**:34-39 presents an informative series of activities using chromonoodles to demonstrate fertilization, the cell cycle, meiosis, karyotyping and genetics concepts, including Punnett squares. These activities are whole class demonstrations, in contrast to the more structured modeling activities for small groups of students presented in our student handout.

One of the major simplifications in the current hands-on activity is that our simulation of meiosis ignores crossing over which contributes greatly to genetic diversity. Sockosomes or chromonoodles can be modified so they can be used to model crossing over and recombination. For example, using a larger pair of socks, cut off a portion of the top of the sock to be stuffed and sewed close separately. The top portion can then be reattached with Velcro, allowing it to be removed and swapped with the top portion of another sock. This can be particularly useful for teacher demonstrations.

The current hands-on activity discusses how DNA is replicated and condensed in preparation for mitosis, but these processes are not included in our simulation. One way to help students understand the process of DNA replication is to use our hands-on activity, "DNA", available at http://serendip.brynmawr.edu/sci_edu/waldron/. The possible supplementary activity described on page 10 of these notes can be inserted on page 2 of the student handout to help reinforce the need for condensing the chromosome at the beginning of mitosis, as well as the concept of homologous chromosomes.

Additional videos you may find useful include:

- Videophotography of dividing cells:
  - http://www.youtube.com/watch?v=s1ylUTbXyWU
  - http://www.dnatube.com/video/328/Mitosis
- Animation: http://www.youtube.com/watch?v=VlN7K1-9QB0
- Videotape: "Cell Division: Mitosis and Cytokinesis" which provides an excellent overview; available for purchase from http://www.cytographics.com/.

Possible Supplementary Activity

Prose for Student Handout:
As you probably know, most of the time, chromosomes are contained inside the nucleus in a cell. Chromosomes are very long and thin, much longer than the diameter of a nucleus. To mimic this real-life situation inside a cell, you will be given four long pieces of thread to represent two pairs of homologous chromosomes. Only a few of the genes on these chromosomes will be labeled. Use a piece of paper to represent a cell and draw a nucleus inside the cell. Pile your four pieces of thread inside the nucleus.

Separate the thread into the two pairs of homologous chromosomes. To keep the chromosomes inside the cell, keep the pieces of thread on the paper while you do this.

How can you tell which chromosomes are homologous and which chromosomes are not homologous?

Did you have any problems while you were trying to sort out the chromosomes on the piece of paper which represents the cell?

Next, wrap each piece of thread around a piece of straw, put these on the nucleus, and separate them into two pairs of homologous chromosomes (while keeping them on the paper).

Was it easier to sort out the pairs of homologous chromosomes after you wrapped them around the pieces of straw?

Before a cell divides, the DNA molecules in each chromosome are wound tightly, similar to winding the thread around the piece of straw. This makes it easier to separate the two copies of each chromosome as the cell divides.

Supplies needed for each pair of students for this activity**:**
-- 4 long pieces of thread (24" for the first two chromosomes shown below and 36" for the second two chromosomes shown below; all the same color)
-- masking tape to label each piece of thread with alleles as shown below (the labels should be small and the alleles should be written on both sides):

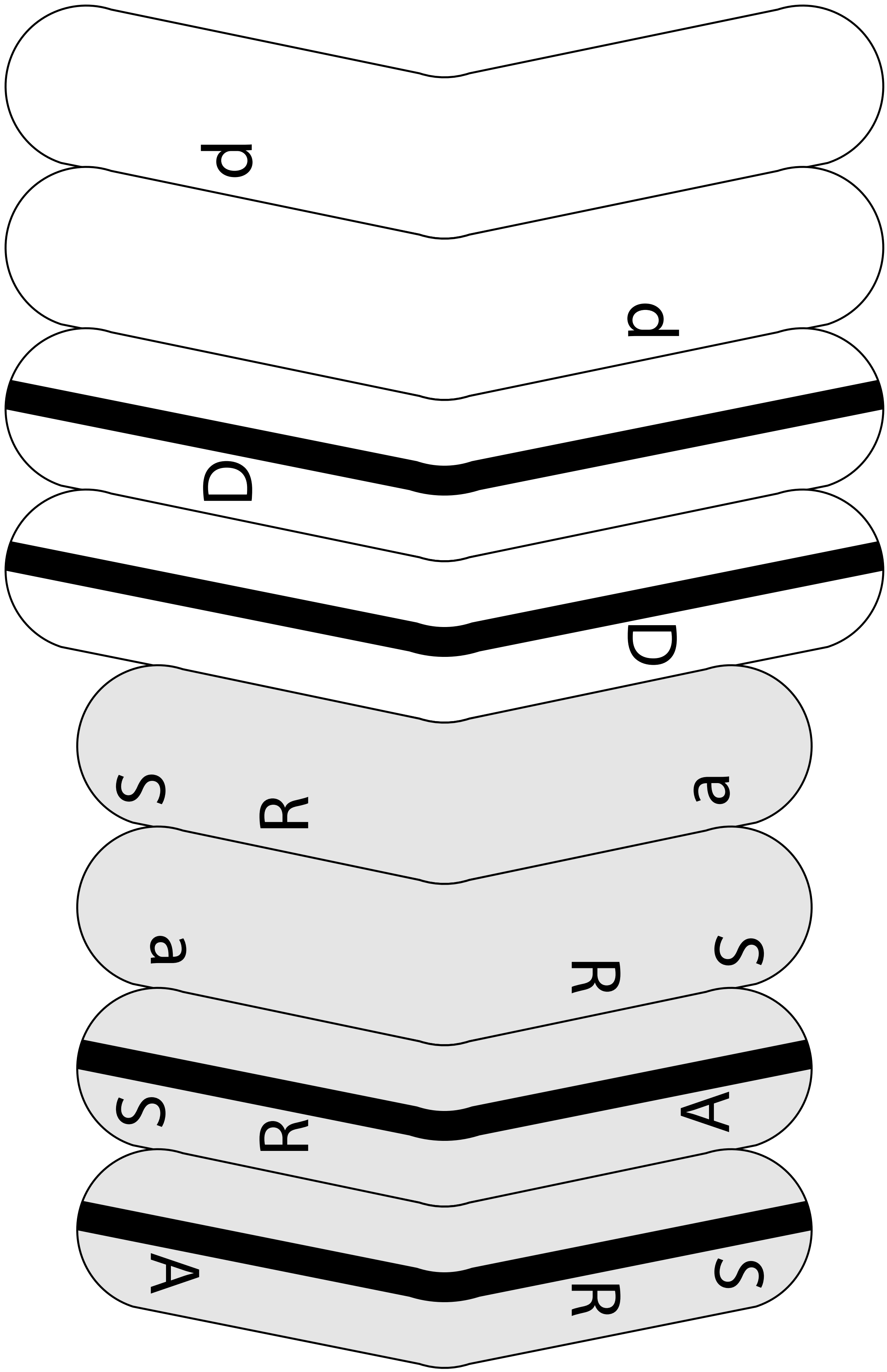
_____S___r___________________________a___________________

_____s___R___________________________A___________________

______d____________________________________________________________________

______D____________________________________________________________________

-- piece of 8 1/2 x 11" paper
-- short pieces of plastic straw to roll the thread around for the second part of the activity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