SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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SS&C Research and Development Center
Gerry Wheeler, *Principal Investigator*
Erma M. Anderson, *Project Director*
Nancy Erwin, *Project Editor*
Rick McGolerick, *Project Coordinator*
Arlington, Va., 703.312.9256

Evaluation Center
Frances Lawrenz, *Center Director*
Doug Huffman, *Associate Director*
Wayne Welch, *Consultant*
University of Minnesota, 612.625.2046

Houston SS&C Materials Development and Coordination Center
Linda W. Crow, *Center Director*
Godrej H. Sethna, *School Coordinator*
University of Houston-Downtown, 713.221.8583

Houston School Sites and Lead Teachers
Jefferson Davis H.S., Lois Range
Lee H.S., Thomas Ivy
Jack Yates H.S., Diane Schranck

California Coordination Center
Tom Hinojosa, *Center Coordinator*
Santa Clara, Calif., 408.244.3080

California School Sites and Lead Teachers
Sherman Indian H.S., Mary Yarger
Sacramento H.S., Brian Jacobs

Iowa Coordination Center
Robert Yager, *Center Director*
University of Iowa, 319.335.1189

Iowa School Sites and Lead Teachers
Pleasant Valley H.S., William Roberts
North Scott H.S., Mike Brown

North Carolina Coordination Center
Charles Coble, *Center Co-Director*
Jessie Jones, *School Coordinator*
East Carolina University, 919.328.6172

North Carolina School Sites and Lead Teachers
Tarboro H.S., Ernestine Smith
Northside H.S., Glenda Burrus

Puerto Rico Coordination Center*
Manuel Gomez, *Center Co-Director*
Acenet Bernacet, *Center Co-Director*
University of Puerto Rico, 809.765.5170

Puerto Rico School Site
UPR Lab H.S.

* * * * * * * * * * * *

Pilot Sites
Site Coordinator and Lead Teacher
Fox Lane H.S., New York, Arthur Eisenkraft
Georgetown Day School, Washington, D.C., William George
Flathead H.S., Montana, Gary Freebury
Clinton H.S., New York, John Laffan*

*not part of the NSF-funded SS&C Project.

Project Associates

Bill G. Aldridge
SciEdSol, Henderson, Nev.

Dorothy L. Gabel
Indiana University

Stephen D. Druger
Northwestern University

George Miller
University of California-Irvine

National Science Education Standard—Life Science

The Molecular Basis of Heredity

Most of the cells in a human contain two copies of each of 22 different chromosomes. In addition, there is a pair of chromosomes that determines sex: a female contains two X chromosomes and a male contains one X and one Y chromosome. Transmission of genetic information to offspring occurs through egg and sperm cells that contain only one representative from each chromosome pair. An egg and a sperm unite to form a new individual. The fact that the human body is formed form cells that contain two copies of each chromosome—and therefore two copies of each gene—explains many features of human heredity, such as how variations that are hidden in one generation can be expressed in the next.

In all organisms, the instructions for specifying the characteristics of the organism are carried in DNA, a large polymer formed from subunits of four kinds (A, G, C, and T). The chemical and structural properties of DNA explain how the genetic information that underlies heredity is both encoded in genes (as a string of molecular "letters") and replicated (by a templating mechanism). Each DNA molecule in a cell forms a single chromosome.

Changes in DNA (mutations) occur spontaneously at low rates. Some of these changes make no difference to the organism, whereas others can change cells and organisms. Only mutations in germ cells can create the variation that changes an organisms' offspring.

Inferred Generalization

Recombinations and crossing over are also factors affecting mutation rates.

Teacher Materials

Learning Sequence Item:

1005

Mitosis and Meiosis

May 1996
Adapted by: William Leonard and Tom Hinojosa

Heredity, Traits, Genes, Chromosomes, and DNA. Students should distinguish between the phases of mitosis and meiosis, specifically in humans. They should examine the Mendelian principles of segregation and independent assortment and how they relate to meiosis, correlating chromosomal behavior with observations of segregation and independent assortment. As they examine the structure of chromosomes and their action during meiosis, students should determine that sex cells contain half the amount of genetic information of one parent and half the amount of genetic information of the other parent. (Students should study basic probability and statistical significance, using the mean, standard deviation, and chi-square.) *(Biology, A Framework for High School Science Education, p. 104.)*

Contents

This micro-unit was adapted by **William Leonard** (Clemson Univ., Clemson, S. C.) and
Tom Hinojosa (SS&C Center Coordinator, Santa Clara, Calif.)

1005

Learning Sequence

Heredity, Traits, Genes, Chromosomes, and DNA. Students should distinguish between the phases of mitosis and meiosis, specifically in humans. They should examine the Mendelian principles of segregation and independent assortment and how they relate to meiosis, correlating chromosomal behavior with observations of segregation and independent assortment. As they examine the structure of chromosomes and their action during meiosis, students should determine that sex cells contain half the amount of genetic information of one parent and half the amount of genetic information of the other parent. (Students should study basic probability and statistical significance, using the mean, standard deviation, and chi-square.). (*Biology, A Framework for High School Science Education, p. 104.)*

Science as Inquiry	Science and Technology	Science in Personal and Social Perspectives	History and Nature of Science
Oops! There It Grows Again **Activity 1**		Oops! There it Grows Again **Activity 1**	
Chromosomes in Motion **Activity 2**		Caught in the Act **Activity 4**	
So That's Mitosis! **Activity 3**		Mitosis and Me **Assessment 2**	
Caught in the Act **Activity 4**		Characteristics of Mitosis **Assessment 4**	
The Significance of Sexual Reproduction **Activity 5**			
Chromosomes on Parade **Activity 6**			
Mitosis Critic **Assessment 1**			
Mitosis by Stages **Assessment 3**			
Chromosome Count **Assessment 5**			
Who's Doing Meiosis? **Assessment 6**			
Purpose of Meiosis **Assessment 7**			
Meiosis by Steps **Assessment 8**			

Suggested Sequence of Events

Event #1

Lab Activity

1. Oops! There It Grows Again (45 minutes)

Event #2

Lab Activity

2. Chromosomes in Motion (45 minutes)

Alternative or Additional Activities

3. So That's Mitosis! (40 minutes)

Event #3

Lab Activity

4. Caught in the Act (45 minutes)

Event #4

Lab Activity

5. The Significance of Sexual Reproduction (30 minutes)

Alternative or Additional Activities

6. Chromosomes on Parade (45 minutes)

Event #5

Readings from Science as Inquiry, Science and Technology, Science in Personal and Social Perspectives, and History and Nature of Science

Suggested readings:

Marx, Jean, "How DNA Replication Originates," [Frontiers in Biology: Chromo somes], *Science*, Vol. 270, No. 5242, Dec. 8, 1995, pp. 1585–1587.

Sekelsky, Jeff J., and R. Scott Hawley, "The Bond between Sisters," *Cell*, Vol. 83, Oct. 20, 1995, pp. 157–160.

Shaposhnikof, Yuliy G., Gurgen A. Kesyan and Irina E. Kondrat'eva, "New Concepts of the Pathogenesis in the Healing Process of Gunshot Wounds," *Clinical Orthopaedics and Related Research*, New York: Lippincott-Raven Publishers, No. 320, 1995, pp. 40–42.

Silver, Lee M. "The Acquisition of Sex," *Science*, Vol. 264, No. 5155, April 1, 1994, p. 116.

Assessment items are at the back of this volume.

Assessment Recommendations

This teacher materials packet contains a few items suggested for classroom assessment. Often, three types of items are included. Some have been tested and reviewed, but not all.

1. Multiple-choice questions accompanied by short essays, called justification, that allow teachers to find out if students really understand their selections on the multiple choice.

2. Open-ended questions asking for essay responses.

3. Suggestions for performance tasks, usually including laboratory work, questions to be answered, data to be graphed and processed, and inferences to be made. Some tasks include proposals for student design of such tasks. These may sometimes closely resemble a good laboratory task, since the best types of laboratories are assessing student skills and performance at all times. Special assessment tasks will not be needed if measures such as questions, tabulations, graphs, calculations, etc., are incorporated into regular lab activities.

Teachers are encouraged to make changes in these items to suit their own classroom situations and to develop further items of their own, hopefully finding inspiration in the models we have provided. We hope you may consider adding your best items to our pool. We also will be very pleased to hear of proposed revisions to our items when you think they are needed.

Teacher Sheet

Science as Inquiry/
Science in Personal and Social Perspectives

Oops! There It Grows Again

What do replicating cells look like?

Overview:

Students observe mitosis in prepared slides of the tip of an onion root. These observations will serve as an example of what happens not only in plants, but in many multicellular organisms which undergo mitosis.

Materials:

Per lab group:
compound microscope
prepared slides of mitosis in the onion root tip
diagrams of mitosis for reference

Procedure:

Students work in groups of two. The students should scan the prepared slide of the onion root tip under appropriate magnification (medium power, about 100x) for a section which appears to be only one cell thick and for which they can see the insides of the cells clearly. Upon locating a suitable cell, they should switch to high power (400x) in order to more clearly see the chromosomes. Once they have located a cell with several rod-shaped bodies (chromosomes), the students sketch the cell and the chromosomes in the position they occur.

Next, the students should scan for another cell which has its chromosomes in a different position than the first cell they observed. Students sketch this new cell as before. Students should repeat the process for several differently-appearing cells. They may need to view more than one slide to find different phases of mitosis.

Ask students to compare their sketches of the cells to the reference diagram of mitosis. Tell students to number each cell they sketched in the order they think represents the chronological sequence of development of these cells, using a “1” for the first developed cell and so on.

Background:

Mitosis is going on nearly all over your body. Mitosis is the process of making new cells from existing cells through the process of nuclear division. Most of the activity involves the cell’s chromosomes. Each cell in your body needs a full set of your chromosomes. Duplication of a cell’s chromosomes and redistribution of them to new cells is essential in producing fully functional new cells. This is necessary so that each cell can carry out its particular activities, including the production of proteins which allow the cell to function properly. After all, don’t you want all your skin cells to look like all your other skin cells, to produce normal pigment and be able to metabolize?

Cells divide and make new cells for two major reasons, growth in size of an individual and maintenance of tissues in which cells die normally. Your skin is a good example of both cases. When you were younger, your body was growing in size and the skin needed to grow in size with the rest of your body. At your age, your skin is probably still growing in size, even though you may have attained your adult height. You also lose skin cells continuously during you life as these cells die and are sloughed off. Dying and replacement of skin cells is part of the normal maintenance process because life is tough on your skin. Have you ever been sunburned, cut your skin or bruised it? Thanks to mitosis and the rest of the cell cycle, your damaged skin cells get replaced.

Most of your other tissues undergo cell duplication as well. These all include mitosis as part of the process. Bone tissue, muscle tissue, digestive tissue, and some nerve tissue are also included. You simply could not live without mitosis.

Recommended prepared slides are Carolina Biological F6-E355 and F6-B551 Ascaris and Onion Mitosis set, 2 slides, $13.75. Some teachers prefer Whitefish mitosis slides for their clarity.

In this activity, students should be focusing on the positions of the chromosomes in each cell. The intent is to give students concrete observations of the phases of mitosis and a common example of mitosis as a process necessary for growth of an organism.

Replication of chromosomes (DNA) occurs before mitosis, in a period called interphase. Interphase, mitosis, and cytokinesis (division of cytoplasm and cell organelles into two equal halves) are the three phases of the cell cycle, i.e. the sequence of events which occurs throughout the life of a cell. Like mitosis, interphase can be divided into a number of stages, referred to as G_1, S, and G_2. G_1 is described as a high metabolic activity state resulting from cell growth; During the S phase DNA replication occurs; In G_2 centrioles (if present) replicate and mitotic spindle of microtubules is formed.

Mitosis is the division of a cell's nucleus to form two "daughter" cells. These two cells are identical. Each has a nucleus containing identical amounts and sequences of DNA. The DNA is normally in the form of chromatin, which appears as a grainy, unstructured substance in the nucleus at times other than during mitosis. Cells only undergo mitosis when they reach some optimum size. During the early stage of mitosis, the chromatin condenses into thick strands visible as chromatids. The "sister" chromatid strands (duplicate strands of DNA) are held together by the centromere. During mitosis, the sister chromatids are separated to form the chromosomes in the daughter cells.

The study of living cells shows the continuity of cell division. It is convenient, however, to describe the process in discrete phases. Phase names and a brief description are given below:

Interphase. Chromosomes replicate

Prophase. Chromosomes condense and spindle forms

Metaphase. Chromosomes line up on equator of spindle

Anaphase. Chromatids pulled to opposite ends of spindle

Telophase. New nuclear envelope forms, spindle disappears

Cytokinesis often begins during telophase. In animal cells it occurs when a ring of actin microfilaments develops around the cell, usually in the region of the equator of the disintegrating spindle. These microfilaments are attached to the cell surface membrane. When they contract they pull the surface membrane inwards to make a division furrow. Eventually, the division furrow contracts to nothing; the cell surface membranes on each side join up and the two cells separate.

Students should focus simply on distinguishing between the phases of mitosis and chromosomal structure and action during mitosis. However, care should be taken not to obscure the concept of continuity in the process.

It is recommended that this activity be followed by a 15 minute teacher led discussion revealing the major purposes of mitosis. This is to be an interactive discussion, with most of the information coming from the students. Among the major purposes of mitosis to be discussed are: Growth in size of an individual; Tissue Replacement; and Reproduction, as in the case of single-celled organisms, notably bacteria.

Variations:

Virtually the same activity can be done using prepared slides of roundworm embryo (Ascaris).

Adapted from:
Harless, William, *Continuity of Life,* Waco, Texas: CORD Communications, 1991.
Rowland, Martin, *Biology*, Walton-on-Thames Surrey, UK: Thomas Nelson and Sons, Ltd., 1992.

Science as Inquiry

Chromosomes in Motion

How can you model the sequence of mitosis?

Overview:

Students will reconstruct the events and sequence of mitosis using clay to model the chromosomes. This will allow them to visualize in three dimensions the changes in the chromosomes during this process. To simplify the model, somewhat, students will work only with two pairs of chromosomes instead of an entire set. Note: a human has a total of 23 pairs of chromosomes.

Materials:

Per lab groups (2 students):
modeling clay, blue and red, 100 g each
pipe cleaner
paper, white, 8.5 x 11
metric ruler
scissors

Procedure:

The clay is used to make chromatid models. Students work in groups of two. Students make a long roll about the width of a pencil with each color of clay. They should pinch the clay roll colors into 2 sections about 8 cm in length and 2 sections 4 cm in length. These will be the chromatids.

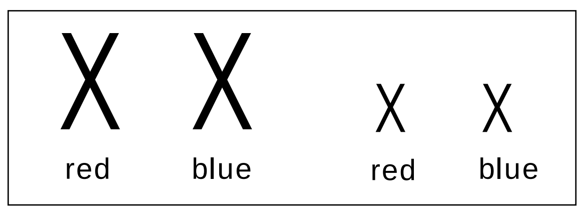


Fig. 1

The pipe cleaner is used to join two chromatids together simulating a centromere. Students should cut or break by bending the pipe cleaner into four equal sections. They use these to join two chromatids of similar color and length. The result will be four X-shaped bodies (chromosomes) each containing two sister chromatids, such as shown in Fig. 1.

Next, the students should lay the chromosomes randomly on the sheet of paper. This sheet represents the nucleus of a cell. Students should place similar sized red and blue chromosomes next to each other so that they actually touch. These represent homologous chromosomes. This step represents Prophase stage of mitosis.

The students are now asked to imagine (or actually draw) an equatorial line on the paper. They should move the chromosomes and orient them horizontally along the equator so that both homologues of all chromosomes pairs are lined up on the equator. They should position all chromosomes so that one sister chromatid is on the north side of the equator and the other chromatid is on the other side of the equator as shown in Fig. 2. This position represents the Metaphase phase of mitosis.

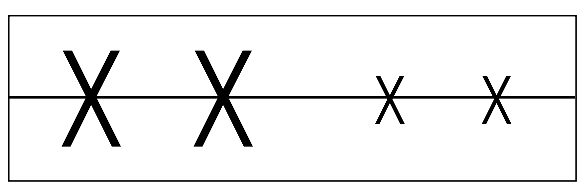


Fig. 2

Now the students make a small circle at the top and bottom centers of the page. This will symbolize the north and south poles of the cell respectively. Students should detach the sister chromatids from each chromosome by removing the pipe cleaner. Students are told to draw a line from each sister chromatid on the north side of the equator to the north pole; the same for the sister chromatids on the south side to the south pole. They then move all the sister chromatids to their respective poles. This marks the Anaphase phase of mitosis. Students may need guidance during this part of the procedure.

Next the students should cut the paper in half along the equator. There are now the beginning of two cells, each containing one sister chromatid from each homologous chromosome. This represents the telophase stage.

To simulate a newly formed cell membrane, the students draw a circle around the sister chromatids on each of the two pieces of paper. Cytokinesis has now occurred. Two distinct and separately functioning cells are now represented. This marks the beginning of the 2-celled stage or interphase of the new cells.

Finally, the students can simulate the new cells entering prophase to repeat the entire process to produce two more cells from each of the new daughter cells. To do this, they should roll and cut enough clay to make a duplicate set of sister chromatids for chromosomes, placing one next to each of the previously single sister chromatids and tying the new sister chromatids together with pipe cleaner. At this point, the new cells will have generated a new sister chromatid for every homologue.

Background:

The sister chromatids are a product of replication during interphase of the Cell Cycle. During Prophase they thicken and become visible.

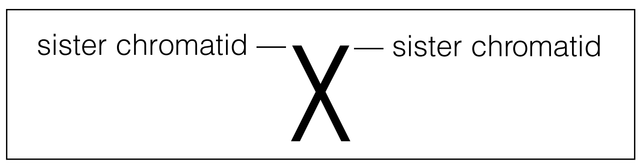


Fig. 3

It is important that the students understand that the chromosomes do not look like the X's during Interphase, the phase in which the cell usually exists. The DNA is normally in the form of chromatin, which appears as a grainy, unstructured substance in the nucleus at times other than during mitosis.

Homologous chromosomes each contain genes for the same trait and on the same position of the chromosome. In this case, one of each homologous chromosomes, such as the blue chromosomes, originally came from one parent and the other homologue (red) from the other parent.

Variations:

Students may enjoy making a "claymation" movie using their models. Obtain a video camera and have students create videos providing their own narration and sound track. You may even have the capacity to have students create a computer simulation using appropriate software.

Adapted from: none

an alternative activity for Event 2

Teacher Sheet

Science as Inquiry

So That's Mitosis!

What are the important events of mitosis?

Overview:

Students work in groups to discuss and explain the important events of mitosis and discover the evolutionary and reproductive benefits of these events.

Materials:

Per lab group:
diagram of mitosis
diagram of cell cycle

Procedure:

Students work in groups of three or four. They should refer to the mitosis diagrams the teacher provided and any other notes, diagrams, or models about mitosis that they have made so far. One student in the group reads aloud the following passage (see student version) while the others follow it on a diagram of mitosis. The group should try to make sense of what is written in the passage and write answers to the questions that follow about the cell cycle. Encourage the students to discuss the materials until everyone in the group understands the reading.

Background:

Some students may not yet understand mitosis even after doing the previous activities and readings. This activity may help by using a kind of peer coaching. This activity, however, could be done individually as homework, or even as an assessment by focusing on students' answers to the questions which follow the reading.

Variations:

Students could be challenged to develop their own group presentation (including an instructional poster) on the material discussed in the reading.

Adapted from: none

Teacher Sheet

Science as Inquiry/
Science in Personal and Social Perspectives

Caught in the Act

What do cells and chromosomes look like during meiosis?

Overview:

Students observe prepared slides of meiosis in the testes of the adult worm, Ascaris. This will serve as an example of what happens not only in human, but in many other multicellular organisms that reproduce sexually.

Materials:

Per lab group:

compound microscope
prepared slides of Ascaris meiosis in various stages
diagram of meiosis

Procedure:

Students work in groups of two. They should scan the prepared slide under appropriate magnification (medium power, about 100x) for a section which appears to be only one cell thick and for which they can see the insides of the cells clearly. Upon locating a suitable cell, they should switch to high power (400x) in order to more clearly see the chromosomes. Once they have located a cell with several rod-shaped bodies (chromosomes), the students sketch the cell and the chromosomes in the position they occur.

Next, the students should scan for another cell which has its chromosomes in a different position than the first cell they observed. Students sketch this new cell as before. Students should repeat the process for several differently-appearing cells. They may need to view more than one slide to find different phases of meiosis.

At this point, students should examine briefly a diagram of meiosis in a male and note the different positions of the chromosomes with each progressive stage of development from testis to sperm cell. Ask students to compare their sketches of the cells to the reference diagram of meiosis. Tell students to number each cell they sketched in the order they think represents the chronological sequence of development of these cells, using a “1” for the first developed cell and so on.

Background:

Most multicellular organisms can reproduce sexually. This means that new individuals produced must have parents, one male and one female. The male parent contributes a sperm cell to a new individual. A female parent contributes an egg cell to the individual. When the sperm cell fertilizes the egg cell, a new one-celled individual is created. The new individual then begins a long process of growth as an embryo. The embryo gains more and more cells until it becomes recognizable an immature individual of that species. Ultimately, over time, the individual grows further to reproductive maturity as an adult.

But how and where are the sperm and egg cells formed in the first place? Adult multicellular organisms, like humans, have specialized organs for reproduction. Human sperm are produced in the testes of males and human eggs are produced in the ovaries of females. How these sex cells are produced is through a process called meiosis.

In order to fully understand sexual reproduction, many questions must be answered. Why is meiosis absolutely necessary for normal sexual reproduction? Why is meiosis important in the process of evolution? How is meiosis different from mitosis? What does meiosis do to the number of chromosomes in a cell and why? Is meiosis a form of mitosis? Is mitosis a part of meiosis? What would happen to the number of chromosomes in offspring if two regular cells from each parent joined to form the embryo? How would you answer the question posed in the title of this reading?

By discussing with students the questions at the end, the teacher can determine the degree of understanding students may already have about sexual reproduction. In the next few activities students will investigate the processes of meiosis by examining testicular and ovarian tissues and see some of the events in the formation of sperm and egg cells.

Recommended slides are Carolina Biological, F6-E334, $6.15 ea. and F6E335, $7.95 ea.

During meiosis, cells are formed which are genetically different from each other and have half the number of chromosomes of the parent cell. Meiosis occurs during sex cell (gamete) formation creating sperm and egg with half the normal complement of chromosomes, the haploid state. In humans, the haploid number is 23 chromosomes. After fertilization, the embryo has a restored normal number of chromosomes, the diploid state, with half the number of chromosomes coming from each parent. In humans, the diploid number is 46 chromosomes. A key concept is that haploid cells have one copy of each of their chromosomes while diploid cells have two copies of each of their chromosomes, forming homologous pairs. The importance of this process cannot be overemphasized since it holds the key to the pattern of inheritance of the different forms of a particular character and to genetic variation.

The study of living cells shows the continuity of cell division. It is convenient, however, to describe the process in discrete phases. Meiosis consists of two nuclear divisions. The second, meiosis II, usually follows on immediately from the first, meiosis I. Phase names and a brief description of meiosis are given below:

Prophase I. Chromosomes condense and appear as two chromatids; spindle forms.

Homologous. Chromosomes exchange material.

Metaphase I. Chromosomes line up on equator of spindle.

Anaphase I. Chromosomes pulled to opposite ends of spindle—each chromosome is still made of two chromatids.

Telophase I. The cell divides into two; spindle disappears; two haploid nuclei now form.

Prophase II. New spindles form at right angles to the old spindles.

Metaphase II. Chromosomes line up along equator; centromeres attach to spindle fibers.

Anaphase II. Centromeres divide; chromatids separate; each chromatid now becomes a new Chromosome with its own centromere.

Telophase II. Spindles disappear; nuclear envelopes reform; each haploid cell divides into two, each still haploid.

Plants have a complex life cycle involving alternation of generations. In this cycle, meiosis is involved in the production of spores and mitosis in gamete production during sexual reproduction.

Variations:

This activity can be done in virtually the same manner, only using prepared slides from a flower ovary (recommended slides are Carolina Biological F6-B682, $2.99 ea; F6-B682B, $3.09 ea.; F6-B683, $4.32 ea; and F6-B684, $4.37 ea.) It might be interesting for students to compare the slides from a plant example vs. the animal example. It would be a reinforcing learning activity to do both activities, animal and plant versions.

Adapted from:
Rowland, Martin, *Biology,* Walton-on-Thames Surrey, UK: Thomas Nelson and Sons Ltd., 1992.
Goodman, H. D., L. E. Graham, T. C. Emmel and Y. Shechter, *Biology Today*, Orlando, Fla.: Holt, Rinehart and Winston, Inc., Harcourt Brace Jovanovich, Inc., 1991.

Teacher Sheet

Science as Inquiry

The Significance of Sexual Reproduction

What are the important events of meiosis?

Overview:

Students work cooperatively to review the important events of meiosis and discover the evolutionary and reproductive benefits of these events.

Materials:

Per lab group:
diagram of meiosis

Procedure:

Students work in groups of four. One member of the student group reads aloud the following paragraph (see student sheet version), while the others follow it on the diagram. The team should try to make sense of what is written in the paragraph and answer the following questions:

- What is significant about prophase I?
- What is significant about anaphase I?
- What is the evolutionary significance of meiosis I?
- If each human sperm and egg had the same number of chromosomes as all other cells, how many chromosomes would be present in a fertilized egg? What is the problem with this?
- Why does meiosis II separate the pair of homologous chromosomes into different cells?
- Why does meiosis II separate the sister chromatids into different cells?

Background:

Among the major three purposes of meiosis are:

Variation in chromosome makeup as a means of evolutionary change. This can occur in at least two ways during meiosis:

1) Crossing over during Prophase I. Crossing over exchanges the base-pair sequence of one homologue with the corresponding section on the other homologue. If the genes on the two sections are the same, such as in the case if the individual is heterozygous for the traits carried on those sections, there is no net change in the resulting homologues. If there are different alleles present for traits on the homologues exchanged, those new alleles are carried on the other homologue. The result of this is that a different mix of expressions of those traits represented will result in the individual and these will be associated with the expressions of the traits already present on the homologue. A different combination of expressions of traits is then possible in the individual.

2) Random segregation of homologues during Anaphase I. Segregation of homologous chromosomes occurs in Anaphase. Which homologue goes to which pole is determined entirely by chance. All other homologous pairs segregate randomly as well. The genes present on these chromosomes

will eventually end up in different gametes. If different alleles for any traits are present on one or the other homologue, then only these alleles will end up in the gamete and be expressed.

For humans, since there are 23 pairs of chromosomes, the probability that a specific combination which occurs during anaphase occurs again is 2^n (2 to the 23rd) or 1 in 8,388,608. This means that there is a very slim or zero chance of a same egg or sperm cell occurring again with exactly the same combination of homologous chromosomes.

Both crossing over and random segregation of alleles are important factors in creating genetic change in subsequent generations. This can, over time, create enough variation to help drive natural selection or just random (but significant) evolutionary changes in organisms.

Reduction in the number of chromosomes which ultimately end up in the gametes.

During anaphase I the homologous chromosomes separate and go to different cells. This reduces the chromosome composition from doubled (2N) to single (1N). Thereafter, all subsequent cells contain only that homologue. During meiosis II, the sister chromatids (identical copies of the homologue), also separate, so that the gametes end up with only one sister chromatid from one pair of homologues. This reduction by half in the number of chromosomes is necessary because, during fertilization, one egg with 1N chromosomes and egg sperm with 1N chromosomes combine to form a 2N set, which is the normal complement in the adult cells (except gametes). Without this reduction division during meiosis II, the resulting gametes would be 2N and the fertilized egg would be 4N, or a double set of paired chromosomes. The consequences of doubling the chromosome composition in newly formed individuals is also significant. Several examples can be cited, such as giant fruit produced for the commercial market. Doubling chromosomes in animals has been less successful, but some interesting possibilities exist.

Production of new chromosomes.

Adult individuals produce many more gametes than are ever fertilized. A human female produces one or two eggs monthly during reproductive maturity. A reproductively mature human male produces hundreds of thousands over a lifetime. Prior to prophase I, the chromatids duplicate, producing sister chromatids. These new chromatids eventually become part of the chromosome complement of new gametes. New chromosomes must be continuously produced to produce more gametes.

Variations:

This activity could be done as homework or as an assessment by focusing on students' answers to the questions. In class, students could be challenged to make an instructional poster to go along with a group presentation on the material in the reading.

Adapted from: none

an alternative activity for Event 4

Teacher Sheet

Science as Inquiry

Chromosomes on Parade

How can you model the sequence of meiosis?

Overview:

Students reconstruct the events and sequence of meiosis using clay to model the chromosomes.

Materials:

Per lab group:

modeling clay, blue and red, 100 g each
pipe cleaner
plain paper, white, 8.5 x 11
metric ruler
scissors

Procedure:

Students work in groups of two. The clay is used to make chromatid models. Students make a long roll about the width of a pencil with each color of clay. They should pinch the clay roll colors into 2 sections about 8 cm in length and 2 sections 4 cm in length. These will be the chromatids.

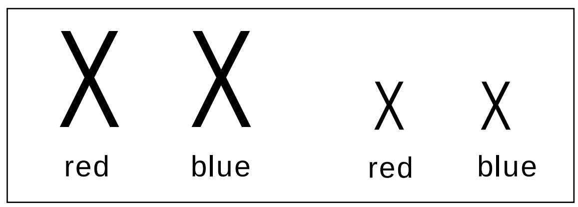


Fig. 1

The pipe cleaner is used to join two chromatids together simulating a centromere. Students should cut or break by bending the pipe cleaner into four equal sections. They use these to join two chromatids of similar color and length. The result will be four X-shaped bodies (chromosomes) each containing two sister chromatids, such as shown in Fig. 1.

Next, the students should lay the chromosomes randomly on the sheet of paper. This sheet represents the nucleus of a cell which produces eggs or sperm. Students should place similar sized red and blue chromosomes next to each other so that they actually touch. These represent homologous chromosomes. To demonstrate crossing over, instruct students to pinch off a section of one chromatid from one homologous chromosome (a red one) and replace it with a similar-sized piece from the same part of the other (blue) homologous chromosome.

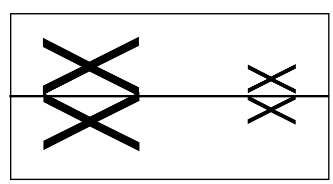


Fig. 2

The students are now asked to imagine (or actually draw) an equatorial line on the paper. They should move the chromosomes and orient them horizontally along the equator so that one homologue (with both sister chromatids) is to the North of the equator and one to the South as shown in Fig. 2.

Now the students make a small circle at the top and bottom centers of the page. This will symbolize the north and south poles of the cell respectively. The two chromosomes on either side of the equator are moved to their respective poles. The paper is now cut in half along the equator. There are now two cells, each containing one homologous chromosome from each chromosome pair. This marks the end of meiosis I.

A small circle is now placed at the other end of each of the two halves of the paper to symbolize the north and south poles of the new cells beginning meiosis II. The chromosomes should be kept on the papers as they were at the end of meiosis I.

A line is drawn across the center of each of the two new cells to represent their equators. The chromosomes are placed horizontally along the equator so that one sister chromatid is in the upper half (north) of the nucleus and the other chromatid is on the south side as shown in Fig. 3.

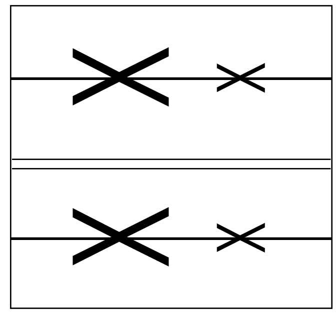


Fig. 3

The pipe cleaners are now detached from all sister chromatids. The two sister chromatids on the north sides of the equators move to the north poles and the ones on the south side to the south poles. Finally, the two halves of paper are cut along the equator representing the formation of nuclei of what is now four cells. Note that each new cell contains two different chromosomes. This represents the formation of eggs or sperm cells at the end of meiosis II. Another name for sperm and egg cells is gametes.

Background:

Among the major three purposes of meiosis are:

Variation in chromosome makeup as a means of evolutionary change. This can occur in at least two ways during meiosis:

1) Crossing over during Prophase I. Crossing over exchanges the base-pair sequence of one homologue with the corresponding section on the other homologue. If the genes on the two sections are the same, such as in the case if the individual is heterozygous for the traits carried on those sections, there is no net change in the resulting homologues. If there are different alleles present for traits on the homologues exchanged, those new alleles are carried on the other homologue. The result of this is that a different mix of expressions of those traits represented will result in the individual and these will be associated with the expressions of the traits already present on the homologue. A different combination of expressions of traits is then possible in the individual.

2) Random segregation of homologues during Anaphase I. Segregation of homologous chromosomes occurs in Anaphase. Which homologue goes to which pole is determined entirely by chance. All other homologous pairs segregate randomly as well. The genes present on these chromosomes will eventually end up in different gametes. If different alleles for any traits are present on one or the other homologue, then only these alleles will end up in the gamete and be expressed.

For humans, since there are 23 pairs of chromosomes, the probability that a specific combination which occurs during anaphase occurs again is 2^n (2 to the 23rd) or 1 in 8,388,608. This means that there is a very slim or zero chance of a same egg or sperm cell occurring again with exactly the same combination of homologous chromosomes.

Both crossing over and random segregation of alleles are important factors in creating genetic change in subsequent generations. This can, over time, create enough variation to help drive natural selection or just random (but significant) evolutionary changes in organisms.

Reduction in the number of chromosomes which ultimately end up in the gametes.

During anaphase I the homologous chromosomes separate and go to different cells. This reduces the chromosome composition from doubled (2N) to single (1N). Thereafter, all subsequent cells contain only that homologue. During meiosis II, the sister chromatids (identical copies of the homologue), also separate, so that the gametes end up with only one sister chromatid from one pair of homologues. This reduction by half in the number of chromosomes is necessary because, during fertilization, one egg with 1N chromosomes and egg sperm with 1N chromosomes combine to form a 2N set, which is the normal complement in the adult cells (except gametes). Without this reduction division during meiosis II, the resulting gametes would be 2N and the fertilized egg would be 4N, or a double set of paired chromosomes. The consequences of doubling the chromosome composition in newly formed individuals is also significant. Several examples can be cited, such as giant fruit produced for the commercial market. Doubling chromosomes in animals has been less successful, but some interesting possibilities exist.

Production of new chromosomes.

Adult individuals produce many more gametes than are ever fertilized. A human female produces one or two eggs monthly during reproductive maturity. A reproductively mature human male produces hundreds of thousands over a lifetime. Prior to prophase I, the chromatids duplicate, producing sister chromatids. These new chromatids eventually become part of the chromosome complement of new gametes. New chromosomes must be continuously produced to produce more gametes.

Variations:

Students may enjoy making a “claymation” movie using their models. Obtain a video camera and have students create videos providing their own narration and sound track. You may even have the capacity to have students create a computer simulation using appropriate software.

Adapted from: none

Science as Inquiry

Mitosis Critic

Item:

Criticize this statement: “Mitosis proceeds abruptly finishing one stage then moving on to another, such as metaphase to anaphase.”

Answer:

The statement is technically incorrect. The study of living cells shows the continuity of cell division. That is, mitosis is a dynamic process which proceeds somewhat smoothly through each “stage” although there is not an easily observable beginning and end to each one. It could be likened to the process of human maturation and adolescence. It is convenient, however, to describe the process of mitosis in discrete phases primarily for the field of study called cytology.

Science in Personal and
Social Perspective

Mitosis and Me

Item:

Describe in your own words why mitosis is important for your own well being.

Answer:

Among the major purposes of mitosis to be discussed are: Growth in size of an individual and tissue replacement.

Science as Inquiry

Mitosis by Stages

Item:

Describe the stages of mitosis and what is happening to the chromosomes during each stage.

Answer:

The study of living cells shows the continuity of cell division. It is convenient, however, to describe the process in discrete phases. Phase names and a brief description are given below:

Interphase. Chromosomes replicate.

Prophase. Chromosomes condense and spindle forms.

Metaphase. Chromosomes line up on equator of spindle.

Anaphase. Chromatids pulled to opposite ends of spindle.

Telophase. New nuclear envelope forms, spindle disappears.

Science in Personal and
Social Perspectives

Characteristics of Mitosis

Item:

Which of the following in not a purpose of cell division?

A. development of the organism as an embryo
B. replacement of worn or dead tissue
C. growth of the organism as a juvenile
D. carrying out metabolic processes
E. continual growth of tissue such as hair

Justification:

Where does mitosis fit into the overall picture of the life of an individual?

Answer:

D. Among the major purposes of mitosis are: Growth in size of an individual and tissue replacement. Therefore, mitosis is involved in all stages of an individual's life where growth occurs such as when an embryo and as a juvenile as well as in the ongoing growth of tissues such as hair. Also, mitosis is involved in the continual process of tissue replacement as in the example of skin cells. So, it can be said that mitosis is part of the entire life of a human.

Science as Inquiry

Chromosome Count

Item:

Illustrate the process of mitosis showing the stages of interphase, prophase, metaphase, anaphase, and telophase. Be sure to label the chromosomes and tell how many there are at each stage. Use an imaginary cell which has just 3 homologous pairs of chromosomes.

Answer:

Check to see that students start out and end up with the correct number of chromosomes in the cell. They should show a total of six X-shaped chromosomes (each chromosome having formed sister chromatids) going through the phases of mitosis.

Science as Inquiry

Who's Doing Meiosis?

Item:

Select the best and most inclusive answer. Meiosis occurs in:

A. animals
B. organisms who do not reproduce sexually
C. organisms who reproduce sexually
D. organisms who reproduce both sexually and non-sexually
E. all organisms

Justification:

Briefly describe at least one major purpose for meiosis.

Answer:

C. Meiosis is necessary in sexually reproducing organisms for several reasons: it creates variation in chromosomal make-up by crossing over during prophase 1 and random segregation of homologues during anaphase 1; reduction in the number of chromosomes which ultimately end up in the gametes; production of new chromosomes in the sex cells.

Science as Inquiry

Purpose of Meiosis

Item:

Choose the best and most inclusive answer. If an organism normally has 5 pairs of homologous chromosomes (10 actual chromosomes) in nearly all its body's cells, how many chromosomes are present in cells at the end of Meiosis 1:

A. 2.5
B. 5
C. 10
D. 20
E. none of the above.

Justification:

What is the major reproductive purpose of Meiosis 1?

Answer:

B. The major purpose of meiosis 1 is to divide the homologous chromosomes into two cells, thus reducing the number of chromosomes in each cell by one-half.

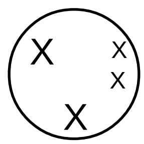
Science as Inquiry

Meiosis by Steps

Item:

Here is an example of a cell nucleus at the beginning of meiosis. Complete the illustration by drawing in each important step of meiosis through both the first and second divisions. Be sure to show the important phases of meiosis and the cellular results of the completed process. Label the phases if you can.

Beginning of Meiosis.



End of Meiosis.

Answer:

See any reference diagram of states of meiosis.

Consumables

Item	Quantity (per lab group)	Activity
diagram, cell cycle	1	3*
diagram, mitosis	1	1, 3*, 4, 5
prepared slides, Ascaris meiosis in various stages	—	4
prepared slides, mitosis in onion root tip	—	1
modeling clay, blue and red	100 g each	2, 6*
paper, whte, 8.5 x 11	1	2, 6*
pipe cleaner	1	2, 6*

Nonconsumables

Item	Quantity (per lab group)	Activity
compound microscope	1	1, 4
metric ruler	1	2, 6*
scissors	1 pr	2, 6*

*indicates alternative or additional activity

Key to activities:
1. Oops! There It Grows Again
2. Chromosomes in Motion
3. So That's Mitosis!
4. Caught in the Act
5. The Significance of Sexual Reproduction
6. Chromosomes on Parade

Activity Sources

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