Modeling Mitosis & Meiosis

A Problem-Solving Activity

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Models are useful in classroom settings for the same reason they are employed by the scientific community: models allow the investigator (or student) to easily examine processes that are not amenable to traditional study. While one often envisions models being extensively used in chemistry, they are also important learning tools in the biological sciences where illustrating molecular structure and function is critical to understanding the field of molecular biology, for example. Indeed, many studies suggest that the use of models in biology greatly enhances student understanding and problem-solving ability. For instance, reports by Levy and Benner (1995), Stencel (1995) and Oakley (1994) demonstrate recent attempts to model chromosomes and chromosomal behavior as well as the continued interest of teachers in finding new and effective ways of conveying the processes of mitosis and meiosis to students.

The processes of mitosis and meiosis, while simple in nature, are conceptually difficult for students. This is a concern for instructors because these processes are fundamental to an understanding of growth, development, reproduction and genetics (Cordero & Szweczak 1994). Instructors at all academic levels struggle to find new ways to effectively present this material. For example, one activity frequently used includes ''line dancing'' where students act out the duplication and division of chromosomes during mitosis and meiosis. Although this exercise increases student interest, it is often logistically difficult and may not allow the student to observe the details of the overall process. Commercially available model kits also have drawbacks. Aside from the cost, these materials illustrate only a limited number of concepts and do not provide the flexibility needed to demonstrate advanced topics or evaluate novel situations.

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We have developed materials that we package in kit form which can be effectively used to *solve problems* related to normal mitotic and meiotic activity. The materials also allow the student to investigate how aberrant occurrences during nuclear division result in human genetic disorders such as Down syndrome. The use of this model activity, in addition to guidance from the instructor, helps both the student and teacher to identify misconceptions about the processes of nuclear division and to develop problem-solving skills rather than to simply memorize the sequence of events.

Development of Materials

Chenille stems, colored yarn, plastic straws, petri dishes, clothesline, miscellaneous containers, a little glue, and ingenuity can produce a low-cost manipulative model kit for classroom use. Our kit uses larger materials and improves on previous efforts to construct modeling materials in the study of mitosis and meiosis by introductory biology students (Mathis 1979). A complete list of the materials and a description of their use is presented in Table 1 and illustrated in Figure 1. A complete set of materials, as depicted, can be assembled for approximately $4.00. All materials are packaged in polyethylene storage boxes or in plastic bags for use by pairs of students during a laboratory period in our Introductory Genetics course at Middle Tennessee State University. Students may also check out kits for review at home. These materials are used to show chromosomal structure, chromosome replication, synapsis, genetic segregation, independent assortment of alleles, reduction division, stages of mitosis and meiosis, and chromosomal nondisjunction. Figure 2 shows students enrolled in General Genetics working with one of these kits.

An Example Exercise on Meiosis

The mitosis/meiosis kit described here is a component of a laboratory on nuclear division which also includes examination of prepared slides showing mitosis in the onion root tip and meiosis in the lily (Clark & Mathis 1997). Each pair of students is provided with a set of materials and a description of what each component represents (Table 1) and asked to demonstrate solutions to the following problems.

Problem A: Normal Chromosomal Disjunction

For a cell with 2N = 4 chromosomes, construct a succession of model cells showing interphase (G_1) prior to meiosis; G_2 prior to meiosis; prophase I (zygotene); prophase I (pachytene); metaphase I; anaphase I; telophase I; prophase II; metaphase II; anaphase II, and telophase II. As you construct each successive stage, try to imagine the dynamic flow of events that would occur in real life. Refer to a textbook representation of meiosis prior to beginning your modeling simulation. When you are comfortable with the process of normal chromosomal disjunction, answer the questions below and have your instructor check your work for accuracy.

1. Would chromosomes be visible (microscopically) during interphase? Would they be visible during prophase I?

Table 1. Materials required for assembly of chromosomal macromanipulation kit.

Component Parts of Cell Models	*Description of Use*
Clothesline (150 cm formed into a circle)	Animal cell body; the line can be manipulated to illustrate the changes in the cell membrane during division.
Petri dishes (150 mm) (both the top and bottom can be used)	Cell nucleus; removed prior to beginning of division
Stylized drawing of spindle apparatus printed or drawn on label paper	Spindle microtubules
Black posterboard cut into 12 × 22 cm rectangles with label paper attached; one-half of spindle reproduced on one board, second half on second board.	Spindle apparatus; boards can be moved apart to simulate shortening of the spindle fibers as chromosomes are drawn to poles during anaphase.
Red yarn (cut into lengths of 8 cm, 12 cm and 18 cm); three of each length are included in the kit.	Interphase chromatin, maternal origin (lengths correspond to three different chromosomes); to be placed under petri dish to represent interphase; can be joined by straw to represent duplication at S phase.
Blue Yarn (cut into lengths of 8 cm, 12 cm and 18 cm); three of each length are included in the kit.	Interphase chromatin, paternal origin (lengths correspond to three different chromosomes); to be placed under petri dish to represent interphase; can be joined by straw to represent duplication at S phase.
Red chenille stems (cut into lengths of 4 cm, 6 cm and 9 cm); three of each length are included in the kit.	Division chromosomes (chromatids), maternal origin (lengths correspond to three different chromosomes); two stems of equal length and color are joined to represent a duplicated chromosome.
Blue chenille stems (cut into lengths of 4 cm, 6 cm and 9 cm); three of each length are included in the kit.	Division chromosomes (chromatids), paternal origin (lengths correspond to three different chromosomes); two stems of equal length and color are joined to represent a duplicated chromosome.
Plastic straws (cut into lengths of 0.5 cm); 20 pieces are included in the kit.	Centromeres: two pieces of chenille stems or yarn are adjoined by one piece of straw to form a duplicated chromosome; the straw is removed after metaphase to simulate centromere division.
Plastic bags, vials, boxes	Storage of components

2. In the models constructed, how many chromosomes were present in a cell at prophase I? How many at prophase II?
3. How many chromatids were present at prophase I? How many at prophase II?
4. How many tetrads were present at prophase I (pachytene)?
5. If the amount of DNA present in a G_1 interphase cell is represented by a quantity known as *X*, how much DNA would be present during G_2 of interphase? How much DNA would be present at prophase I? At prophase II? In a gamete or spore following telophase II?
6. Meiosis is often termed a ''reduction division.'' What is reduced and when is it reduced?
7. Would the sequence of genes found on one of the sister chromatids of a double-stranded chromosome necessarily be identical to the sequence of genes found on an early (pre-synaptic) prophase I chromosome? Explain.

Problem B: Independent Assortment

Considering a cell for which 2N = 6, construct a cell at metaphase I of meiosis. By arranging and rearranging the chromosomes aligned on the cell equator, demonstrate how independent assortment would allow for the production of genetically *different* daughter cells at the completion of the first meiotic division. How many different combinations of maternal and paternal chromosomes would be possible in this example?

Problem C: Chromosomal Nondisjunction

Construct a cell (2N = 6) in anaphase showing *primary* nondisjunction of one of the pairs of chromosomes. Construct a cell in anaphase showing *secondary* nondisjunction of one of the pairs of chromosomes. Note the number and types of chromosomes that would be present in a sperm or egg cell. Demonstrate your understanding of the process and consequences of nondisjunction by answering the questions below.

1. If primary nondisjunction occurred for one of the three chromosome pairs, how many chromosomes would be expected in the gametes?
2. If disjunction proceeded normally in a 2N = 6 cell, how many chromosomes would be in each gamete?
3. If primary nondisjunction occurred in one parent and normal disjunction occurred in the other parent, what diploid (2N) chromosome numbers would you expect in the offspring?

Identification of Conceptual Problems

We ask students to have the instructor check their initial setup for accuracy before they proceed with the exercise. Many of the students' misconceptions about nuclear division are apparent when they attempt to assemble the division chromosomes for a diploid cell (for example, 2N = 4 in problem A above). Specifically, students struggle to distinguish between chromatids, chromosomes and homologous pairs of chromosomes. For example, we are often presented with a cell nucleus that contains incorrectly matched sister chromatids. While each student realizes that two chromatids (chenille stems) should be connected by a centromere (piece of straw), they often use chenille stems of different color and/or length. The correct representation (i.e. two chenille stems of the same color and length) is a vivid reminder of the fact that sister chromatids are *identical* structures. Misconceptions about chromosome structure and behavior can be easily identified and

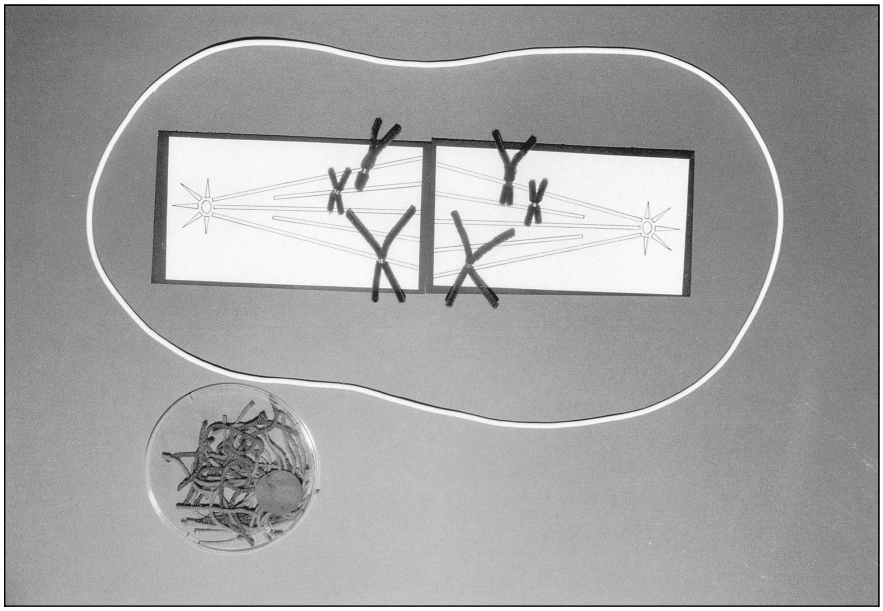

Figure 1. Low-cost, manipulative model kit materials.

Figure 2. Students working with manipulative model in General Genetics class.

corrected as students utilize these hands-on materials.

Evaluation & Discussion

We have obtained feedback regarding our modeling kits from experienced secondary teachers and from college genetics students. In December 1997, in conjunction with a workshop called ''Designer Cells,'' we demonstrated the use of our materials to a group of secondary teachers. More than 98 percent (73 of 74) of those completing the requested evaluation felt that the materials would be an effective means of teaching the processes of mitosis and meiosis in their classrooms. Compared to other modeling materials/methods available for teaching mitosis and meiosis, 12% of the respondents (9 of 74) indicated they were the ''best yet'' and 85% of the teachers (63 of 74) judged the materials to be ''superior.'' Only two respondents (3%) indicated that the materials/methods were ''inferior'' or ''below average.'' Perhaps the most encouraging response was that 73 of the 74 respondents said that they would ''. . . probably build 'Designer Cells' kits for use in their classrooms.''

College genetics students at Middle Tennessee State University have also responded positively to our modeling/problem-solving approach. After using the materials, students (N = 28) were given a short questionnaire consisting of bipolar, Likert-type items, each with seven response options (1 = most negative; 7 = most positive). Our students found the materials to be especially purposeful (6.5 ± 0.75), creative (6.39 ± 0.92), and worthwhile (6.36 ± 1.03). Of the written comments received, the following is representative: ''The model kits made things much more clear for me—and I'm a senior who has seen this (meiosis) many times.''

We feel our modeling materials/methods have been well received by both college students and teachers at the secondary level. With modification, these materials can be used to introduce students at lower grade levels to the basic concepts of genetics. Finally, as pointed out by an anonymous reviewer, these modeling materials can also be effective learning tools for students who are visually impaired and/or learning disabled.

Acknowledgments

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