Demonstrating Mitosis and Meiosis

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AN UNDERSTANDING OF chromosome behavior in meiosis can serve as the basis for subsequent learning of the Mendelian principles of segregation and independent assortment. As Mertens (1971a) has observed, "Teaching meiosis first results in Mendelism's being less abstract—much less a matter of pure probability and mathematical theory."

Our experiences in teaching both high school and college students indicate that many students confuse mitosis and meiosis due to similarities between the processes. Many students also become overburdened with the terminology and descriptions of the various phases. Their confusion prevents them from realizing the positive effects that can result when a comprehension of meiosis is used as a foundation for understanding Mendelian genetics. In this paper we will describe a model that helps students distinguish the major similarities and differences between mitosis and meiosis. The model has been used successfully in the introductory plant and animal genetics laboratory exercises at Cornell University.

Description of the Model

The components of the model are poppet beads of two colors, clay of two colors, and posterboard. The idea of using a poppet bead model is not new; however, because poppet beads are difficult to procure, such models are seldom used. A major objection to the model has been the difficulty of illustrating the centromere as a doublet (Borden 1973). We feel that this objection to the model can be overcome by using modeling clay for centromeres.

Chromosomes of different lengths can easily be constructed from the ball-and-socket type poppet beads. We choose to use one pair of long and one pair of short beads to represent chromosomes. The color of the beads and clay denotes whether chromosomes and centromeres are of maternal or paternal origin. The only assembly required is popping the beads together to make the desired chromosome lengths, molding the clay into centromeres, and drawing spindle fibers on the posterboard. The clay centromeres are formed by rolling the clay into a ball, placing the ball of clay between two beads at the desired location in the chromosome, and then popping the beads together into the clay. The clay surrounds the beads and serves as a sticky surface to hold the chromatids together. The clay is molded so that one side protudes. This permits students to observe the orientation of the centromeres at mitotic and meiotic anaphases.

The poppet beads can be obtained from Parco Scientific Co., P.O. Box 595, Vienna, Ohio 44473. In December 1975, the cost of 500 grams of beads (two colors) was only ten dollars. This included enough beads to make at least ten models of the size we use. Certain link-type beads can be substituted for poppet beads. Link-type beads have the advantage of greater flexibility than the poppet beads, which permits the instructor to more easily demonstrate chromosome shapes at anaphase. We have found link-type beads, type A1 from Creative Playtime, 26 LaSalle Rd., West Hartford, Conn. 06107, suitable for our purpose. The cost of these beads is approximately $4 for a container containing several colors of beads of sufficient quantity to make several models. Modeling clay of at least two colors and posterboard can be obtained at little cost from numerous sources.

Use of the Model

The model can be used by small groups of 5–10 students or by individual students. Our method is to introduce the model to small groups and later ask each student to demonstrate the model to the instructor. The size of the model permits all individuals of the small group to easily observe the instructor as he manipulates the chromosomes. In demonstrating the model, we concentrate on chromosome behavior. While the model

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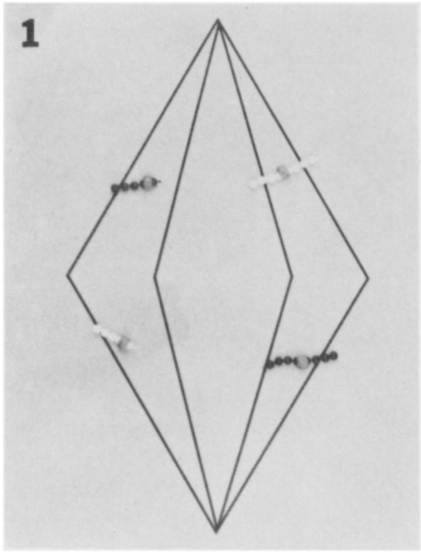
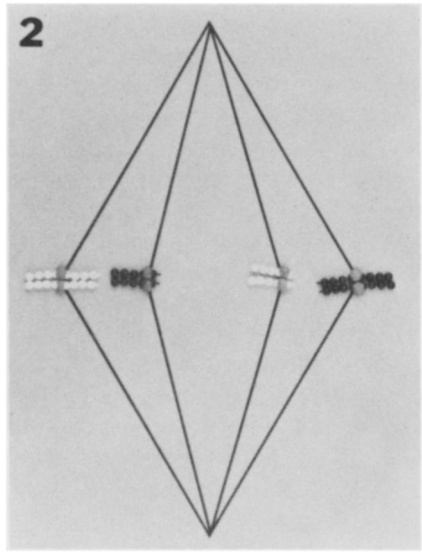
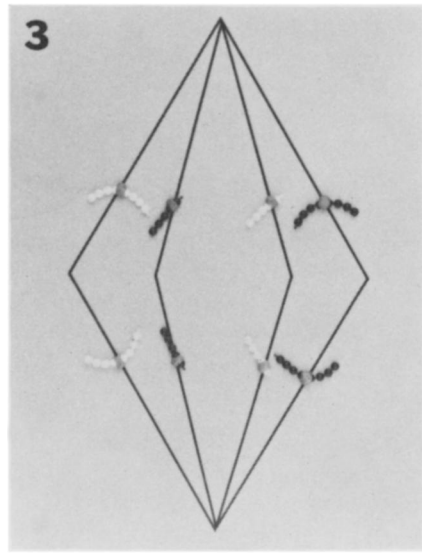
Fig. 1-6. Use of a poppet bead model to illustrate selected stages of mitosis and meiosis.



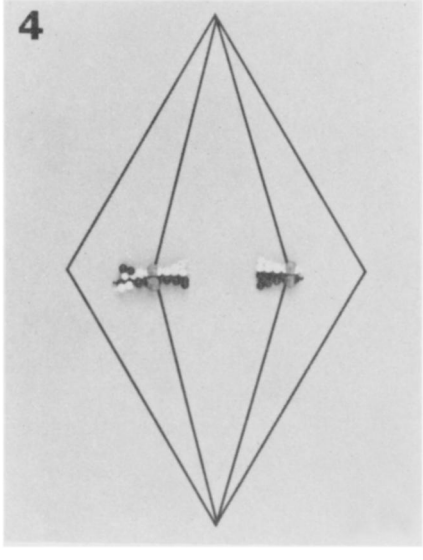
1. Mitotic interphase before DNA replication.



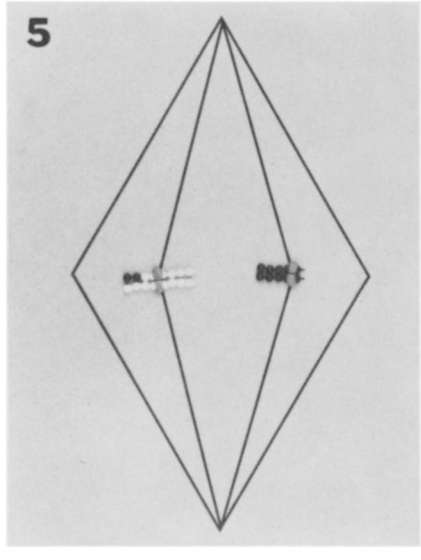
2. Mitotic metaphase.



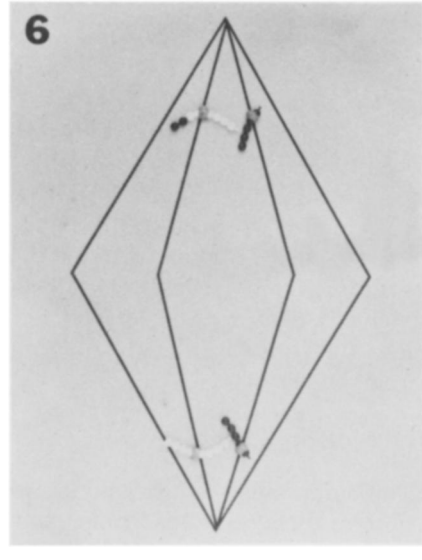
3. Mitotic anaphase.



4. Meiotic metaphase I.



5. Meiotic metaphase II.



6. Meiotic telophase II.

is being demonstrated to one group, the other groups of students are preparing their own slides of mitosis and meiosis and observing prepared slides and visuals. Students are encouraged to ask questions at any point, and the instructor can stop at any time to indicate distinguishing features of a particular stage as well as to compare and contrast mitosis and meiosis. The amount of detailed information included depends on the group of students. The same model can be successfully used at both high school and college levels by adjusting for cognitive differences between students.

Mitosis:

The instructor begins with the model at mitotic interphase before replication has occurred (fig. 1). Replication of chromosomes is demonstrated by adding an extra strand of beads with its clay centromere to the beads already present in the model. Students are asked to keep count of the number of chromosomes, chromatids, and amount of genetic information at each stage. For example, after chromosomal replication they will determine that although the amount of information has doubled (2c→4c), the number of chromosomes has not been changed. The "c-value" indicates the amount of DNA at various stages of the cell cycle. The amount of DNA in the gametes is used as the base amount, that is, 1c (Wolfe 1972). At this point the instructor can ask the students to distinguish between the chromatids and chromosomes. Concepts of homology and diploidy can also be introduced. Students can readily distinguish the homologous pairs by their

lengths and centromere positions. Fig. 2 depicts the individual alignment of the chromosomes at mitotic metaphase.

Students observe the characteristic shape of the chromosomes as they are led to the poles by the centromeres at anaphase (fig. 3). By counting the number of strands and chromosomes in the daughter cells formed in late telophase, students can determine that daughter cells contain the same amount of information as did the mother cell before DNA replication. Although chromosome number has remained constant, informational content has gone from 2c→4c→2c. Since the daughter cells contain the same kinds of chromosomes that were present in the mother cell, they are also qualitatively the same. The colored beads accentuate this qualitative identity of mother and daughter cells.

Meiosis I:

Next, the instructor illustrates meiosis at interphase prior to replication. The chromosomes are replicated as in mitosis and the similarities between mitosis and meiosis up to this point are mentioned.

Prophase—Crossing-Over. In meiotic I prophase, homologous pairing can easily be demonstrated by pairing the homologues to form tetrads, which have a DNA value of 4c. Crossing-over can then be demonstrated by exchanging the colored beads from one chromatid with beads of the other color present in the nonsister chromatid. The resultant recombinant chromatids consist of two colors. The importance of homologous pairing and the consequent segregation of homologues can easily be demonstrated by aligning the chromosomes so that the homologues are *not* paired at the metaphase plate. The students can then postulate what would happen if pairing failed to occur.

Metaphase. Since the chromosomes are easily manipulated, the difference between chromosome alignment at mitotic metaphase (fig. 2) and meiotic metaphase I (fig. 4) can be depicted by arranging the chromosomes as they would appear at metaphase in each process. The role of independent assortment in rearranging the genetic information into gametes can be demonstrated by lining up the homologues in the various combinations. With the two pairs of homologues in this model, there are four possible gametic types due to independent assortment alone. Using the formula 2^n equals the possible number of gamete types due to independent assortment (where n equals the number of pairs of homologous chromosomes), the students gain an appreciation for the number of possible kinds of gametes resulting from independent assortment alone. For example, the number of different arrangements for the 23 pairs of human chromosomes equals 2^{23} or approximately 8 million.

Anaphase and Telophase. At meiotic I anaphase the model shows that sister centromeres remain together and do not separate as in mitotic anaphase. Chromosome and strand counts in daughter cells indicate to students that meiosis I is a reduction division; that is, both chromosome number and amount of information (4c→2c) are halved. Furthermore, the colored beads show that crossover sections of sister chromatids contain information from both parents, whereas noncrossover portions contain information from only one parent. Crossing-over, therefore, results in equational distribution of genetic information. As a result, each daughter cell will contain genes of both paternal and maternal origin in cross-over regions of the chromosome.

Meiosis II:

Next, meiosis II is demonstrated with one of the daughter cells. The similarities and differences between mitotic metaphase (fig. 2) and meiotic metaphase II (fig. 5) are noted. In particular, it is pointed out that whereas in mitosis both chromatids in a chromosome derive from one parent, in meiosis only the noncrossover portions of the chromosome derive from one parent. Following meiosis I, there are two strands of identical information in noncrossover portions. In the crossover portions of the chromosomes the strands are not identical. Segregation at meiosis II leads to the separation of paired strands so that each cell receives one strand of each chromosome (1c). In the noncrossover portions identical strands go to daughter cells. In crossover portions nonidentical strands go to daughter cells. At the end of meiosis II, counts by students indicate that both chromosome number and number of strands have been reduced to the base amount (fig.6).

After the demonstration by the instructor, students are given an opportunity to practice with the model. Each student is then asked to demonstrate the model to the instructor. In this way, misconceptions about mitosis and meiosis can be corrected and aspects that confuse the student can be clarified. This assures the instructor that subsequent explanations of genetic principles can be expressed in terms of concepts the students already understand.

Mendelian Ratios and Probability

After students have mastered the events of meiosis, relationships between meiosis and Mendelian ratios should be demonstrated. Letters representing alleles can be written on small pieces of masking tape and these pieces attached to the beads. This is an opportune time for introducing the concepts of locus and allelism.

Segregation at One Heterozygous Locus. Working with two sets of chromosomes (one color for each parent), students can form gametes and simulate fertilization. They will thus derive the 1:2:1 genotypic ratio. After introducing the concept of dominance, the students can derive the 3:1 phenotypic ratio. Next, individual beads can be used to represent alleles, letting one color represent one allele and another color the

(Concluded on p. 111)

concerned and skilled intellectuals. But the effort persists, and valuable as those criticisms may be in helping to identify weaknesses, the critics have not left their lofty perch to join in the gut-level effort that involves an expanding multitude of workers in the field. Some critics define science and scientific thinking so narrowly as to hold them inappropriate for use in education, and would thereby seem to discredit many whose experimental work has been crucial in revealing new ways of understanding and cultivating human development and behavior.

I am not yet convinced that there is no hope for those efforts and I shall continue to ignore the slanders that now charge educationists, curriculists and behaviorists with a naive scientism. It continues to be obvious that elitism in intellectual pursuits is not yet dead, and until it expires, the term "science educator" may have to suffice with only half a meaning. What do *you* think?

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other allele. Students form a gamete pool for each heterozygous parent by placing beads representing the two alleles in a 50:50 ratio in a beaker. Gametes are pulled out of each pool and brought together to simulate fertilization. The genotype of the zygote is recorded, the beads replaced, and the process repeated. This demonstration serves as an introduction to probability, Mendel's law of segregation, and dominance.

Independent Assortment. Independent assortment can be demonstrated by using two beakers for each parent. Each beaker contains different colored beads in a 50:50 ratio to represent the alleles as before. The two beakers contain separate gene pools formed from genes at two unlinked loci. This independent drawing of the beads from each beaker may help clarify the idea that unlinked genes assort independently into the gametes. Fertilization is simulated, the genotype of the zygote recorded, beads replaced, and the process repeated. Depending on the restrictions placed upon interaction between alleles and between loci, various phenotypic ratios can be demonstrated (Mertens 1971b).

Hardy-Weinberg Equilibrium. At a later time in the genetics course, the beads can be used to teach Hardy-Weinberg equilibrium. A gene pool can be represented by using one color of bead to represent one allele and another color the other allele. Different gene frequencies can be obtained by varying the proportion of each color of bead. Zygotes are formed by pulling out two beads at a time, recording the genotype, replacing the beads, and repeating the procedure.

Conclusions

We feel the model is a very efficient aid for teaching the processes of mitosis and meiosis and for demonstrating the principles of heredity. Both students and instructors have responded favorably to this teaching device, and many students have commented that this was the first time they had really understood meiosis. We feel the time and effort invested in working individually with students on the model has facilitated learning of Mendelian genetics.

Other attributes of the model are that it is (i) inexpensive and nonbreakable, (ii) readily assembled, and (iii) useful for small-group presentation. Students can manipulate the model with their hands, thus coordinating physically and mentally the mechanics of chromosome movements.

The model is also useful in clarifying the meaning of important terms such as diploidy, haploidy, homology, tetrad, chromatid, linkage, chromosome, locus, allele, homozygote, and heterozygote. It effectively demonstrates the process of crossing-over. Using individual beads to represent alleles, the principles of Mendelian segregation, independent assortment, and Hardy-Weinberg equilibrium can be demonstrated by forming gametes from these alleles and then simulating fertilization. The relationship between probability and Mendelian ratios can also be introduced.

We urge others to try this model and share their experiences with us. We are confident many of your students will benefit.

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Omission of Credit

Credit for the drawing of the bighorn sheep on page 462 of the November issue and page 562 of the December issue should be given to Lloyd Way, of Arvada, Colo.