Testing the Effectiveness of a Mitosis/Meiosis Tutorial as a Predictor of Success in Mastery of Basic Course Content in Biology 214 Genetics

An Honors Thesis (HONRS 499)

by

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INTRODUCTION AND LITERATURE REVIEW

Because of the advances in medical genetics, it is necessary that our society become well informed about genetics and the ethical issues that result from the application of new genetic knowledge and technology. We must begin this education by stressing the importance of understanding meiosis which provides the mechanism for gene transmission from parents to offspring. Students need to understand meiosis, if they are to conceptualize Mendelian genetics and be able to formulate educated decisions concerning reproductive issues that may affect their lives. Students also need to have an understanding of genetics and reproduction if they are to influence policy decisions and related legal matters that affect all of society (Mertens and Hendrix, 1990).

Today, teachers teach genetics to students from junior high school through college and graduate school. How much of that genetic knowledge is actually understood by the students—especially those not in graduate programs? And, of those students who claim to understand, how many of them develop the true relationships that exist between such components of the discipline as meiosis and Mendelian gene transmission? The basic foundation of Mendelian genetics is the meiotic process. During meiosis, diploid cells divide so that each gamete produced contains one chromosome from each pair in the diploid cell. This maintains the species
chromosome number in the offspring because the two haploid cells uniting in fertilization produce one diploid cell or zygote. If meiosis did not exist, each succeeding generation would have twice as many chromosomes as the preceding generation. Another important determinant is that each chromosome contains genes, and each gene specifically affects or determines phenotypic expression of a certain trait. Understanding the segregation and independent assortment of genes in Mendelian genetics is directly dependent on understanding these processes in meiosis.

Genetics is a discipline that is perceived as difficult for pre-college, college and post-graduate students to learn as well as for many secondary school biology teachers to teach (Cho et al., 1985; Smith, 1991). “High school science teachers rate genetics as one of the most important, and one of the most difficult biology topics for their students to learn” (Hackling and Treagust, 1984). Several studies reveal that misconceptions about genetics are related to four factors, one of them being the “relationships between meiosis and genetics, as well as a set of relationships among the concepts which are basic to understanding meiosis and genetics” (Cho et al., 1985). It appears that most of the problems concerning Mendelian genetics are meiotically based. The most common misconceptions include: “relationship between chromosomal separation and DNA replication, between allelic pair and trait expression, and between chromosome movement and trait expression” (Cho et al., 1985). All of these
misconceptions deal directly with the meiotic process, and have a bearing on student understanding of Mendelian genetics.

In solving genetics problems, it is more important that students understand the process of getting the answer, than it is to get the answer itself (Stewart, 1982b). Therefore, it becomes even more significant to allow students to see the relationships that exist between Mendel’s principles of genetics and the meiotic process. However, some researchers believe that current instructional procedures often place too much instructional time between meiosis and Mendelian genetics. Longden (1982) noted that “evidence from the teacher questionnaire suggested that the student was presented with ideas relating to meiosis early” in the secondary school biology course but genetics was not taught until the second term shortly before examinations. “To what extent do students link two sets of ideas separated in time?” One student said, “umm... I categorize things too much. I find that er... I put meiosis separately on its own and then mitosis and DNA, finally protein synthesis... all separate categories and don’t let them flow into one another so that when I come to do genetics problems I see it only as a mathematical problem not as part of the whole process” (Longden, 1982). This quotation suggests that students do not relate meiosis and genetics when they are separated by considerable periods of time.

Even worse, many college textbooks deal with Mendelism before
meiosis (Mertens, 1971). It only seems logical to place meiosis before Mendelism because an understanding of what the chromosomes are doing, and thus what the genes are doing, is essential to the understanding of Mendelian ratios. "Why handicap the student in the same manner in which Mendel's contemporaries were handicapped—that is, by not having an understanding of meiosis and the physical basis of gene behavior?" (Mertens, 1971). Tolman (1982) also hypothesized that a standard sequence of teaching could be very beneficial in clarifying misunderstandings about genetics. He too claimed that most textbooks deal with meiosis and Mendelian genetics as separate entities, "without ever bridging the gap between meiosis and genetics." Hackling and Treagust (1984) suggest a new approach in the order of teaching. This is a suggested approach for tenth grade students but it could easily be used at other academic levels as well. Hackling and Treagust have clearly placed meiosis so that it precedes Mendelian genetics (see Table 1, items P10-P16). It is no wonder that students have problems with genetics when they have obstacles such as time, sequencing and difficulty of material to overcome.

Table 1

Propositions Necessary for an Understanding of the Mechanisms of Inheritance Defined at the Level of Sophistication of Meaning Expected of Grade 10 Students

<table>
<thead>
<tr>
<th>Proposition Number</th>
<th>Definition of Proposition</th>
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<tr>
<td>P1</td>
<td>The mechanism of inheritance passes characteristics of parents to</td>
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offspring during reproduction

P2 Genes determine all hereditary characteristics of an organism

P3 Genes for a given trait can exist in alternative forms (alleles)

P4 Genes are located on chromosomes

P5 Genes carried by the sex chromosomes determine the sex of the individual

P6 Males have the sex chromosomes XY and females the sex chromosomes XX

P7 Many traits are determined by one pair of genes

P8 Parental cells contain chromosomes in pairs and genes in pairs

P9 A member of a gene pair is located on each member of a pair of chromosomes

P10 Meiosis is the form of cell division that separates the pairs of chromosomes and pairs of genes of parental cells so that the gametes produced carry one chromosome and one gene from each pair

P11 Gametes produced by a parent may differ genetically in that they can carry alternative forms of a given gene and different sex chromosomes

P12 Gametes carry genetic information from both parents of one generation to the offspring in the next generation

P13 Fertilization of haploid gametes restores chromosome and gene pairs, and the normal diploid number of chromosomes in the zygote which is produced

P14 Chance determines which of the sperm fertilizes each of the eggs and therefore the genotype of the offspring

P15 Offspring (sexually produced) differ from each of their parents as they contain a mixture of genes from both parents

P16 Dominance relationships between genes influence the expression of genes in the phenotype; in the heterozygous condition dominant genes are expressed, recessive genes are masked, and in the case of incomplete dominance (blending) an intermediate phenotype is produced

P17 Environmental factors influence the development of offspring and control the extent to which the genetic potential of the individual is achieved

P18 The multicellular adult organism develops from the single-celled
zygote by mitotic cell division hence all body cells of a given offspring have the same number and type of chromosomes and genes

This table was reproduced from Hackling and Tregust (1984).

Once meiosis is taught, it is extremely important that the teacher stress the relationship of the events in meiosis to the traits of individuals. For if the teacher neglects this important step, students will be left to think of meiosis and genetics as two unrelated phenomena in biology. Too many teachers tend to believe that their students, when postulating gamete types from the parents, associate the gamete types with Mendel’s laws of segregation and independent assortment as well as the mechanisms involved in meiosis (Stewart, 1988).

Stewart (1982b) conducted a study in which subgoals were used to determine the possible routes that the student could take to get the correct answer to a problem. For instance, the first subgoal is the determining of the symbols that are used to express the alleles mentioned in the problem. And “since the class of problems provides a description of which alleles are dominant and which are recessive, students generally complete this step quickly and routinely.” The second subgoal consists of the description of determining the parents’ genotypes, when given information as to their phenotypes. (Students may be given “partial genotypic information” such as whether or not the individual is homozygous.) Stewart points out, however, that when students get to the third subgoal, which deals with the
“procedural knowledge in the determination of gamete types”, it becomes crucial that these students have an understanding of meiosis. He also states that “the conceptual knowledge necessary for the meaningful execution of [the third] subgoal is extensive, as this is the point where Mendelian genetics intersects with meiosis.” The determination of gametes relies solely on the meiotic process.

High school biology instructors typically use the Punnett square as a standard procedure to solve Mendelian genetics problems (Moll and Allen, 1987). Although this approach can be successfully used in solving problems, it is not developed to an extent to show a relationship to meiosis (Moll and Allen, 1987). Without a proper understanding of meiosis, students make errors when constructing their Punnett squares (Tolman, 1982).

In one study, Stewart (1982a) noted that the students interviewed had difficulties in producing solutions to monohybrid and dihybrid cross problems because of an obviously poor understanding of the meiotic process. All of the students used the Punnett square algorithm in solving the problems; however, the students could not explain why they placed certain letters over the boxes in the Punnett square. When one student was asked why he placed the letter H over the top two boxes, and one H next to each box on the left, the student simply replied, “I don’t know, that’s just the way we do it in class.” Later, when another student was
asked why he/she did not just “put one H over each side of [the] square?”
the student replied, “Yeah, I suppose. . .but then you would have this
(Hhh). Then another one like the (Hhh) and these (H-). . .I don’t know. . .I
don’t think that is right.” Stewart reported only a few quotes from
interviews, but concluded on the basis of many similar interviews that
there was no indication that the students working these monohybrid cross
problems had established any relationship between meiosis and Mendelian
genetics. He went on to say that the students probably had some
knowledge of meiosis, but that this knowledge was not used in solving
Mendelian genetics problems.

Stewart (1982b) also studied student use of Punnett squares. After
students completed their problems, Punnett squares were analyzed to see
how much “conceptual knowledge of genetics and meiosis” the students
used to “justify [their] procedures.” The question that Stewart hoped to
answer was whether or not the Punnett square procedure is meaningful to
the solution. The particular student mentioned in the article wrote down
the appropriate symbols for the traits described. The student also
understood the relationships between dominant and recessive (as given in
the problem). For instance, he was asked why the genotype for the
antennae of a beetle could not be heterozygous for short (recessive trait),
and the student replied that “long antenna’s always dominant over the
short antenna.” This student also understood how meiosis relates to the
determination of gamete types. This transcript shows that the student used the "subgoal" techniques, unknowingly, to solve his problems. The use of these techniques also shows that meiosis is important in determining gamete formation.

From the statements given by the first two students quoted at the bottom of page 7 and the top of page 8, it becomes obvious that students are only doing what they are shown to do in class, but have failed to grasp the relationship between meiosis and the Punnett square algorithm (Stewart, 1982a). Aside from misconceptions involving meiosis and genetics, students seem to be unaware of the relationships that exist between them and even if students understand the individual concepts, they often cannot bridge the gap between the concepts (Cho et al., 1985). Often, students are able to get correct answers by chance or by following a rigid pattern, but unfortunately, their method of arriving at the answer may be grossly erroneous. These previous examples show how important it is to develop a meaningful relationship, and to understand how the gametes are involved. According to Hackling and Treagust (1984), studies by Stewart and his co-workers of students' understanding of how chromosomes are involved in gamete formation, revealed that ninth grade American students do not understand the segregation of chromosomes during the meiotic process, and this seems to be a major determinant in the students' inability to solve mono- and dihybrid problems. Meiosis is
not a problem for below average students alone. "Able" students also found difficulty in understanding the meiotic process and claimed that it was a major concern (Longden, 1982). Meiosis is a subject that shows the dichotomy between subjects that require "rote learning" versus "meaningful learning" (Longden, 1982). In other words, some subjects lend themselves easily to basic memorization. However, genetics requires the understanding and application of the concepts and not merely their memorization. Longden points out that many students rely on "a memorized series of stages" rather than develop an understanding of the process. Longden's article contains summaries of interviews pertaining to mitosis and meiosis. In one of the three, a student was asked, "Are there any areas within genetics that you have really tried very hard to learn, understand, but still find very difficult to cope with?" The student responded, "meiosis and mitosis." That student later went on to say "Yeh. . .it's . . .when it's just drawn down in diagrams I can understand but like when you asked me then. . .when actual things happen. . . ."

Another concern for students is the use of "descriptive statements of the meiotic process." An example would be the symbols used to express certain traits, as well as terminology. Clark (1976) mentioned that
the symbols used in setting up simple genetic crosses seem to be widely misunderstood at school level. One of the major errors is... the 2-gamete error, which arises from a misunderstanding of a situation such as this:

1) parent Aa
   gametes
   A and a

This is taken by many students to imply that the parent (signified Aa) somehow divides into two to produce A and a. By analogy then they go on to produce the situation:

2) parent AA
   gametes A and A.

If the students had an understanding of what the letters A and a represent, then they would not make these errors.

In another interview (Longden, 1982), one student had trouble putting his thoughts into words: “yes...well meiosis is...ummm...production of gametes...all of the different stages...the first stage is prophase which in meiosis is divided into five stages...ummm...” The interviewer then asked, “What are you trying to search for?” and the student replied, “Trying to name all the individual stages within prophase.” This indicates how difficult terminology can be for students and how their attention, fully directed to terms, lessens their ability to understand the process itself.
Misunderstanding of basic concepts and basic relationships between concepts were [sic] common. While it is true that vocabulary in a biology course can become very difficult, instructors should not overlook or down play the necessity of students possessing adequate meanings for central concepts. Vocabulary in biology should not be just memorization--it is the meanings of the vocabulary words that are used in constructing generalizations in science. These generalizations give students the power to make explanations and predictions. The inability to describe how concepts are related indicates a lack of understanding of how genetics is structured (Stewart, 1983).

STATEMENT OF THE PROBLEM

In order to clarify and concretize the events of mitosis and meiosis, Carl Bajema of Grand Valley State University developed a tutorial that allows students to follow the chromosomes, and their genes, through the mitotic and meiotic processes. This tutorial was expected to assist them later in understanding the basic principles of Mendelian genetics. The focus of this investigation is to determine the effectiveness of the modified Bajema mitosis/meiosis tutorial on facilitating student understanding of these subjects and then subsequently on student ability to solve Mendelian genetics problems. As has been shown, the literature on the subject of mitosis/meiosis knowledge as a precursor to understanding Mendelian genetics all agrees that a student must have a solid background and general understanding of mitosis and meiosis before
he/she can apply, with repeated success, these principles in solving genetics problems.

MATERIALS AND METHODS

The modified Bajema Mitosis/Meiosis Tutorial (see Appendix I) allows the student to follow the mitotic and meiotic stages through cellular division. The students do this by placing two pairs of chromosomes in a cell, and then moving these chromosomes through the diagrams from parental to daughter cells. This method shows students what the chromosomes do, such as replication of the chromosomes prior to prophase of mitosis or prophase I of meiosis, as well as where the chromosomes are at the completion of each division. The Tutorial is beneficial because it allows students to concretize the similarities and differences that exist between mitosis and meiosis.

The results of Biology 214 students' efforts on the Mitosis/Meiosis Tutorial were recorded by assigning each student a number to retain the student's anonymity. Then, the Tutorial scores were correlated with scores on the mitosis/meiosis and Mendelian genetics questions of Examinations 1 and 2 to assess the students' ability to relate the tutorial to the questions asked on the examinations. The scores on the tutorial ranged from 0-10 with 10 being the top score. Examination 1 (mitosis-meiosis) had a total
raw score of 60 points. Examination 2 (Mendelism) had a raw score of 46.

The first examination covered the recognition of the stages of meiosis and mitosis, the identification of the various stages in the life cycle of an angiosperm (alternation of generations), the identification of chromosome number in various angiosperm cells (e.g., microspore mother cell, tube nucleus, megaspore) when given the chromosome number of a certain angiosperm cell (e.g., endosperm, pollen grain), the identification of chromosome number in various animal cells (e.g., primary spermatocyte, ovum) when given the chromosome number of a certain animal cell (e.g., white blood cell), the identification (by name) of the cell of an animal or plant in which a particular event in meiosis occurs, the diagraming of the processes (e.g., spermatogenesis, oogenesis, microsporogenesis, megasporogenesis), and the labeling of various cells diagrammed by name and indicating the ploidy of those cells.

The second examination covered the identification of Mendel’s two laws (segregation and independent assortment) and also the recognition of the genotypic and phenotypic ratios associated with each law. The examination objectives included: using the Punnett square as one method to solve problems, demonstrating an understanding of Mendel’s two laws by solving mono-, di-, tri-, and polyhybrid problems, listing the conditions (e.g., independent assortment, complete dominance at each locus, no X-linkage, no epistasis, no lethals) necessary for obtaining Mendel’s classic
di- and trihybrid ratios and demonstrating how failure to meet these conditions modifies classic ratios, determining the genotypes of $F_1$ embryos and endosperms and the genotypes of the $F_2$ embryos and endosperms when given the genotypes of the parent maize plants.

The students' raw scores on the two examinations were correlated to the scores on the Mitosis/Meiosis Tutorial. Only those questions from each examination that directly related to the mitotic and meiotic processes were used in establishing the raw scores.

DATA

The data obtained in this study involved students from both sections of Biology 214 (Genetics) from the Fall semester of 1990 and the Spring semester of 1991. The raw data collected from these two classes are summarized in Appendix II. Raw scores were obtained by eliminating from the examination those questions (e.g., probability and chi square) that did not directly deal with mitosis and meiosis or depend on an understanding of mitosis and meiosis. The correlation coefficients were calculated by correlating the raw scores (0 to 10) from the Tutorial with the raw scores of Examination 1 (0 to 60) and with the raw scores of Examination 2 (0 to 46). These correlations are reported in Table 2 and are displayed graphically in Figures 1-4.
Table 2


<table>
<thead>
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<th>Fall 1990</th>
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<th>Spring 1991</th>
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<tr>
<td></td>
<td>Exam 1</td>
<td>Exam 2</td>
<td>Exam 1</td>
<td>Exam 2</td>
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<tr>
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<td>.63</td>
<td>.42</td>
<td>.62</td>
<td>.40</td>
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<td>44</td>
<td>44</td>
<td>43</td>
<td>41</td>
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<tr>
<td>Significance</td>
<td>**</td>
<td>**</td>
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* = number of students in sample  
**α = .01

All four correlations were found to be significantly different from zero using an alpha level of .01, with coefficients ranging from .40 for the relationship between the Tutorial and Examination 2 in 1991 to .63 for the relationship between the Tutorial and Examination 1 in 1990. Very similar results were found for the relationships between the Tutorial and Examination 1 in 1991 and between the Tutorial and Examination 2 in 1990.

All four correlations reported are substantial, indicating a positive relationship between the Tutorial scores and the Examination scores. It does appear that the Examination 1 observed scores correlate more highly
Correlation Mitosis–Meiosis Tutorial with Examination on Mitosis–Meiosis (1990)

Figure 1
Correlation Mitosis–Meiosis Tutorial with Examination on Mendelism (1990)

Figure 2
Correlation Mitosis–Meiosis Tutorial with Examination on Mitosis–Meiosis (1991)

Figure 3
Correlation Mitosis–Meiosis Tutorial with Examination on Mendelism (1991)

Figure 4
with the Tutorial scores than do the Examination 2 scores. The Tutorial scores explained about 40% of the variation in the Examination 1 scores and about 18% of the variation in the Examination 2 scores.

Information dealing with calculation and interpretation of correlation coefficients can be found in more detail in any of the following sources: Hinkle et al. (1979); Mode (1951); and Zar (1984).

**DISCUSSION**

In light of the literature reviewed and the data gathered, it would seem to be essential that students thoroughly understand the processes of mitosis and meiosis if they are to have a functional understanding of Mendelian genetics. Long-time use of the Mitosis/Meiosis Tutorial developed by Bajema had suggested to Dr. Mertens that there was a correlation between student performance on the Tutorial and mastery of the content of Examinations 1 and 2 in Biology 214 (Genetics) at Ball State University. As mentioned by several sources, students need an understanding of mitosis and meiosis before they can successfully grasp the concepts of Mendelian genetics, and students need to be taught in a sequential order with many types of aids to assist them. The Mitosis/Meiosis Tutorial is an excellent aid because it allows the students to work through cellular and chromosomal division on their own and to concretize the events or stages of the two processes. The Tutorial allows
students to see the relationship between chromosome behavior and gene behavior in the mitotic and meiotic processes. Without the Tutorial, students may possess a vague understanding in which they believe they comprehend the processes, but when test time comes, they suddenly find out that they really did not understand well enough to apply their understanding to solving problems. However, using the Tutorial early in the course will allow students to see what they do and do not understand and to remedy any deficiencies in their understanding.

Although the correlations obtained in this study may not appear to be extremely high, they do, in fact, show that a positive relationship exists and that the Tutorial allows for prediction of success on Examinations 1 and 2 in Biology 214. For example, the considerable differences in the correlation coefficients between the first examination and the Tutorial and the second examination and the Tutorial may be explained in part by the time lapse that occurred between the two events. For instance, the amount of time between the Tutorial and Examination 1 was relatively small (i.e., nearly 7 days) and the correlation between these two scores was fairly high. However, the amount of time between the Tutorial and the second examination was much greater (i.e., nearly 28 days), perhaps causing the correlation coefficient to be much smaller.

There are, however, some other possible reasons why these data do not show a higher correlation:
1. Students who receive low scores on their Tutorials, realize where they have made mistakes, and then study hard for the examinations thereby increasing their scores.

2. Students may answer examination questions incorrectly by misreading them due to test anxiety which is probably greater for Examination 2 since it requires analysis of quantitative data.

3. Examination 1 showed a higher correlation than Examination 2 because Examination 1 is a direct measure of the students' understanding of mitosis and meiosis; Examination 2 forces students to apply their knowledge of mitosis and meiosis in order to solve Mendelian genetics problems, and thus may be more difficult for the students. Examination 2 is, therefore, an indirect measure of student understanding.

4. Low correlations for Examination 2 could also be attributed to the students' lack of ability to solve arithmetic problems using quantitative data.

5. Some students did not follow the directions on the Tutorial, which may have influenced their score by not expressing the true knowledge that they had about the subject. Similarly, if students did not take the Tutorial seriously, and did not do well on it, they no doubt failed to master concepts necessary for the best possible performance on the examinations.
Results of this study suggest that the Tutorial should be used for instructional purposes because it helps students see exactly what takes place during the different mitotic and meiotic stages. Students are able to notice exactly what is taking place because they are responsible for moving the chromosomes, and adding spindles, centromeres, sister chromatids, and genes. Without the in-depth examination of the stages that the Tutorial allows, students might simply glance at class handouts or textbook illustrations and listen to class lectures and say to themselves, “This stuff is easy.” The Bajema Tutorial allows students to see mitosis and meiosis for what they really are by causing students to become directly involved with the processes that take place during each stage. Furthermore, by placing letters (representing genes) on the chromosomes they are diagramming on the Tutorial, students experience the mechanical basis for Mendel’s principles of segregation and independent assortment.

MOST COMMON STUDENT ERRORS ASSOCIATED WITH THE TUTORIAL

Tutorial scores ranged from 0 to 10 with a score to ten indicating a full comprehension of the processes. Students who scored a ten showed no or only minor mistakes; however, those students who received a score of zero had such common problems as: failing to show the spindle at mid-
prophase of mitosis; failing to show chromosomes at G\textsubscript{1}, G\textsubscript{2}, and nothing at mid-prophase of mitosis; failing to show centromeres and genes on chromosomes; and showing genes that are supposed to be on homologues on the same chromatid of a given chromosome. Because of the latter mistake, students did not show synapsis and therefore, drew metaphase I of meiosis to look like metaphase of mitosis. Some of the mistakes made by the students were a result of a lack of reading the directions; however, most were caused by a complete lack of understanding of the processes. Some Tutorial scores of zero resulted from the failure to submit the completed Tutorial for grading.

Students with scores of two made mistakes such as: failing to show DNA synthesis prior to prophase I, failing to show a difference in daughter cells at anaphase I, showing alleles (e.g., A, a) attached to the same chromosome, showing chromosomes as not aligned as tetrads in metaphase I, having a chromatid with gene (e.g., A) attached by a centromere to another chromatid with a (e.g., B) gene on it.

Students with scores of five made mistakes such as: writing numbers of chromosomes instead of genotypes in the cell, showing homologues unequal in size, failing to write genes on chromosomes and chromatids.

Students with scores of six made these mistakes: failing to show DNA synthesis, failing to write genotypes in boxes, failing to show that
centromeres lead the way to the poles in anaphase and failing to show the alternatives at anaphase I. The first alternative occurs when two nonhomologous chromosomes carrying genes \( A \) and \( B \) migrate toward the same pole while the nonhomologous chromosomes with the genes \( a \) and \( b \) migrate toward the opposite pole. The second alternative occurs when two nonhomologous chromosomes carrying genes \( A \) and \( b \) migrate toward the same pole while the chromosomes carrying the genes \( a \) and \( B \) migrate toward the opposite pole (Instructions page of Bajema Tutorial).

Students scoring an eight made mistakes such as: showing no genes on chromatids, not showing the centromeres as leading the way to the poles, not showing the effect of DNA synthesis at G\(_2\).

Students with scores of nine made such mistakes as: not showing centromeres leading the way to the poles at anaphase, showing no spindle at mid-prophase, and failing to show homologous chromosomes paired at prophase I of meiosis.

**CONCLUSIONS AND RECOMMENDATIONS**

The Bajema tutorial has been used by Drs. Jon Hendrix and Thomas R. Mertens in classes such as Honors 299 (biology) and Biology 214 (genetics) at Ball State University. Several modifications to the Tutorial were made as a result of this study and consultations with Drs. Mertens and Hendrix. In the revised Tutorial (see Appendix III), the diagrams
were redrawn on the Macintosh SuperPaint system. Another change was made on the General Instructions page with the addition of the words “chromosome 1 and 1’ and chromosome 2 and 2’.” These changes were made for future use because of mistakes and misunderstandings of this year’s students. With these changes, we hope to increase student understanding of, and success with, the Tutorial.

The Bajema Tutorial should also be an excellent instructional aid to use with students at the pre-college level. Students of biology can benefit from the Tutorial because it increases student involvement in the learning process. And because student involvement is increased, student retention and proper understanding of the material should also be improved. However, for this Tutorial to be beneficial, it should be taught in a sequential manner; that is, the Tutorial must be administered before the introduction of Mendelian genetics and ratios.

Experience suggests that it is helpful to dedicate at least one class period to instruction about mitosis and meiosis before administering the Tutorial. Students will understand better if they have been introduced to the material in class and if they have been allowed to take notes and ask questions. Supplementary material such as course hand-outs might also be appropriate to aid the students in their learning.
LITERATURE CITED


APPENDIX I
WHAT HAPPENS TO GENES DURING CELL DIVISION?

HOW TO FACILITATE MEANINGFUL LEARNING ABOUT PROCESSES
RATHER THAN ROUTE MEMORIZATION OF ISOLATED FACTS!

Carl Bajema, 1983 Revision

Grand Valley State University, Allendale, MI

Many teachers and virtually all textbook authors are missing an excellent opportunity to help students better understand what cell division is all about -- the reproduction of genes (DNA) and the subsequent distribution of the chromosomes carrying those genes to daughter cells during mitosis and meiosis. Four studies of the difficulties students experience in learning genetics all concluded that educators need to be far more explicit when attempting to link the events which occur during the reproduction of genes (DNA replication) with the chromosome movements during mitosis and meiosis that result in different distributions of genes to daughter cells (Cochrane & Dockerty, 1984; Longden, 1982; Stewart, 1982; Tolman, 1982). More of our students can be expected to gain an adequate understanding of the genetic aspects of cell division and gain this understanding more easily if educators:

1) Diagram what happens to the genes on four chromosomes (including chromatids) of a dihybrid (AaBb) cell as DNA is replicated and the cell goes through each of the stages of (a) mitosis, and (b) meiosis (both alternatives with respect to independent assortment). Such diagrams should be published in all introductory biology and genetics texts and animated sequences should be included in all films on cell division. The students should gain additional experience by drawing/physically manipulating/computer manipulating chromosome models carrying genes to simulate both mitosis and meiosis.

2) Spend more time showing how the processes of meiosis and random fertilization are combined and represented in the Punnett square method for solving simple Mendelian genetics problems. Students should learn about the mathematical logic of the Punnett square -- how it graphically combines the mathematical probabilities associated with the production of gametes by particular individuals and the production of zygotes by random fertilization.

Computer assisted instruction and other forms of individualized instruction may be used to help as many of our students as possible to learn the biological basis of genetics -- genetic cloning as well as Mendelian genetics.

References


GENERAL INSTRUCTIONS

CELL DIVISION: What Happens to the GENES During MITOSIS and MEIOSIS?

1. On the attached pages you are to diagram what happens to two pairs of genes, A/a and B/b, as they get replicated (duplicated) and distributed in a cell that is undergoing MITOSIS and then in a cell that is undergoing MEIOSIS. In your diagram the A and a alleles will be located on the pair of homologous chromosomes #1; the B and b alleles will be situated on the pair of homologous chromosomes #2.

2. Use __________________ (colored pen or pencil) first to draw the CHROMOSOMES #1 and their CHROMATIDS and then to locate and label ALL the A and a genes on the appropriate arms of the CHROMOSOMES (and/or CHROMATIDS) present in each cell in each stage of cell division.

3. Use __________________ (another color) first to draw the CHROMOSOMES #2 and their CHROMATIDS and then to locate and label ALL the B and b genes on the appropriate arms of the CHROMOSOMES (and/or CHROMATIDS) present in each cell in each stage of cell division.

4. Use the small rectangular boxes to RECORD the GENOTYPE of the cells, that is, the number of A, a, B and b alleles present in every phase.

5. Indicate the CENTROMERE of each chromosome in each phase by drawing a circle, o.

6. Draw an outline of the SPINDLE APPARATUS in every stage for which it is present. Remember that the poles of the spindle are at a 90 degree angle to the EQUATORIAL PLATE.

7. For the sake of clarity draw the CHROMOSOMES as if they are flexibly shaped rods in every phase.

8. Assume that none of the chromosomes swap, lose, or gain genes. That is, assume no crossing over between homologous chromosomes and assume no translocation of genes between nonhomologous chromosomes.

9. Consult your textbook or lecture notes on the events that occur in each stage of these two cell divisions.

INSTRUCTIONS FOR DIAGRAMMING THE TWO ALTERNATIVES FOR METAPHASE I OF MEIOSIS

Nonhomologous chromosomes line up at the equatorial plate and then segregate independently of each other with respect to which of the two poles of the spindle they migrate to during Anaphase I.

ALTERNATIVE 1: The two nonhomologous chromosomes carrying genes A and B migrate toward the same pole of the spindle apparatus while those nonhomologous chromosomes carrying genes a and b migrate toward the opposite pole.

ALTERNATIVE 2: The two nonhomologous chromosomes carrying genes A and B migrate toward the same pole of the spindle apparatus while those nonhomologous chromosomes carrying genes a and b migrate toward the opposite pole.
MITOSIS

G₁ Interphase → DNA Synthesis → G₂ Interphase → Middle Prophase (spindle present)

cell membrane → nuclear membrane

Metaphase → Anaphase

Metaphase: equatorial plate

Late Telophase

Interphase following Mitosis
**MEIOSIS**

$G_1$, Interphase  

DNA Synthesis  

$G_2$, Interphase  

Middle Prophase I

See instructions at bottom of page 2.

Metaphase I  
**(first alternative)**

Equatorial plate

Either -- Or

Anaphase I  
**(alternative A)**

Metaphase I  
**(second alternative)**

Anaphase I  
**(alternative B)**
MEIOSIS (continued)

Telophase I
(alternative A)

Prophase II
(alternative A)

Metaphase II
(alternative A)

Telophase I
(alternative B)

Prophase II
(alternative B)

Metaphase II
(alternative B)

Equatorial Plate
MEIOSIS (continued)

Anaphase II
(alternative A)

Telophase II
(alternative A)

Interphase following Meiosis
(alternative A)

Anaphase II
(alternative B)

Telophase II
(alternative B)

Interphase following Meiosis
(alternative B)
APPENDIX II
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**Biology 214**

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APPENDIX III
WHAT HAPPENS TO GENES DURING CELL DIVISION?  
HOW TO FACILITATE MEANINGFUL LEARNING ABOUT PROCESSES  
RATHER THAN ROTE MEMORIZATION OF ISOLATED FACTS!

CARL BAJEMA, 1983 REVISION  
Grand Valley State University, Allendale, MI

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1. Diagram what happens to the genes on four chromosomes (including chromatids) of a dihybrid (AaBb) cell as DNA is replicated and the cell goes through each of the stages of (a) mitosis, and (b) meiosis (both alternatives with respect to independent assortment). Such diagrams should be published in all introductory biology and genetics texts and animated sequences should be included in all films on cell division. The students should gain additional experience by drawing/physically manipulating/computer manipulating chromosome models carrying genes to simulate both mitosis and meiosis.

2. Spend more time showing how the processes of meiosis and random fertilization are combined and represented in the Punnett square method for solving simple Mendelian genetics problems. Students should learn about the mathematical logic of the Punnett Square—how it graphically combines the mathematical probabilities associated with the production of gametes by particular individuals and the production of zygotes by random fertilization.

Computer assisted instruction and other forms of individualized instruction may be used to help as many of our students as possible to learn the biological basis of genetics—genetic cloning as well as Mendelian genetics.

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**GENERAL INSTRUCTIONS**

**CELL DIVISION: What happens to the GENES during MITOSIS and MEIOSIS?**

1. On the attached pages, you are to diagram what happens to two pairs of genes, \( A/a \) and \( B/b \), as they get replicated (duplicated) and distributed in a cell that is undergoing MITOSIS and then in a cell that is undergoing MEIOSIS. In your diagram, the \( A \) and \( a \) alleles will be located on the pair of homologous chromosomes that you will denote as chromosome 1 and chromosome 1'. The \( B \) and \( b \) alleles will be situated on a shorter pair of homologous chromosomes that you will number as chromosomes 2 and 2'.

2. Use ________(colored pen or pencil) first to draw the CHROMOSOMES 1 and 1' and their CHROMATIDS and then locate and label ALL of the \( A \) and \( a \) genes on the appropriate arms of the CHROMOSOMES (and/or CHROMATIDS) present in each cell in each stage of cell division.

3. Use ________ (another color) first to draw the CHROMOSOMES 2 and 2' and their CHROMATIDS and then locate and label ALL of the \( B \) and \( b \) genes on the appropriate arms of the CHROMOSOMES (and/or CHROMATIDS) present in each cell in each stage of cell division.

4. Use the small rectangular boxes to RECORD the GENOTYPE of the cells, that is, the number of \( A, a, B, \) and \( b \) alleles present in every phase.

5. Indicate the CENTROMERE of each chromosome in each phase by drawing a circle, o.

6. Draw an outline of the SPINDLE APPARATUS in every stage for which it is present. Remember that the poles of the spindle are at a 90 degree angle to the EQUATORIAL PLATE.

7. For the sake of clarity draw the CHROMOSOMES as if they are flexibly shaped rods in every phase.

8. Assume that none of the chromosomes swap, lose, or gain genes. That is, assume no crossing over between homologous chromosomes and assume no translocation of genes between nonhomologous chromosomes.

9. Consult your textbook or lecture notes on the events that occur in each stage of these two cell divisions.

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**INSTRUCTIONS FOR DIAGRAMMING THE TWO ALTERNATIVES FOR METAPHASE I OF MEIOSIS**

Nonhomologous chromosomes line up at the equatorial plate and then segregate independently of each other with respect to which of the two poles of the spindle they migrate to during Anaphase I.

**ALTERNATIVE 1:** The two nonhomologous chromosomes carrying genes \( A \) and \( B \) migrate toward the same pole of the spindle apparatus while those nonhomologous chromosomes carrying genes \( a \) and \( b \) migrate toward the opposite pole.

**ALTERNATIVE 2:** The two nonhomologous chromosomes carrying genes \( A \) and \( B \) migrate toward the same pole of the spindle apparatus while those nonhomologous chromosomes carrying genes \( a \) and \( b \) migrate toward the opposite pole.
MITOSIS

G₁ Interphase

G₂ Interphase

Middle Prophase (spindle present)

DNA synthesis

Metaphase

Anaphase

equatorial plate

Late Telophase

Interphase following Mitosis
MEIOSIS

G₁ Interphase → G₂ Interphase → Middle Prophase I

DNA synthesis

Metaphase I (first alternative)

equatorial plate

Either--Or

Anaphase I (alternative A)

See instructions at bottom of page 2.

Metaphase I (second alternative)

Anaphase I (alternative B)
MEIOSIS (continued)

Telophase I
(alternative A)

Prophase II
(alternative A)

Metaphase II
(alternative A)

equatorial plate

Telophase I
(alternative B)

Prophase II
(alternative B)

Metaphase II
(alternative B)
MEIOSIS (continued)

Anaphase II
(alternative A)

Telophase II
(alternative A)

Interphase following Meiosis
(alternative A)

Anaphase II
(alternative B)

Telophase II
(alternative B)

Interphase following Meiosis
(alternative B)