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Genetics Education Note

Innovations in Teaching and Learning Genetics

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Using Pool Noodles to Teach Mitosis and Meiosis

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ABSTRACT

Although mitosis and meiosis are fundamental to understanding genetics, students often find them difficult to learn. We suggest using common "pool noodles" as teaching aids to represent chromatids in classroom demonstrations. Students use these noodles to demonstrate the processes of synapsis, segregation, and recombination. Student feedback has been overwhelmingly positive.

LEARNING the biological processes of mitosis and meiosis (M&M) is fundamental to understanding transmission genetics and molecular biology. The basics are often taught using simple, monochromatic diagrams, with the chromosomes and chromatids being shown as one-dimensional lines. To the beginner, the similarity of these lines often confuses and fails to impart the needed understanding of the similarities and differences between and among DNA strands, chromatids, chromosomes, and homologs. Computer animations have added movement but some students still fail to learn because watching a screen is a passive process. In introductory university courses, many students are bored with reviewing M&M. They believe they learned these concepts in high school, but exam performance clearly shows the contrary. In our second-year Introductory Genetics course (~200 students), the use of pool noodles to represent chromosomes/chromatids during M&M offers an active, exciting demonstration that will engage students and allow them to identify and correct previous misunderstandings and appreciate the more subtle concepts of M&M. We have found that this exercise engages the students (it is very different from previous approaches), requires active participation (active learning), and requires that they think about the process of M&M in a four-dimensional sense (3D plus time). They need to "become" a chromosome/chromatid to participate in the exercise.

Pool noodles are ~4- to 6-ft-long, ~4- to 6-in.-diameter, flexible, foam rods that can be found in most retail stores that sell beach or pool toys or equipment. A typical classroom demonstration or "chromosome dance" requires eight students holding pool noodles to represent eight chromatids or two pairs of replicated homologous chromosomes, forming a "hypothetical diploid cell" with $2n = 4$. We use noodles of identical size to show homologous chromosomes, different colors to differentiate homologs, and identically colored noodles to represent sister chromatids (Figure 1a). The two pairs of homologs consist of a long pair (pink maternal and green paternal) and a short pair (purple maternal and blue paternal). The location of the centromere (where the students grip their pool noodles) can also differ between the chromosomes to demonstrate telo-, acro-, and metacentric positions and thus further differentiate the chromosomes.

We start the exercise at the G_1 phase of the cell cycle, where each of four chromosomes is represented by a single noodle held by one person. We describe the maternal and paternal contributions to the diploid cell by reminding the students of the origin of a diploid cell and the process of syngamy that follows fertilization. To further reinforce the concept of homologs, maternal chromosomes are held by female students, paternal chromosomes by male students. The diploid G_1 cell then goes through S phase and each chromosome is replicated by adding four additional students; now each chromosome has two sister chromatids and is represented by two identically colored noodles held together at the centromere by a pair of students. Thus, it takes a group of four students (two male, two female) to act

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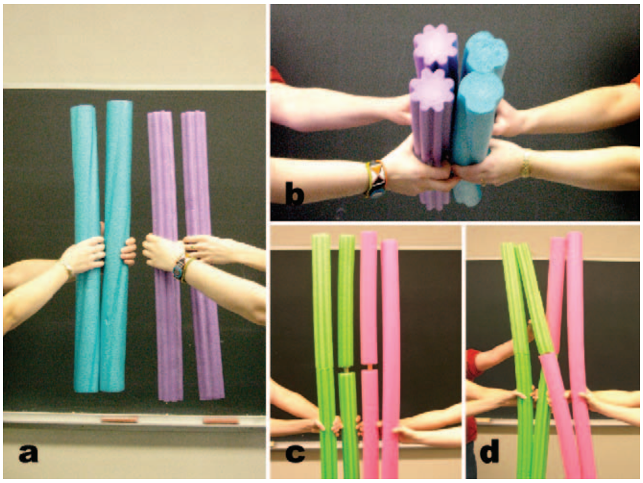

Figure 1.—Pool noodles represent chromatids in the classroom. (a) Noodles representing a pair of synapsed, homologous, metacentric chromosomes, each with two chromatids. The hands of the four students represent the two centromeres. The background is a blackboard. (b) An end-on view of noodles representing a synapsed pair of homologous chromosomes representing the 3-D arrangement of the four chromatids. (c) Pool noodles with a central wooden dowel holding two pieces together. A breakage event between non-sister chromatids is represented and their rejoining leads to a crossover. Here, longer noodles (chromatids) are more convenient to demonstrate the processes of crossing over. (d) The result of a crossover event showing a chiasma between the synapsed noodles.

as a pair of homologous chromosomes during M&M, one student for each of the four chromatids. This reinforces the origin, structure, and function of sister chromatids.

For mitosis, the students will have to organize their noodles on a single metaphase plate, which you can organize for them by positioning imaginary spindle poles at opposing sides of the classroom. The students will spontaneously create a metaphase plate where the pairs of noodles line up. Then as metaphase proceeds into anaphase the noodles will segregate, with one noodle and student going to each pole, into the two genetically identical daughter cells.

For meiosis, after chromosome replication, the cell (a meiocyte) will enter prophase I and the homologous chromosomes (pairs of noodles) will synapse. This can be demonstrated by the pairing up of noodles of the same size (homologs), bringing the four sets of hands (centromeres) together. This is a particularly useful time to demonstrate the 3-D structure of the bivalent (Figure 1b), which shows synapsis. Remember to discuss or show (see below) crossing over.

At metaphase I the two homologs (four students with synapsed noodles) on the metaphase plate show segregation of chromosomes in anaphase I (reductional division—Mendel's first law). By altering the orientation of the two synapsed chromosomes, the independent assortment of two pairs of homologous chromosomes can be easily demonstrated as well (Mendel's second law). In meiosis II, the segregation of individual noodles/students as sister chromatids (equational division) can be shown. The process can be "rewound" to compare reductional *vs.* equational divisions and to compare the different orientations of independent assortment. The different allele combinations can be followed with the use of paternal and maternal alleles. The process can proceed slowly so that comments can be made or questions asked. Student errors can be examined and corrected. For example, nondisjunction at either stage leads to aneuploidy. You can reinforce the concept that these same mistakes sometimes occur in nature.

The process of crossing over can be demonstrated by using two sections (long and short) of a noodle that are connected by a short dowel to reconstitute the intact-appearing noodle (Figure 1c). When chromosomes are synapsed, the instructor can exchange the ends between different-colored noodles (non-sister chromatids) to show crossing over and produce a chiasma (Figure 1d).

We have no difficulty getting students to volunteer for a "chromosome dance." Of 48 written student teaching evaluations that gave unsolicited comments on this demonstration held 1 month previously, 46 suggest that the pool noodles are a useful teaching tool. For example: "*The demonstrations using the pool noodles for mitosis/meiosis were particularly effective…*" and " . . . *as silly as the meiosis dance was, it was really helpful.*" For undergraduates, manipulating pool noodle chromosomes/chromatids provides an active teaching/learning tool for understanding basic Mendelian genetics, the foundation from which molecular genetics can grow.

We thank the many undergraduate students who have participated in our chromosome dances and the teaching assistants who have provided suggestions along the way and who modeled the noodles/chromatids in our photos.