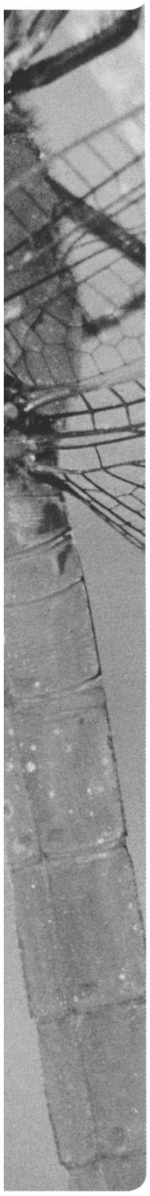
HOW-TO-DO-IT



USING "Chromosomal Socks"

To Demonstrate Ploidy in Mitosis & Meiosis

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Today, many biology instructors use visual models to help students understand abstract concepts like cell division. Available cell division chromosome models now come in many varieties. A simple string and paper game can demonstrate the stages of meiosis as well as the effects of crossing over, breakage, and recombination (Stencel, 1995). Instructors may also choose to make chromosomes represented by wooden blocks (Pashley, 1994), pin-boards (Gow & Nicholl, 1988), yarn and chenille stems (Clark & Mathis, 2000), pieces of ribbon (Levy & Benner, 1995), and wooden clothes pegs (Coleman, 1986). Among the more creative innovations, "pizza chromosomes" are actual pizza recipes that illustrate syngamy, crossing over, gene expression, and ploidy (Rindos & Atkinson, 1990). Alternatively, "dragon chromosomes" are slips of paper labeled with imaginary dragon genotypes (fire/non-fire breathing, red/yellow wings, two/three toes, etc.) that aid in simulating meiosis and its role in genetic variation (Harrell, 2001). Probably the most straightforward illustrations of mitosis and meiosis are hand models. Used mainly for introductory purposes, these handy models manipulate the fingers and hands to imitate chromosomal behavior during cell division (Mickle, 1990; Ward, 1988).

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For all biology instructors, dealing with student misconceptions of cell division may seem hopeless at times–even after using visual models. Smith (1991) asks a frustrating question that most instructors can identify with: "If students have 'studied' cell division repeatedly, why do they continue to have difficulties with it?" Although student errors in cell division are built around the three key events of cell division (i.e., chromosome doubling, pairing, and separating) (Smith, 1991), no panacea exists to relieve biology instructors of the recurrent learning patterns that seem to afflict students year after year. Therefore, each type of misconception must be treated separately to effectively resolve student misunderstanding. Taking advantage of models carefully designed to address specific misconceptions is an excellent means to achieve this goal.

Confusing ploidy with chromosome structure is recognized as a common misconception of mitosis and meiosis (Kindfield, 1991). Some students mistakenly equate haploid cells with unreplicated chromosomes (or single double-stranded DNA molecules) and diploid cells with replicated chromosomes (or two double-stranded DNA molecules). Clark and Mathis (2000) point out that, essentially, "students struggle to distinguish between chromatids, chromosomes and homologous pairs of chromosomes." To help students gain a meaningful understanding of ploidy, we have developed a quick, straightforward activity using colorful pairs of socks to represent chromosomes during cell division. Expanding on Oakley's (1994) sweat sock chromosome model, our activity focuses on karyotype formation from scattered arrays of "chromosomal socks" and on ploidy differences in body cells and gametes (diploid vs. haploid) rather than on the various individual stages of mitosis or meiosis. In addition, Stavroulakis (2005) uses socks to represent chromosomes during cell division.

Materials

We built our "chromosomal socks" model using simple, inexpensive components. We gathered six pairs of colorful socks used by infants, toddlers, elementary school children, teenagers, and adults so that the various pairs would be noticeably different in size, color, and markings. These socks represent autosomal chromosomes. We used one large solid red sock and one solid blue sock to represent the X (red) and the Y (blue) sex chromosomes. Near the open end of each sock, we attached a one-inch square of Velcro® (the "looped" part) by securely stapling it to the sock. To keep the socks lying flat, we inserted within each sock a piece of cardboard cut to shape. Next, from a local crafts store we purchased two cardboard "presentation boards" of the type used in science fairs to mount displays. These sturdy boards are 24" wide x 36" tall when folded and 48" wide x 36" tall when unfolded. On the larger area (24" x 36" portion) of one board, we laid out the 14 socks in a random pattern to simulate chromosomes during interphase of the cell cycle and securely stapled one-inch squares of Velcro® (the "hooked" part) in the appropriate positions on the board to hold the chromosomal socks in place (Figure 1). We refer to this board as the "interphase presentation board."

Figure 1. Presentation board showing a random arrangement of "chromosomal socks" in a diploid cell with 14 chromosomes.

Figure 2. Presentation board showing the 14 chromosomes arranged as a karyotype with six pairs of autosomes in decreasing size and an XY pair of sex chromosomes on the right.

Figure 3. A student placing the longest pair of autosomes, represented by "chromosomal socks" onto the karyotype presentation board.

On the other presentation board, we paired up similar socks and lined up the six autosomal pairs within three rows, proceeding from the longest pair to the shortest pair within each row to simulate a karyotype diagram. On one of the side panels, we placed the red X and the blue Y socks. Then we attached one-inch squares of Velcro® (the "hooked" part) in the appropriate positions on the board to secure the socks in place (Figure 2). We refer to this board as the "karyotype presentation board."

How We Use These Materials

At the beginning of the unit on Mitosis and Meiosis, we begin with a section called "General Observations About Chromosomes." We ask our students to play the roles of young scientists who are observing chromosomes during cell division for the first time. As they observe more and more cells, they should begin to notice three general patterns in chromosome number and pairing:

1. Within a species, the number of chromosomes in the body cells of each normal individual is identical. For example, each somatic cell of a chimpanzee would contain 48 chromosomes.

2. Based on size and shape, each type of chromosome is present in two doses in each body cell. Thus, the 48 chromosomes of a chimpanzee could be arranged into 24 similar pairs, called "homologous pairs" due to their physical similarities. However, one pair is not homologous in the body cells of males, because one chromosome is larger (the X) and the other is smaller (the Y). These are the sex chromosomes. At this point, we mention that the body cells of females would have two X chromosomes instead of the XY pair. Thus, body cells are said to be diploid since they contain two sets of 24 chromosomes.

3. If the chromosomes of sex cells are observed, sperm and eggs contain half the number of chromosomes found in body cells, just 24 chromosomes for chimpanzee gametes. Upon observation, just one chromosome from each of the 24 pairs seen in body cells is present in sex cells. Thus, sex cells are said to be haploid or monoploid since they contain half the diploid number of chromosomes, which represent one set of 24 chromosomes.

To visualize these concepts, we use common objects within the student's everyday experience as analogies for pairs of chromosomes, namely pairs of socks. First, we show them the interphase presentation board with the socks randomly arranged (Figure 1). We ask them to notice the different patterns and colors in the socks and explain that scientists have developed ways to get real chromosomes to show different "banding patterns" and colors using various chemicals (Giemsa staining and fluorescent dyes, respectively). Then, we open up the empty karyotype presentation board and call for student volunteers to each pick out the largest remaining pair of socks and place them onto the karyotype board (Figure 3). Finally, the last volunteer takes the sex chromosomes and places them into the karyotype (Figure 2). We point out that the completed karyotype represents the chromosomes from a diploid cell, symbolized 2n because it contains two sets of chromosomes, which are paired up within the karyotype.

Next, we ask students how to convert this diploid karyotype into one containing chromosomes from a haploid/monoploid sex cell. When a student correctly states that a haploid karyotype would have one chromosome from each pair, the student demonstrates this concept by removing one chromosome (randomly, either the left or the right one) from each pair (Figure 4). Regarding the sex chromosome pair, students realize that males can make two types of sperm, bearing either the X or Y chromosome.

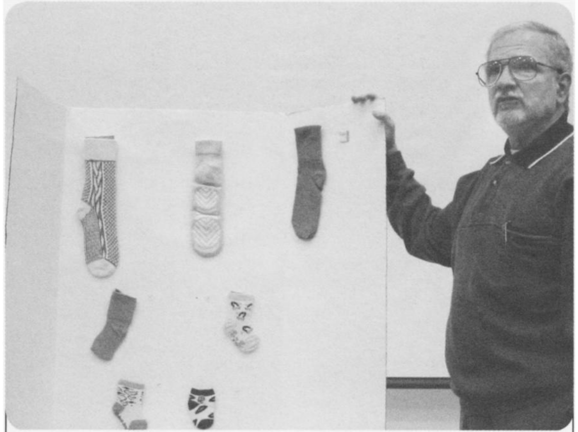

Figure 4. A teacher standing next to the karyotype presentation board showing one set of chromosomes that might be found in a haploid/ monoploid sperm cell from an organism with seven pairs of chromosomes in its somatic cells.

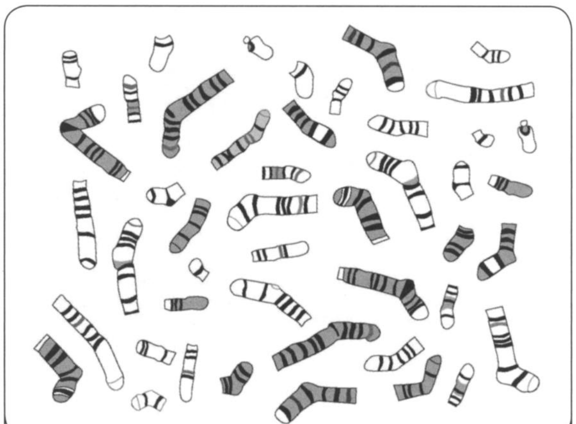

Figure 5. A "chromosomal socks" spread from a diploid cell with 46 chromosomes from a male individual, using humans as a model.

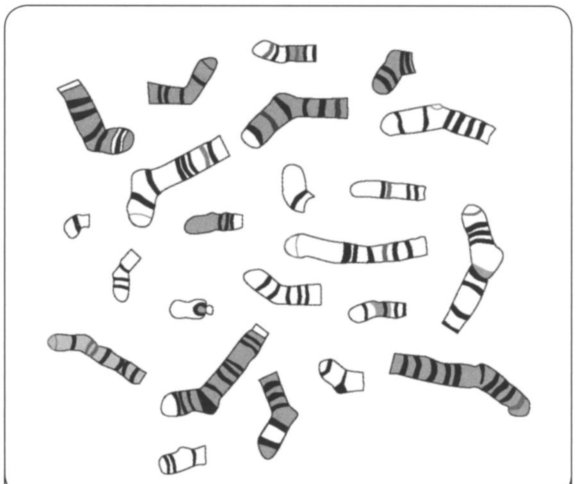

Figure 6. A "chromosomal socks" spread from a haploid cell with 23 chromosomes from a sperm cell, using humans as a model.

A Karyotyping Exercise Using Virtual Chromosomal Socks

Based on the human chromosome number of 2n = 46, Figures 5 and 6 are computer-generated images of scatter diagrams of chromosomal socks from a diploid (2n = 46, Figure 5) and a haploid (n = 23, Figure 6) cell. The corresponding karyotypes made from these chromosome spreads are found in Figures 7 (diploid) and 8 (haploid). Instructors may desire to have their students use the scatter diagrams to generate karyotypes by cutting out the chromosomes and pasting them onto a karyotype form. Electronic color versions of Figures 5-8 for use as teaching tools are available upon request by e-mailing the author at jpchinni@vcu.edu.

Brief Comments

One author has used the chromosomal socks exercise to introduce ploidy to non-science students in his BIOL 102 (Science of Heredity) general education course at Virginia Commonwealth University for the past five years with great success. On their anonymous written course evaluations each semester, BIOL

102 students comment that the chromosomal socks are very helpful in understanding and remembering the distinction between diploidy and haploidy and the relationship between the chromosomes in a diploid cell (23 pairs of chromosomes for humans) and a haploid cell (23 chromosomes, one from each pair, for humans). We recommend this exercise to high school teachers and would not be surprised if middle school teachers find that this is an effective teaching tool as well.

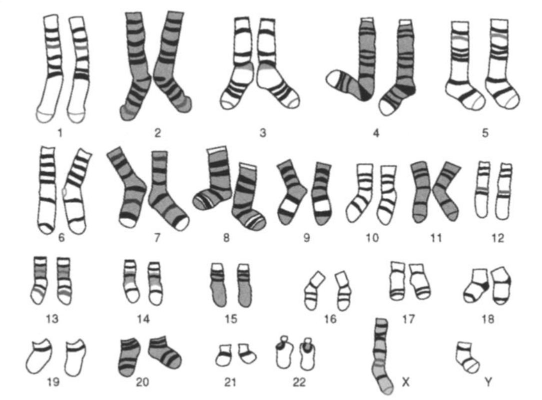

Figure 7. A "chromosomal socks" karyotype prepared from the diploid chromosomes in Figure 5, using humans as a model.

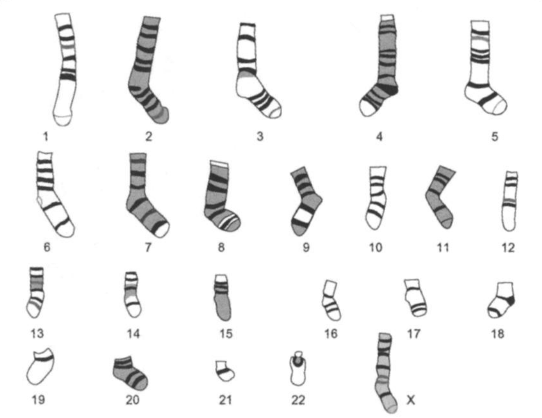

Figure 8. A "chromosomal socks" karyotype prepared from the haploid chromosomes in Figure 6, using humans as a model.

Acknowledgments

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