Unit 5: Heredity

Topic	Learning Objective(s)
5.1 Meiosis	**IST-1.F** Explain how meiosis results in the transmission of chromosomes from one generation to the next.
	IST-1.G Describe similarities and/ or differences between the phases and outcomes of mitosis and meiosis.
5.2 Meiosis and Genetic Diversity	**IST-1.H** Explain how the process of meiosis generates genetic diversity
5.3 Mendelian Genetics	**EVO-2.A** Explain how shared, conserved, fundamental processes and features support the concept of common ancestry for all organisms.
	IST-1.I Explain the inheritance of genes and traits as described by Mendel's laws
5.4 Non-Mendelian Genetics	**IST-1.J** Explain deviations from Mendel's model of the inheritance of traits.
5.5 Environmental Effects on Phenotype	**SYI-3.B** Explain how the same genotype can result in multiple phenotypes under different environmental conditions.
5.6 Chromosomal Inheritance	**SYI-3.C** Explain how chromosomal inheritance generates genetic variation in sexual reproduction.

Free Response Practice

2022 #2

During meiosis, double-strand breaks occur in chromatids. The breaks are either repaired by the exchange of genetic material between homologous non-sister chromatids, which is the process known as crossing over (Figure 1A), or they are simply repaired without any crossing over (Figure 1B). Plant breeders developing new varieties of corn are interested in determining whether, in corn, a correlation exists between the number of meiotic double-strand chromatid breaks and the number of crossovers.

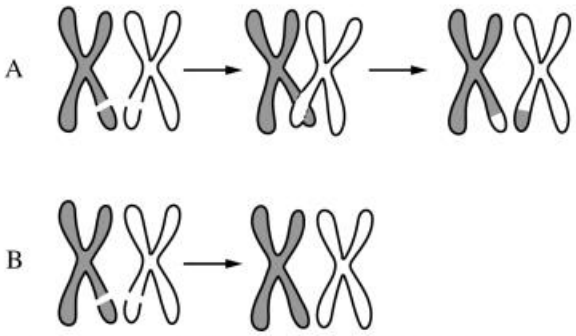


Figure 1. Double-strand breaks in chromatids are repaired with crossing over (A) or without crossing over (B).

Using specialized staining and microscopy techniques, scientists counted the number of double-strand chromatid breaks and the number of crossovers in the same number of meiotic gamete-forming cells of six inbred strains of corn (Table 1).

TABLE 1. NUMBER OF CHROMATID DOUBLE-STRAND BREAKS AND AVERAGE NUMBER OF CROSSOVERS IN INBRED STRAINS OF CORN

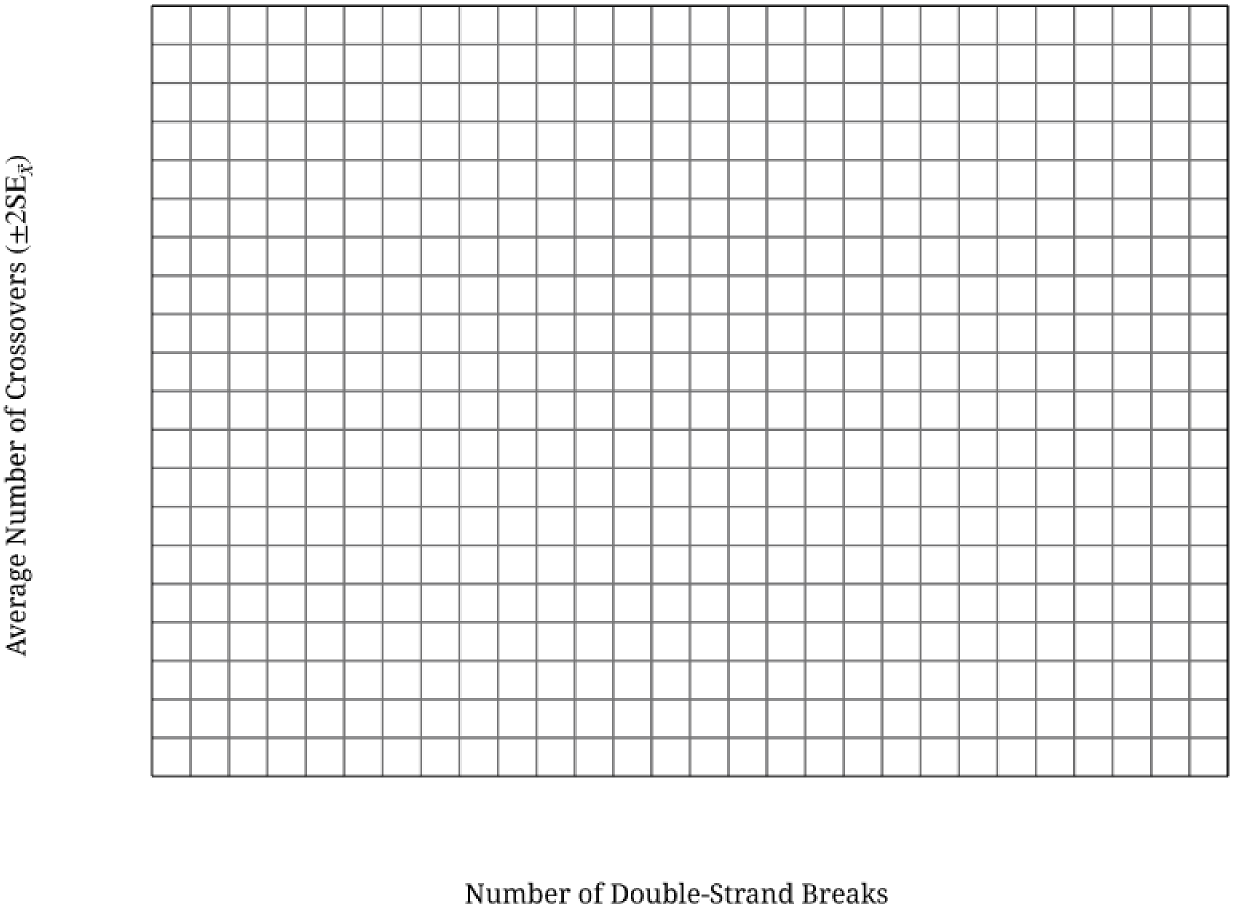
Strain of Corn	Number of Double-Strand Breaks	Average Number of Crossovers ($\pm 2SE_{\bar{x}}$)
I	710	19.5 ± 0.5
II	650	18.0 ± 0.7
III	600	17.5 ± 1.0
IV	510	16.0 ± 1.0
V	425	14.0 ± 0.5
VI	325	11.0 ± 1.5

(a) The double-strand breaks occur along the DNA backbone. **Describe** the process by which the breaks occur.

(b) Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1 and allows examination of a possible correlation between double-strand breaks and crossovers. Based on the data, determine whether corn strains I, II, and III differ in their average number of crossovers.

(c) Based on the data, **describe** the relationship between the average number of double-strand breaks and the average number of crossovers in the strains of corn analyzed in the experiment.

(d) Crossing over (Figure 1A) creates physical connections that are required for proper separation of homologous chromosomes during meiosis. A diploid cell with four pairs of homologous chromosomes undergoes meiosis to produce four haploid cells. Crossing over occurs between only three of the pairs. **Predict** the number of chromosomes most likely present in each of the four haploid cells. Provide reasoning to **justify** your prediction. Explain how plant breeders can use the information in Table 1 to help develop new varieties of corn.



2019 #3

The pyruvate dehydrogenase complex (PDC) catalyzes the conversion of pyruvate to acetyl-CoA, a substrate for the Krebs (citric acid) cycle. The rate of pyruvate conversion is greatly reduced in individuals with PDC deficiency, a rare disorder.

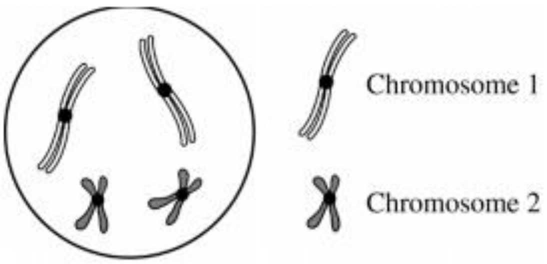
(a) **Identify** the cellular location where PDC is most active.

(b) **Make a claim** about how PDC deficiency affects the amount of NADH produced by glycolysis AND the amount of NADH produced by the Krebs (citric acid) cycle in a cell. **Provide reasoning** to support your claims based on the position of the PDC-catalyzed reaction in the sequence of the cellular respiration pathway.

(c) PDC deficiency is caused by mutations in the *PDHA 1* gene, which is located on the X chromosome. A male with PDC deficiency and a homozygous female with no family history of PDC deficiency have a male offspring. **Calculate** the probability that the male offspring will have PDC deficiency.

2016 #7

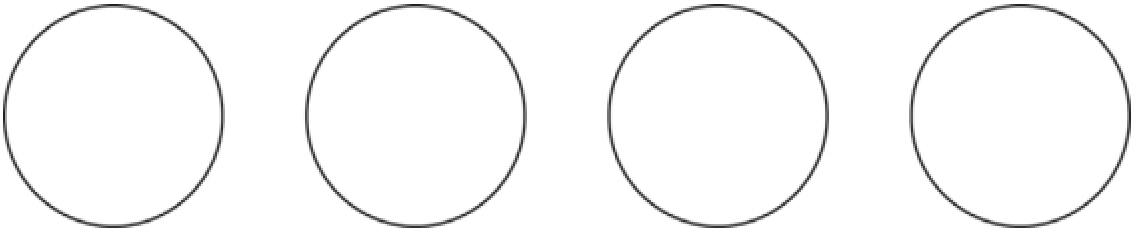
In a certain species of plant, the diploid number of chromosomes is 4 (2n = 4). Flower color is controlled by a single gene in which the green allele (G) is dominant to the purple allele (g). Plant height is controlled by a different gene in which the dwarf allele (D) is dominant to the tall allele (d). Individuals of the parental (P) generation with the genotypes GGDD and ggdd were crossed to produce F_1 progeny.



(a) **Construct** a diagram below to depict the four possible normal products of meiosis that would be produced by the F_1 progeny. Show the chromosomes and the allele(s) they carry. Assume the genes are located on different chromosomes and the gene for flow color is on chromosome 1.

(b) **Predict** the possible phenotypes and their ratios in the offspring of a testcross between an F_1 individual and a ggdd individual.

(c) If the two genes were genetically linked, **describe** how the proportions of phenotypes of the resulting offspring would most likely differ from those of the testcross between an F_1 individual and a ggdd individual.



2015 #4

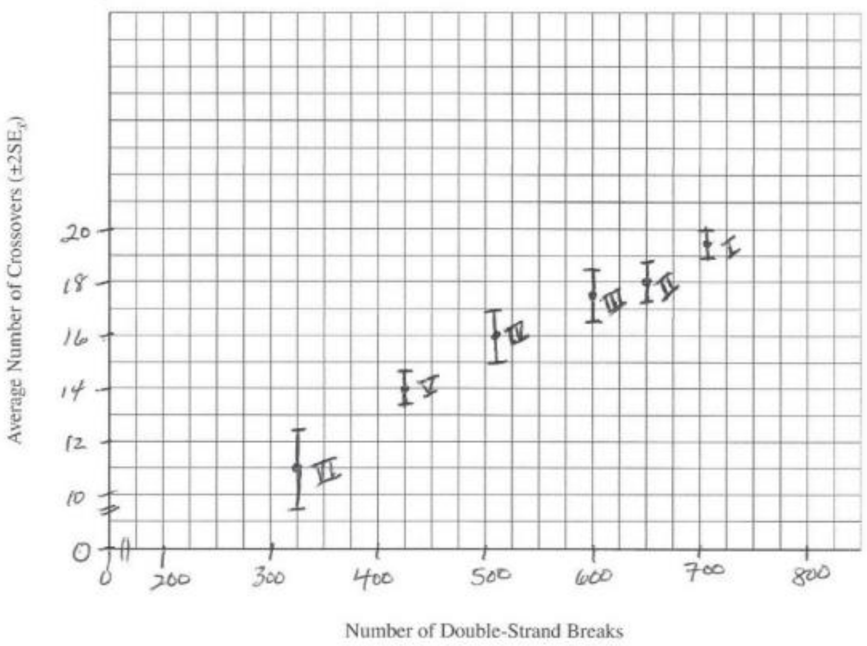
Both mitosis and meiosis are forms of cell division that produce daughter cells containing genetic information from the parent cell.

(a) **Describe** TWO events that are common to both mitosis and meiosis that ensure the resulting daughter cells inherit the appropriate number of chromosomes.

(b) The genetic composition of daughter cells produced by mitosis differs from that of the daughter cells produced by meiosis. **Describe** TWO features of the cell division processes that lead to these differences.

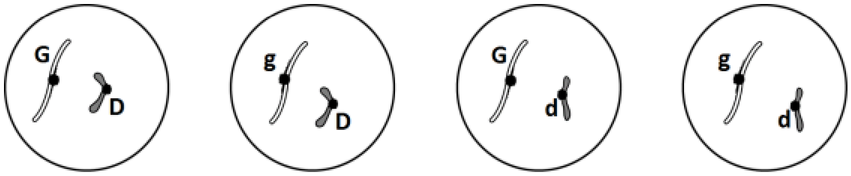
Free Response Scoring Guidelines

2022 #2

Part	Scoring Guidelines	Topic
(a)	The double-strand breaks occur along the DNA backbone. **Describe** the process by which the breaks occur. Accept one of the following: • (Enzymatic) hydrolysis occurs between the <u>sugars and phosphates</u>/<u>nucleotides</u>. • The covalent bonds between the <u>sugars and phosphates</u>/<u>nucleotides</u> are broken.	1.3
(b)	Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1 and allows examination of a possible correlation between double-strand breaks and crossovers.  • Appropriate axis scaling Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1 and allows examination of a possible correlation between double-strand breaks and crossovers. • Accurately plotted X,Y graph with separate points for the average number of crossovers for each strain Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1 and allows examination of a possible correlation between double-strand breaks and crossovers. • Accurate error bars Based on the data, **determine** whether corn strains I, II, and III differ in their average number of crossovers. • There is no (statistical) difference (in the average number of crossovers) between strains II and III. Strain I is <u>higher</u>/<u>different</u> (in the average number of crossovers) compared with strains II and III.	

(c)	Based on the data, **describe** the relationship between the average number of double strand breaks and the average number of crossovers in the strains of corn analyzed in the experiment. • (In general) there is a direct correlation/positive relationship (between the number of double-strand breaks and the number of chromatid crossovers).	
(d)	Crossing over (Figure 1A) creates physical connections that are required for proper separation of homologous chromosomes during meiosis. A diploid cell with four pairs of homologous chromosomes undergoes meiosis to produce four haploid cells. Crossing over occurs between only three of the pairs. **Predict** the number of chromosomes most likely present in each of the four haploid cells. • Two cells will have three/n−1 chromosomes; two cells will have five/n+1 chromosomes. Provide reasoning to **justify** your prediction. • During meiosis I, (three homologous pairs separate normally, and) one pair does not separate/experiences nondisjunction. In meiosis II, the sister chromatids separate normally. **Explain** how plant breeders can use the information in Table 1 to help develop new varieties of corn. Accept one of the following: • Because crossing over increases genetic diversity, the plant breeders can breed strains with high crossover numbers/double-strand breaks. • They can increase the number of double-stranded breaks, which may lead to more crossovers that increase genetic variation.	5.2 5.6

<table>
<tr><th colspan="3">2019 #3</th></tr>
<tr><th>Part</th><th>Scoring Guidelines</th><th>Topic</th></tr>
<tr><td>(a)</td><td>Identification (1 point)
• Mitochondria
• Mitochondrial matrix</td><td>3.5</td></tr>
<tr><td>(b)</td><td>(1 point per row; 2 points max.)
<table>
<tr><th></th><th>Claim</th><th>Reasoning</th></tr>
<tr><td>Glycolysis</td><td>No change</td><td>• Glycolysis continues; PDC is not needed.
• Glycolysis occurs before conversion of pyruvate to acetyl-CoA.</td></tr>
<tr><td>Krebs cycle</td><td>Decrease</td><td>• The Krebs cycle is greatly reduced/slowed down if there is no/less acetyl-CoA.
• The Krebs cycle occurs after conversion of pyruvate to acetyl-CoA.</td></tr>
</table></td><td>3.5</td></tr>
<tr><td>(c)</td><td>Calculation (1 point)
• The probability of inheritance is 0.
• The offspring cannot/will not have PDC deficiency.</td><td>5.4</td></tr>
</table>

<table>
<tr><th colspan="3">2016 #7</th></tr>
<tr><th>Part</th><th>Scoring Guidelines</th><th>Topic</th></tr>
<tr><td>(a)</td><td>Construct diagram (1 point)
• Diagram must include all of the following:
o Each cell has one unduplicated chromosome 1 (with G or g).
o Each cell has one unduplicated chromosome 2 (with D or d).
o Genotype combinations should be: GD, Gd, gD, gd.
 </td><td>5.1</td></tr>
<tr><td>(b)</td><td>Prediction (1 point)
• 1 green dwarf: 1 green tall: 1 purple dwarf: 1 purple tall</td><td>5.3</td></tr>
<tr><td>(c)</td><td>Identify difference (1 point)
• The majority/greater than 50 percent would have the parental plant phenotypes
• Greater than 25 percent would be green dwarf plants and greater than 25 percent would be purple tall plants
• Less than 25 percent would be green tall plants and less than 25 percent would be purple dwarf plants</td><td>5.4</td></tr>
</table>

<table>
<tr><th colspan="3">2015 #4</th></tr>
<tr><th>Part</th><th>Scoring Guidelines</th><th>Topic</th></tr>
<tr><td>(a)</td><td>Description (1 point each; 2 points maximum)
• Spindle elements (microtubules) form/attach to chromosomes
• Chromatin condenses
• Alignment of chromosomes across center of cell prior to chromosome separation
• Separation of chromatids/centromeres to daughter cells
• G2/M checkpoint occurs in both processes
• Replication or synthesis of DNA precedes mitosis/meiosis
• Cytokinesis separates daughter cells after mitosis/meiosis</td><td>5.1</td></tr>
<tr><td>(b)</td><td>
<table>
<tr><th rowspan="2">Feature</th><th colspan="2">Description (1 point each row; 2 points maximum)</th></tr>
<tr><th>Mitosis</th><th>Meiosis</th></tr>
<tr><td>Number of divisions/ number of resulting cells</td><td>1 division/ 2 cells result</td><td>2 divisions/ 4 cells result</td></tr>
<tr><td>Ploidy of daughter cells</td><td>• Same as parent cell
• Diploid
• (2n-->2n or n-->n)</td><td>• Half of parent cell
• Haploid
• (4n-->2n; 2n-->n)</td></tr>
<tr><td>Chromatids separate</td><td>Occurs</td><td>Not in meiosis I/only in meiosis II</td></tr>
<tr><td>Crossing over</td><td>Does not occur</td><td>Occurs</td></tr>
<tr><td>Homologous chromosomes separate/independently assort</td><td>Does not occur</td><td>Occurs</td></tr>
</table>
</td><td>5.2</td></tr>
</table>