Teacher Preparation Notes for
Meiosis and Fertilization – Understanding How Genes Are Inherited

In this hands-on, minds-on activity, students use model chromosomes and answer analysis and discussion questions to learn about the processes of meiosis and fertilization. As they model meiosis and fertilization, students follow the alleles of a human gene from the parents’ body cells through gametes to zygotes; thus, students learn how a person inherits one copy of each gene from each of his/her parents. To learn how meiosis contributes to genetic variation, students analyze the results of crossing over and independent assortment. Students also compare and contrast meiosis and mitosis, and they learn how a mistake in meiosis can result in Down syndrome or death of an embryo. This activity can be used to introduce meiosis and fertilization or to review these processes.

In addition to the more complete Student Handout (described above), we provide a shorter Student Handout which omits the analyses of independent assortment and mistakes in meiosis and adds a section on asexual vs. sexual reproduction. In these Teacher Preparation Notes, the page numbers and question numbers refer to the more complete version of the Student Handout.

We estimate that the more complete Student Handout will require approximately 2-3 50-minute periods. Obviously, the time required for this activity will vary, depending on how much your students already know and which version of the Student Handout you use.

We recommend that, before your students begin this activity, you have them complete “Mitosis – How a Single Cell Develops into the Trillions of Cells in a Human Body” (http://serendipstudio.org/exchange/waldron/mitosis).

These Teacher Preparation Notes include:
- Learning Goals (pages 2-3)
- Model Chromosomes (pages 3-4)
- Additional Supplies and Requirements for the Modeling Activities (page 4)
- Instructional Suggestions and Background Biology
  - General (page 4)
  - Introductory Section (on pages 1-2 in the Student Handout) (page 4)

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1 By Drs. Ingrid Waldron, Jennifer Doherty, Scott Poethig and Lori Spindler. Department of Biology, University of Pennsylvania, 2018. These Teacher Preparation Notes, and both the more complete and shorter versions of the Student Handout are available at http://serendipstudio.org/exchange/waldron/meiosis. We are grateful to K. Harding for her helpful suggestion to use hair curler rollers for the model chromosomes and to local high school and middle school teachers who contributed helpful suggestions for revision of this activity.

2 This activity helps to correct common misconceptions, including:
  - Students have difficulty distinguishing between mitosis and meiosis and between somatic and germ lines.
  - Students don’t understand the role that meiosis plays in heredity (e.g. why offspring resemble their parents and why there are genetic differences between siblings).
(These misconceptions are paraphrased from Chapter 3 of Hard to Teach Biology Concepts by Susan Koba with Ann Tweed, 2009, NSTA Press.)

3 For middle school students, you can use the shorter versions of the Student Handouts for our mitosis activity and meiosis and fertilization activity to help your students prepare for the following NGSS Performance Expectation.
  - MS-LS3-2, "Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation."

4 These cell division activities are part of an integrated sequence of learning activities for teaching genetics presented in "Genetics – Major Concepts and Learning Activities" (http://serendipstudio.org/exchange/bioactivities/GeneticsConcepts).
How Meiosis Makes Haploid Gametes (page 5)
How Meiosis Makes Genetically Diverse Gametes (pages 5-7)
Comparing Meiosis and Mitosis (page 7)
Genes are inherited via meiosis and fertilization. (Pages 7-8)
How Mistakes in Meiosis Can Result in Down Syndrome or Death of an Embryo (pages 9-10)
Asexual vs. Sexual Reproduction (in shorter version of Student Handout) (page 11)

Follow-Up and Related Activities (page 11)
Sources for Figures in the Student Handout (pages 11-12)
Labels Needed for Meiosis and Fertilization Modeling Activity (page 13)

**Learning Goals**

In accord with the Next Generation Science Standards:

- Students will gain understanding of several **Disciplinary Core Ideas**:
  - LS1.A: Structure and Function – "All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins."
  - LS3.A: Inheritance of Traits – "Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA."
  - LS3.B: Variation of Traits – "In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation."

- Students will engage in the **Scientific Practices**:
  - “Developing and Using Models – Develop, revise, and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems."
  - “Constructing Explanations – Apply scientific ideas, principles and/or evidence to provide an explanation of phenomena…".

- This activity provides the opportunity to discuss the **Crosscutting Concepts**
  - "Systems and system models – … Models can be valuable in predicting a system’s behaviors…"
  - “Cause and Effect: Mechanism and Explanation – … A major activity of science is to uncover such causal connections, often with the hope that understanding the mechanisms will enable predictions… [Students] suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about small-scale mechanisms within the system."

- This activity helps to prepare students for the **Performance Expectations**:
  - HS-LS3-1, "Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring."

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5 For more detailed learning goals and common misconceptions, see "Mitosis, Meiosis and Fertilization – Major Concepts, Common Misconceptions and Learning Activities" (http://serendipstudio.org/exchange/bioactivities/MitosisMeiosis).

• HS-LS3-2, "Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis…"

Model Chromosomes
Instructions for making the model chromosomes are provided in the Teacher Preparation Notes for the first activity in our two-part introduction to cell division, “Mitosis – How a Single Cell Develops into the Trillions of Cells in a Human Body” (http://serendipstudio.org/sci_edu/waldron/#mitosis).

For the more complete Student Handout, each student group will need both pairs of model chromosomes shown in this chart to model meiosis.

<table>
<thead>
<tr>
<th>First Pair of Homologous Model Chromosomes</th>
<th>Second Pair of Homologous Model Chromosomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>A</td>
</tr>
<tr>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>a</td>
<td>A</td>
</tr>
<tr>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For the section entitled “Genes are inherited via meiosis and fertilization”, each student group will need two pairs of model homologous chromosomes with the a and A alleles. The two pairs should be different colors to represent the mother’s and father’s chromosomes. To prepare these chromosomes, students will follow the instructions on page 7 of the Student Handout to modify the chromosomes they have used for the meiosis part of the activity. You will need to print copies of the labels shown on the last page of these Teacher Preparation Notes for the students to use. Each student group will need eight blank labels to cover the S, s, L, and l alleles plus two each of the a and A labels to convert the second pair of model chromosomes so they have the a and A alleles. Thus, each page of labels provides enough labels for three student groups. Each label can be wrapped around the model chromosome and the ends taped together for easy removal for future use of the original model chromosomes. You may need to adjust the size of the labels to work with your specific model chromosomes. We recommend that you use these labels and do not put tape directly on the rolosomes, since the foam of the rolosomes may be damaged when you remove the tape to prepare the rolosomes for use in another class.7

Instructions to use the model chromosomes to demonstrate independent assortment are included on page 5 of the Student Handout. However, the model chromosomes are not used to demonstrate crossing over. If you would like to use the model chromosomes to demonstrate crossing over, you can modify the model chromosomes as follows. For rolosomes, you can cut the hair roller curlers with wire cutters and use Velcro dots on the cut ends; if you do this, you may want to put transparent tape around the crossing over location during the modeling activities which do not involve crossing over. If you are using sockosomes and want to demonstrate crossing over, you can use a larger pair of socks and cut off a portion of the top of each sock to be stuffed and sewed close separately. The top portion can then be reattached with Velcro.

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7 For the shorter Student Handout, modeling meiosis requires only the first pair of model chromosomes. To model meiosis and fertilization, each student group will require a second set of these chromosomes, but in a different color. We recommend that you switch from having pairs of students work together to model meiosis to having student groups of four work together to model meiosis and fertilization; if half of your pairs of model chromosomes are in one color and half in another color, then you will not need any additional chromosomes for modeling meiosis and fertilization. Alternatively, you can keep the size of your student groups the same, in which case you will need to make a second set of model chromosomes for the part of the activity where students model meiosis and fertilization.
allowing it to be swapped with the top portion of another sock. Alternatively, you could use chromosomes made of different color pop beads to illustrate crossing over.

**Additional Supplies and Requirements for the Modeling Activities**

Students sometimes have difficulty recognizing which chromosomes are in the different daughter cells produced by meiosis. Therefore, we recommend that you provide pieces of string or yarn for students to use as cell membranes. For the modeling activity on page 4 of the Student Handout, each student group will need approximately 8 feet of string to represent the membranes surrounding the cells and, optionally, a pair of scissors to cut the string into appropriate length pieces for the various cells produced by meiosis. Alternatively, you can have the students use chalk or dry erase marker to draw the cell membranes on their lab tables.

Students should carry out the modeling activities on a lab table or similar large flat surface, so they can more easily see the processes and outcomes. On page 8 of the Student Handout, students are instructed to draw the rectangles of the chart on their lab table with chalk, dry erase markers or tape. These rectangles will help students to carry out the fertilization part of the activity in a systematic manner.

**Instructional Suggestions and Background Information**

In the Student Handout, numbers in bold indicate questions for the students to answer and ➢ indicates a step in the modeling procedures for the students to do.

If you are using the Word version of the Student Handout, please check the PDF version to make sure that all figures and formatting are displayed properly in the Word version on your computer.

If you would like to have a key with the answers to the questions in the Student Handout, please send a message to iwaldron@upenn.edu. The following paragraphs provide additional background information and instructional suggestions.

During the modeling activities, it is crucial to circulate among student groups continuously and provide considerable input in order to prevent student confusion.

**Introductory Section**

Page 1 of the Student Handout will start students thinking about the essential question for this activity, “How does a person get one copy of each gene from each parent?” For some students, you may need to begin by reviewing the concept of a gene as a segment of a DNA molecule that provides the instructions for making a protein. (For a brief discussion of more sophisticated definitions of a gene, see page 6 of http://serendipstudio.org/sci_edu/waldron/pdf/MitosisTeachPrep.pdf).

**Question 2** engages students in reviewing mitosis in the context of understanding the human lifecycle. Questions 3a and 3b alert students to the distinction between the role of mitosis in the cell cycle and the role of meiosis in the human lifecycle (which of course also requires mitosis).

Page 2 of the Student Handout introduces the terms diploid and haploid and reinforces student understanding of the human lifecycle, as a context for understanding the significance of meiosis and fertilization. To answer question 8, students should integrate the information from questions 1-7. If this question is challenging for your students, they may benefit from a preliminary small group discussion of the points they want to include in their answers, using the vocabulary list to suggest relevant concepts. However, each student should prepare a written answer in his or her own words.
How Meiosis Makes Haploid Gametes

Page 3 of the Student Handout will help students understand how meiosis makes haploid gametes. Student understanding of this process is reinforced in the modeling activity on page 4 of the Student Handout. You may want to contrast meiosis, which involves one replication of DNA and two cell divisions, with mitosis, which involves a cell division for each time the DNA is replicated (question 11). Both meiosis II and mitosis involve separation of sister chromatids, but meiosis II begins with haploid cells and produces haploid cells, whereas mitosis begins with a diploid cell and produces diploid cells (question 12). Additional comparisons between mitosis and meiosis are provided in questions 18-20.

The Student Handout implies that meiosis results in the production of four gametes. This is accurate for meiosis in males. However, in females each meiotic division produces one cell which has most of the cytoplasm and another tiny polar body cell. Thus, meiosis produces a single egg with a lot of cytoplasm, which is useful when the fertilized egg begins to undergo mitotic cell divisions. We have omitted this information from the Student Handout to avoid excessive complexity in this introductory activity.

How Meiosis Makes Genetically Diverse Gametes

This section of the Student Handout reinforces student understanding of the process of meiosis and introduces crossing over and independent assortment as processes that contribute to the genetic diversity of gametes. For information about the phenotypic effects of the alleles introduced in this section, see the introductory activity, “Mitosis – How a Single Cell Develops into the Trillions of Cells in a Human Body” (http://serendipstudio.org/exchange/waldron/mitosis).

You may want to use the following figure and question to reinforce student understanding of meiosis and to help students understand how crossing over contributes to the production of genetically diverse gametes.
16. Match each item in the list below with the appropriate number from this flowchart.

- Chromosome duplication ___
- Crossing over ___
- Homologous chromosomes line up next to each other___
- Meiosis I ___
- Meiosis II ___

To reinforce student understanding of crossing over and independent assortment, you may want to add the following questions:

18a. Explain how different gametes produced by the same person can have different combinations of alleles for two genes that are located far apart on the same chromosome.

18b. Explain how different gametes produced by the same person can have different combinations of alleles for genes that are located on two different chromosomes.

After completing the section on meiosis in the Student Handout, you may want to use one of these videos to consolidate student understanding of meiosis and, if you want, introduce some additional points:

- Meiosis (available at https://www.youtube.com/watch?v=D1_-mQs_FZ0; a brief, clear review of meiosis)
- Meiosis: the Great Divide (available at https://www.youtube.com/watch?v=toWK0f1yFIY&list=PLwL0Myd7Dk1F0iQPGrjehze3eDpc0iEzVz&index=11; this video includes a clear basic introduction to the phases of meiosis I and meiosis II)
- Meiosis: the Movie (available at http://vcell.ndsu.nodak.edu/animations/meiosis/movie-flash.htm; this animation includes considerable additional information and terminology; it has an error near the end where the narrator says that two gametes fuse to form an embryo (should be a zygote! – You can use this as a teachable moment and ask your students to detect and correct the error.))
Comparing Meiosis and Mitosis

To begin this section, we recommend that your students review an animation that compares mitosis and meiosis (click on launch interactive under How Cells Divide at http://www.pbs.org/wgbh/nova/body/how-cells-divide.html).

Some similarities between mitosis and meiosis are:
- Before mitosis or meiosis the DNA is replicated to form two copies of the original DNA.
- At the beginning of mitosis or meiosis the replicated DNA is condensed into a pair of sister chromatids in each chromosome.
- In both mitosis and meiosis, spindle fibers line up the chromosomes in the middle of the cell.
- At the end of each cell division, cytokinesis forms two daughter cells.

Some differences between mitosis and meiosis are:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mitosis</th>
<th>Meiosis</th>
</tr>
</thead>
<tbody>
<tr>
<td># of daughter cells</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Produces:</td>
<td>Diploid body cells</td>
<td>Haploid gametes</td>
</tr>
<tr>
<td># and type of cell divisions</td>
<td>1; separates sister chromatids</td>
<td>2; the first division separates pairs of homologous chromosomes and the second division separates sister chromatids</td>
</tr>
<tr>
<td>Genetic makeup of daughter cells</td>
<td>Identical with each other and the original cell</td>
<td>Different from original cell and from each other</td>
</tr>
</tbody>
</table>

To enhance student understanding of the differences between mitosis and meiosis, you may want to add the following question:

21. Explain why sexually reproducing organisms need to have two different types of cell division. What are the advantages of mitosis and the advantages of meiosis?

The following examples illustrate one effect of the different ways that chromosomes line up at the beginning of meiosis I vs. mitosis.

To understand the difference between mitosis and meiosis it may be helpful to understand about the infertility of mules and seedless watermelons: Mules are the result of a cross between a horse (2n = 64) mother and donkey (2n = 62) father, hinnies are the results of the opposite cross, donkey mother, horse father. Since the fertilized egg produces the offspring by mitosis the fact that there are not homologous chromosomes in the mule presents no problem. However, when the mule (male or female) attempts to undergo meiosis to produce gametes, the lack of homologous chromosomes becomes a problem since successful meiosis requires the pairing up of homologous chromosomes. No homologues, no meiosis, no baby mules. Seedless watermelons are the results of a cross between a tetraploid (4n) watermelon (gametes are 2n) and a diploid (2n) watermelon (gametes are n) which gives rise to a triploid (3n) watermelon. The triploid watermelon arises by mitosis but when it attempts meiosis, it fails because there are three instead of two homologous chromosomes. Therefore, runty little seeds instead of the characteristic large black ones are produced. In mitosis all chromosomes go to the metaphase dance alone; in meiosis, chromosomes must find a (single) partner with whom to go to the metaphase I dance.

Genes are inherited via meiosis and fertilization.
This section helps students to understand how meiosis and fertilization result in the inheritance of genes, using the example of two parents who each have the Aa genotype. The flowchart on page 7 of the Student Handout shows one possible outcome of meiosis and fertilization in a context that will be familiar from the introductory section of the Student Handout.
The bottom of page 7 provides instructions for the students to **prepare the model chromosomes** they will use to model meiosis and fertilization for two parents who have the **Aa** genotype. They will need labels and tape (see page 3 of these Teacher Preparation Notes).

The chart on the top of page 8 of the Student Handout will help students model **fertilization** more systematically. For either parent, only two of the four model chromosomes produced by meiosis are used to model fertilization; you may want to suggest that students think of the other two model chromosomes as representing the many gametes that never participate in fertilization and die an anonymous death. Also, it’s important to make sure that students understand that the four zygotes are the possible alternative outcomes of fertilization. Typically, a woman only ovulates one egg at a time, so only one of the fertilization events would actually occur; occasionally, a woman will ovulate two eggs simultaneously and fraternal twins may result. Teachers will recognize that the chart for recording the results of meiosis and fertilization is a Punnett square, which is a formalized way of presenting the results of meiosis and fertilization. We recommend postponing explicit discussion of Punnett squares to our Genetics activity (available at [http://serendipstudio.org/sci_edu/waldron/#genetics](http://serendipstudio.org/sci_edu/waldron/#genetics)).

Your students should recognize that human cells are produced by **mitosis** (almost all cells), meiosis (gametes), or fertilization (zygote). Thus, **all cells are derived from other cells**.

**Question 26** will stimulate students to synthesize what they have learned about how meiosis and fertilization contribute to **genetic diversity**. During meiosis, independent assortment of the 23 pairs of homologous chromosomes can produce more than 8 million different combinations of chromosomes in the different eggs or sperm produced by one person. If each of the different types of egg from one mother could be fertilized by each different type of sperm from one father, this would produce zygotes with approximately 70 trillion different combinations of chromosomes! Crossing over results in an even greater amount of genetic diversity. Thus, it is easy to understand why no two people are genetically identical (except for identical twins who both developed from the same zygote).

**Question 26** can be used for **formative assessment**. Students may benefit from a preliminary small group discussion of question 26 where they could brainstorm the points that should be included in their answers, using the vocabulary list to suggest relevant concepts. However, each student should prepare a written answer in his or her own words.

After question 26, you may want to have a class discussion of the **Crosscutting Concepts**, Systems and System Models and Cause and Effect: Mechanism and Explanation (see page 2). You can ask students how the modeling activities and cause and effect relationships help them to understand the similarities and differences between siblings.
How Mistakes in Meiosis Can Result in Down Syndrome or Death of an Embryo
In the activity thus far, students have learned how normal meiosis and fertilization result in multiple genetic differences between siblings. In this section, students learn how a mistake in meiosis can produce a major genetic difference. Mutations are another source of genetic differences, as discussed in The Molecular Biology of Mutations and Muscular Dystrophy (http://serendipstudio.org/exchange/bioactivities/mutation).

You may want to use an analogy to help your students understand why abnormalities result when each cell has an extra copy of one of the chromosomes and therefore has extra copies of the proteins coded for by the genes in that chromosome. For example, you could ask your students what would happen if someone added too much milk when preparing a box of macaroni and cheese or what would happen if there were too many tubas in a marching band. Cells are much more complicated than these examples, and cells cannot function properly when there are too many copies of some types of proteins due to an extra copy of one of the chromosomes.

Students can extrapolate from the information at the top of page 10 of the Student Handout to answer question 28. As described in the table on the next page, autosomal monosomy is always fatal in utero.

Most cases of Down syndrome are due to trisomy 21 which typically is the result of meiotic nondisjunction during the first or second meiotic division in the formation of a gamete. This type of trisomy 21 is genetic, but it is not inherited.

Roughly 2% of cases of Down syndrome are due to inheritance of a translocated chromosome 21. A parent may be a carrier of a balanced translocation (i.e. one chromosome 21 free and most of a second chromosome 21 attached to a different chromosome); a person with a balanced translocation does not have symptoms, but does have a propensity to produce gametes with two copies of chromosome 21.

Mosaic Down syndrome is due to mitotic nondisjunction and is of variable severity, depending on how many and which cells have trisomy 21. This condition can be used to illustrate the general point that Down syndrome varies in severity.


For question 32, students are expected to argue that trisomy for chromosomes 1, 2, 3, 4 or 5 is more likely to be lethal than trisomy for chromosome 21 because the longer chromosomes would be expected to have more genes and a third copy of all of these genes would be more likely to disrupt cellular functions so much that the embryo dies. It should be mentioned that the severity of abnormalities resulting from trisomy is not strictly related to the length of the trisomy chromosome. One reason is that the number of genes on a chromosome is not strictly proportional to the length of the chromosome; for example, chromosome 4 appears to have 1000-1100 genes, while chromosome 11 appears to have 1300-1400 genes (chromosome 21 appears to have 200-300 genes; http://grh.nlm.nih.gov/chromosomes).
This table describes a variety of mistakes in fertilization, meiosis and mitosis and their outcomes in humans. The conditions listed in this table are genetic, but not inherited.

<table>
<thead>
<tr>
<th>Mistake</th>
<th>Results in</th>
<th>E.g.</th>
<th>Pregnancy outcome</th>
<th>Outcome after birth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilization by more than one sperm</td>
<td>Polyploidy</td>
<td>Triploidy</td>
<td>Almost always fatal in utero; ( \rightarrow \sim 15% ) of miscarriages</td>
<td>Fatal within a month</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tetraploidy</td>
<td>Fatal in utero; ( \rightarrow \sim 5% ) of miscarriages</td>
<td></td>
</tr>
<tr>
<td>Meiotic non-disjunction</td>
<td>Aneuploidy</td>
<td>Autosomal trisomy</td>
<td>Usually fatal in utero, but trisomy 8, 13 and 18 sometimes survive until birth and trisomy 21 can survive into adulthood; trisomies ( \rightarrow \sim 1/3 ) of miscarriages</td>
<td>Trisomy 8, 13 or 18 severely disabled and do not survive to adulthood; trisomy 21 can survive to adulthood, although heart defects and leukemia relatively common; degree of mental retardation variable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45XO (44 autosomes plus 1 X chromosome) = Turner syndrome</td>
<td>99% die in utero; but this is the only viable monosomy*</td>
<td>Infertile, normal IQ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>47XXY = Kleinfelter syndrome</td>
<td>Majority die in utero, but some survive into adulthood*</td>
<td>Very low fertility and learning disabilities common</td>
</tr>
<tr>
<td>Mitotic non-disjunction</td>
<td>If occurs very early in embryonic development, can result in polyploidy or aneuploidy or mosaic</td>
<td>Kleinfelter syndrome mosaic can have similar symptoms, but some cells have normal chromosome makeup</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Primary source: Michael Cummings, 2006, *Human Heredity*)

*In each cell all but one X chromosome is inactivated, so variation in the number of X chromosomes does not produce as severe abnormalities as autosomal trisomy or monosomy. A small part of each X chromosome is not inactivated, which explains why abnormal numbers of X chromosomes result in some abnormalities.
Asexual vs. Sexual Reproduction (in shorter version of Student Handout)
This section will help middle school students prepare for the following NGSS Performance Expectation.

- MS-LS3-2, "Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation."  

Additional information and examples are available at:
- http://www.saburchill.com/ans02/chapters/chap049.html

Follow-Up and Related Activities
We recommend that this activity be followed by our Genetics activity (available at http://serendipstudio.org/sci_edu/waldron/#genetics), so your students will develop a better understanding of how meiosis and fertilization provide the basis for understanding inheritance. These activities are part of an integrated sequence of learning activities for teaching genetics, presented in "Genetics – Major Concepts and Learning Activities" (available at http://serendipstudio.org/exchange/bioactivities/GeneticsConcepts).

A Mitosis and Meiosis Card Sort activity to reinforce understanding of the processes of mitosis and meiosis and a Mitosis, Meiosis and Fertilization Vocabulary Game to reinforce learning of relevant vocabulary are available at http://serendipstudio.org/exchange/bioactivities/#celldivision.

As a follow-up challenge question, you may want to ask your students:

Sally and Harry fall in love. They introduce Sally's identical twin, Emily, to Harry's identical twin, Ken. Soon there is a double wedding where Sally marries Harry and Emily marries Ken. Both Sally and Emily get pregnant. They wonder "Will their babies look exactly alike?" Answer their question, and explain your reasoning.

Additional relevant resources are described in the Teacher Preparation Notes for "Mitosis – How a Single Cell Develops into the Trillions of Cells in a Human Body" (available at http://serendipstudio.org/sci_edu/waldron/#mitosis).

Sources for Figures in the Student Handout (The other figures were prepared by the authors.)
- Figure on the bottom of page 1 modified from https://dr282zn36sxxg.clo Cloudfront.net/dastreams/f-d%3A878df64c63462553305d51d5deccdec3c0cb0aee48fa51aeb9297f1b%2BIMAGE_THUMB_POSTCARD_TINY%2BIMAGE_THUMB_POSTCARD_TINY.1
- Figure on the bottom of page 4 adapted from http://www.phschool.com/science/biology_place/labbench/lab3/images/crossovr.gif

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• Figure on the top of page 6 from source similar to https://i.pinimg.com/736x/d9/ba/19/d9ba196121c59daf57ca71fc2e4e7106--compare-and-contrast-visual-aids.jpg
• Figure on page 10 modified from http://bio3400.nicerweb.com/Locked/media/ch02/02_04-human_karyotype.jpg