Dance of the Chromosomes: A Kinetic Learning Approach to Mitosis and Meiosis

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Abstract: Understanding mitosis and meiosis is fundamental to understanding the basics of Mendelian inheritance, yet many students find these concepts challenging or confusing. Here we present a visually and physically stimulating activity using minimal supplies to supplement traditional instruction in order to engage the students and facilitate understanding and retention of these concepts. This kinesthetic activity has students modeling the events of mitosis and meiosis by acting as human chromosomes. This exercise has been used in a sophomore level genetics class at a state university, but it should also be suitable for high school and introductory college classes. An on-line survey was used as an assessment of transfer of knowledge, and this also allowed students the opportunity to comment on this exercise as a learning experience. While it was difficult to be quantitative in our evaluation of learning, student responses to the survey overwhelmingly characterized the exercise as advancing their ability to understand or visualize the processes of mitosis and meiosis.

Keywords: cell division, kinetic learning, meiosis, mitosis

Introduction

A challenge in any educational endeavor is finding ways to present abstract concepts to students in a manner that makes the ideas more concrete. Biology, and genetics in particular, seems rife with abstract concepts that serve as fundamental building blocks for other topics and are necessary for scientific literacy in today's society. One common approach is to provide students with interactive opportunities to apply knowledge gained from lecture or reading. Following Gardner's (1983) concept of multiple intelligences, such a learning approach would tap into an individual's spatial and bodily-kinesthetic intelligences. The benefits of externalizing learning in this fashion are widely appreciated in elementary education (Griss, 1994). Our main objective was to assess the effectiveness of a kinesthetic activity for learning about mitosis and meiosis suitable for upper educational levels in a college genetics course. Several hands-on approaches have already been described (Anderson, 1996; Luinstra, 1996; Chinnici et al. 2004). The exercise described here takes a slightly different approach in that it requires minimal materials and provides for more interaction between instructor, audience and participants.

This exercise was tested on large (80-100 students) college classes in genetics during 2003 and 2004, although this exercise may easily be modified to fit the size and scope of any classroom situation. The exercise was conducted during the recitation session that students voluntarily attend, and we designed an on-line survey to assess transfer of knowledge. On the survey students were asked to identify whether they had observed the exercise, participated in the exercise or had been absent from class. Students then answered one of two sets of questions depending on their attendance, and responses to the open-ended questions were assigned to a generalized category for the purposes of quantification. The mitosis/meiosis section of the students' exam was used to assess comprehension of the concepts, and scores of students present and absent from class were then compared statistically using SPSS (v. 10.0).

Methodology & Results

Student volunteers were solicited to act as chromosomes and illustrate the steps of mitosis and meiosis for a diploid cell. In this case we have set up the exercise to use a cell with 2N=6 due to space and time constraints, although this can easily be modified. The materials required are minimal and can be modified by the instructor according to needs and resources. Chromosome identifiers were made by labeling two sets of paper with the numbers 1-3. The maternal and paternal origins of these chromosomes is indicated by the use of pink and blue paper or some other system (e.g. white numbers on a black background and black numbers on a white background). Additionally, six pieces of rope or cord about 2-3 feet long are used to represent centromeres and the point of attachment between sister chromatids.

Before the commencement of the exercise, students may benefit from a brief review of key terms (e.g. bivalents, chromatids, crossing over, synapsis, tetrads). As the volunteers act out mitosis and meiosis, the instructor directs the action through questioning the volunteers and/or audience. Each question/answer segment of the exercise allows the instructor to make important points about the process of mitosis or meiosis. While students act out the movement of the chromosomes, some of the key terms reviewed earlier are perceived in concrete and physical space. This translation of concepts from abstract to concrete can help in understanding the process of mitosis and meiosis.

Dance of the Chromosomes I: Mitosis

The instructor begins the exercise with a question:
QUESTION - If this is a diploid cell with 2N=6, how many chromosomes are we going to need?
The expected student's answer is " 6, there will be three paternal and three maternal chromosomes."
The instructor asks for volunteers, three men and three women, to represent paternal and maternal chromosomes. Each student is given an appropriately colored and numbered piece of paper. Then, the instructor continues to ask questions:
QUESTION - The student chromosomes represent the nucleus at what stage in the cell cycle?
The expected student answer, "Since the DNA has not replicated, this represents Interphase G1."
QUESTION: What event would take place before the cell can begin mitosis?
The expected student answer is "The cell replicates its DNA."
QUESTION: How do we represent the cell with replicated DNA?
The expected student answer is "Add six additional volunteers."
Therefore, the instructor asks for six additional volunteers and gives them a chromosome label as well as a piece of rope. The students are then paired up according to their chromosome color and number, and then they hold the rope between them. The instructor continues to ask questions:
QUESTION - What does the rope represent?
The expected student answer, "The rope is the centromere."
At this point the instructor asks the volunteers to illustrate various chromosome types by holding the centromere in different locations (top of head, shoulder, waist) to represent telocentric, acrocentric and metacentric chromosomes, respectively.
The instructor calls on a student in the audience to describe the action of the chromosomes at the various steps of mitosis—prophase, metaphase, anaphase and telophase. The volunteers then go through the steps of mitosis while the audience monitors the choreography and provides suggestions and corrections. When the choreography is finished, the instructor asks:
QUESTION - So what is the end result of mitosis?
The expected student answer, "Two cells with an identical complement of chromosomes" (Figure 1A & 1B).
Once the students have gone through the exercise, we have them repeat it or begin again with a new set of volunteers if time allows.

Dance of the Chromosomes II: Meiosis

No additional materials are needed for this exercise. The instructor may have the same students perform or request new volunteers. The instructor begins with a series of questions addressed to the volunteers and the audience.
QUESTION - How is prophase I of meiosis different from prophase in mitosis?
The expected student answer is "Homologous chromosomes align. This is called synapsis. Then they move together to the metaphase plate."

QUESTION - What do we call these paired homologous chromosomes?
The expected student answer, "A tetrad." This is another occasion when acting out the movement of the chromosomes provides a visual meaning to the definition of tetrad.

QUESTION - What important event takes place while the homologous chromosomes are synapsed?
The expected student answer, "There may be the actual exchange of genetic material between chromosomes. This action is called recombination or crossing over."

To represent this event, the instructor can have one volunteer from each sister pair exchange his/her chromosome label with another volunteer from a non-sister chromatid in the tetrad. Now some female students will have a paternal chromosome label and vice versa, indicating that genetic material was transferred between homologous maternal and paternal chromosomes. Other chromosomes will remain the same. We have found that this step is potentially confusing for students, so care should be taken to fully explain the significance of these actions.

FIG 1. Each panel (A & B) represents one of the daughter cells produced by mitosis. Each daughter cell has two copies of each chromosome (#1,2,3) - one of maternal and one of paternal origin. The maternal chromosomes are white numbers on black background. The paternal chromosomes are black numbers on white background.

A

B

Next, the volunteers align on the metaphase plate. The instructor continues to ask:
QUESTION - Is there any particular order to how the chromosomes align on the metaphase plate?
The expected answer, "No. Each chromosome moves independently of the others. This is the basis for Mendel's Law of Independent Assortment."
The instructor may have to intervene at this point to make sure that all the male and female volunteers have not arrayed themselves on opposite sides of the metaphase plate. While this event is indeed biologically possible, the students will perceive more of a difference among the end products of meiosis if there is a mixture of maternal and paternal chromosomes.

The volunteers then proceed through anaphase I and telophase I where the tetrads have separated.
QUESTION - What are the end products at this point?
The expected student answer, "Two cells with dyads that equal the haploid number of the cell. In this case there are three dyads in each cell. This is known as the reductional division." At this point the instructor explains the significance of the reductional division. Then the instructor continues to ask:
QUESTION - In preparation for the next stage of meiosis, does DNA synthesis occur again?
The expected student answer, "No."

Finally, a student in the audience is asked to describe the movement of the chromosomes at prophase II, metaphase II, anaphase II and telophase II. The volunteers proceed through the second division in meiosis while the audience monitors the choreography and makes corrections when necessary. To summarize the process, the instructor asks:

QUESTION - What is the end product of meiosis?
The expected student answer, "Four haploid cells (N=3). This last part of meiosis represents the equational division."
At this point, the students note the genetic composition of each cell. Each cell represents a mixture of paternal and maternal chromosomes. Also, crossing over has produced variability among these chromosomes (Figure 2).

FIG 2. The four groups of students represent the end products of meiosis. Note that recombination between homologous chromosomes in Prophase I is evidenced by the four students holding chromosome labels that do not match their gender.

Discussion

The exercise and evaluation were conducted on students enrolled in a sophomore-junior level genetics class (BSC 370 Genetics) during the fall semesters of 2003 (n=91) and 2004 (n=94). Students who witnessed or participated in the exercise answered these two questions:

1. At what stage of the "chromosome dance" did you realize the differences between the processes of mitosis and meiosis?
2. Please complete this statement to describe your learning experience using the "chromosome dance" as a simulation. The "chromosome dance" helped me ___________.

A substantial percentage of students in both years (43% & 43.2%) recognized the difference between mitosis and meiosis during the first couple of steps of meiosis (Prophase I - Metaphase I). In particular, the processes of synapsis and crossing over seemed to help students distinguish meiosis from mitosis. Some students (10.1% & 4.5%) incorrectly stated that the difference between meiosis and mitosis was that there were twice as many people in the meiosis simulation. The second question allowed the students to evaluate the exercise as a learning experience. Most of the responses (40.4% & 51.6%) indicated that the exercise helped them visualize or understand the processes of mitosis and meiosis, and only a small percentage (5.6% & 4.4%) indicated that the exercise aided their understanding only minimally.

Students who missed class the day of the exercise answered these two questions:
1.) Explain how you visualize the differences between the processes of mitosis and meiosis?
2.) Based on your current knowledge of the processes of mitosis and meiosis, do you feel that you may have benefited from attending recitation? Explain why.

Most students who missed class reported visualizing the difference between mitosis and meiosis by either the number of cell divisions that took place (40.0% & 41.7%) or relied on figures from the textbook (46.75 & 58.3%). Only two students described some unique model or analogy that provided them with a visualization of the process. In response to the second question, most students responded that they would have benefited from attending class, and their reasons mainly centered on the chance for extra review (53.8% & 50%) or that they would have benefited from a visual aid (23.1% & 41.7%).

The data on exam scores did not meet the assumptions of ANOVA even after square root transformation, so we relied on a nonparametric test to compare the exam scores of students who attended recitation versus those who did not. The Kruskal-Wallace test did not detect a significant difference between the two groups in either 2003 or 2004 (p values of 0.075 and 0.866 respectively). Whether students participated in or witnessed the exercise did not seem to have an influence on their scores (Table 1) as the means of both groups were very close. However, students who missed class or did not participate in the survey tended to have overall lower means. Admittedly, this difference could be attributable to differences in academic aptitude and motivation of students who attend class compared to those who do not. In lieu of a pre-test for this exercise, we assumed a standard level of baseline knowledge among students as each has gone through a similar series of introductory biology courses at a university or junior college. Even though there was not a statistically significant difference in performance on the exam, we consider this exercise to be successful because students' responses to the survey indicated that they were able to identify key steps that differentiated mitosis and meiosis (e.g., tetrad formation, crossing over, reduction of chromosome number in resulting cells). The majority of these students also characterized the exercise as advancing their ability to understand or visualize the processes of segregation and reduction division. Even many of the students who missed the exercise responded that they would have benefited from a visual presentation of mitosis and meiosis. An additional benefit of this activity, one noted by several students, is that it is an interesting and fun deviation from the normal class routine that sparks interest as well as, hopefully, understanding.

Conclusions

Wyn and Stegink (2000) reported that a high school class that role-played mitosis performed better on an identical quiz than a class that did not experience this instructional strategy. This study provided evidence that role-playing gives students a concrete experience to help them understand and appreciate the logical sequence of mitosis. According to Vygotsky (1978, p.90), what is important is "the learner is interacting with people in his environment and in cooperation with his peers.". Thus, using Vygotsky's concept of the influence of socialization on mental development, we speculate that the difference in the learning environment and socialization process contributes to the adaptability of role-playing as an instructional strategy in the high school science classroom.

However, we have observed that college students are less inclined to participate in role- playing than high school students. This could be explained by the familiarity of high school students to one another because, unlike college students, they stay together for much of the day over a school year. In addition, high school students are conditioned to assume an active role in learning (e.g. hands-on activities and class presentations), while college students behave in isolation as passive learners and problem solvers. The results of this exercise have encouraged us to conduct additional hands-on interactive exercises in order that students get used to collaborative learning and stimulate other intelligences to promote an understanding of genetics. We believe that using these various instructional strategies makes the teaching of genetics more amusing and entertaining, which enhances learning and promotes an appreciation of the logic of science.

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TABLE 1. The characterization and sample sizes of the students in the class as witness to the exercise, participant in the exercise, did not attend class and did not take survey for each year of the study (2003 & 2004). The average, standard deviation and range of the number of points (11 points total) scored by each group on the corresponding exam question is also provided.

Descriptor	Sample size		Avg. # points		Std. Dev.		Range	
	2003	2004	2003	2004	2003	2004	2003	2004
Witness	65	63	8.5	8.6	2.3	2.0	11-1	11-1
Participant	13	19	8.3	8.9	3.3	1.8	11-1	11-5
Missed class	13	13	6.2	8.6	4.2	2.4	11-0	11-3
Did not take survey	24	15	6.8	7.5	2.6	3.4	11-2	11-1

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