2022

AP CollegeBoard

AP® Biology

Sample Student Responses and Scoring Commentary

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Free-Response Question 2

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Question 2: Interpreting and Evaluating Experimental Results with Graphing

9 points

During meiosis, double-strand breaks occur in chromatids. The breaks are either repaired by the exchange of genetic material between homologous nonsister 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.

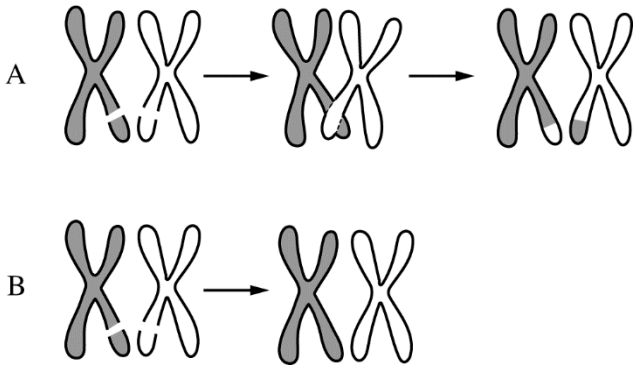


Figure 1. Double-strand breaks in chromatids are repaired with crossing over (A) or without crossing over (B).

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

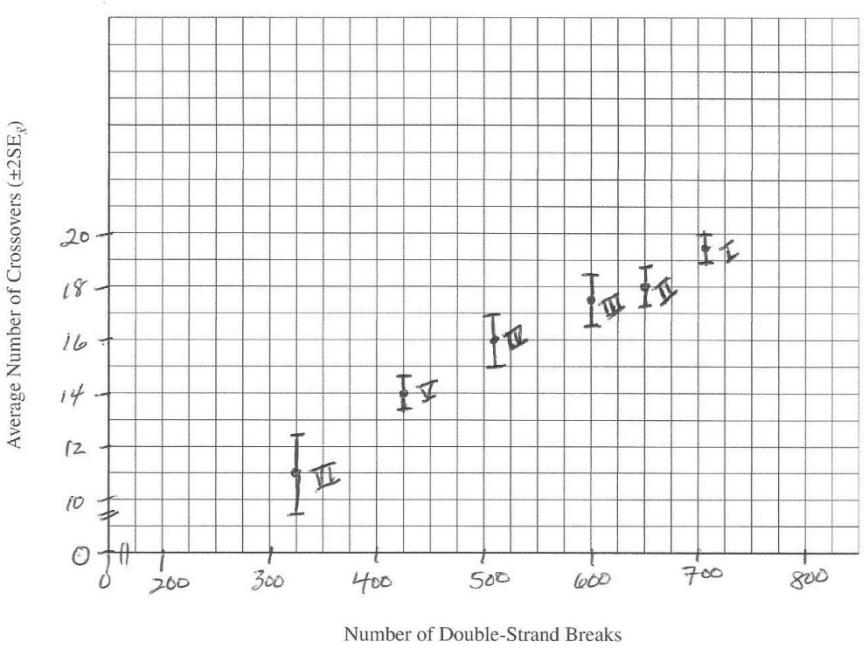
Strain of Corn	Number of Double-Strand Breaks	Average Number of Crossovers ($\pm 2\mathrm{SE}_{\bar{x}}$)
I	710	19.5 ± 0.5
II	650	18.0 ± 0.7
III	600	17.5 ± 1.0
IV	510	16.0 ± 1.0
V	425	14.0 ± 0.5
VI	325	11.0 ± 1.5

(a) The double-strand breaks occur along the DNA backbone. **Describe** the process by which the breaks occur. **1 point**

Accept one of the following:

- (Enzymatic) hydrolysis occurs between the sugars and phosphates/nucleotides.
- The covalent bonds between the sugars and phosphates/nucleotides are broken.

(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.	**1 point**



- 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	**1 point**
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	**1 point**
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 higher/different (in the average number of crossovers) compared with strains II and III.	**1 point**
	Total for part (b) 4 points

(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).	**1 point**

(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.	**1 point**
	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.	**1 point**
	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.	**1 point**
	Total for part (d)	**3 points**
	Total for question 2	**9 points**

BEGIN Question 2

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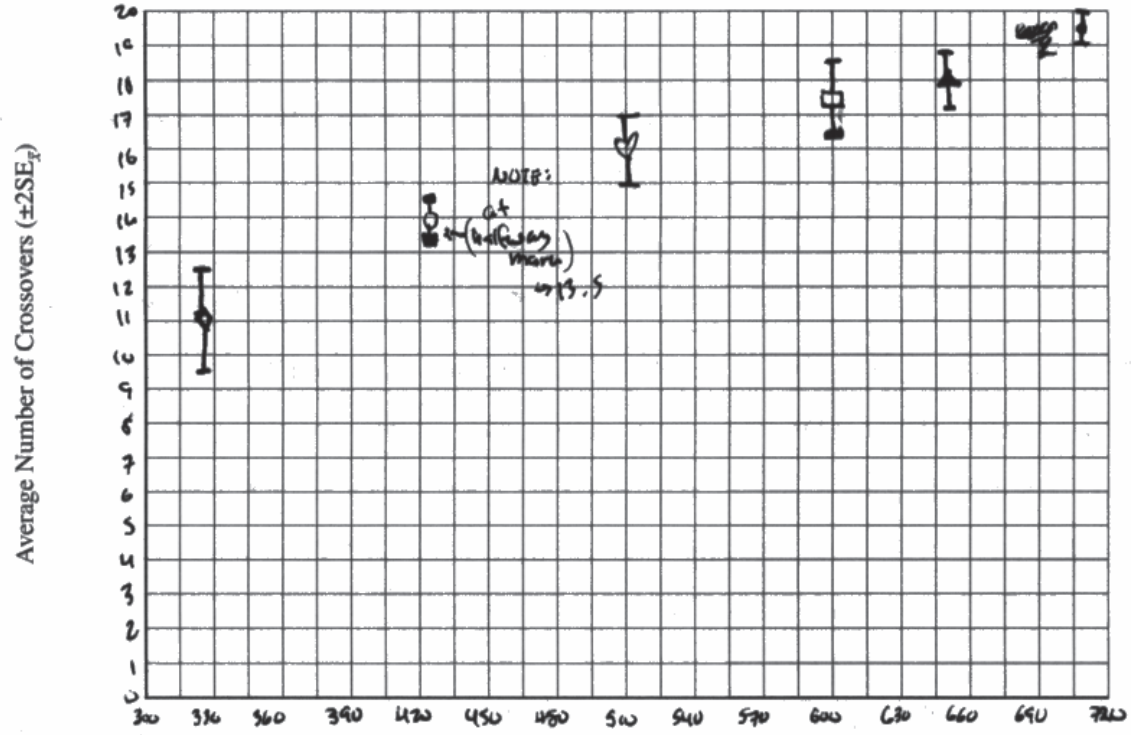

a) The double-strand break occurs along the DNA backbone when the covalent phosphodiester bond between the deoxyribose sugar and phosphate groups are broken. These sugar and phosphate groups are parts of different nucleotides along the backbone.

b) Although corns II and III do not differ in the average number of crossovers, corn I differs from both corn II and III in the number of average crossovers.

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c) As the average number of double-strand breaks increases, the average number of crossovers in the strains of corn analyzed in the experiment increase as well.

d) Two of the haploid cells will have three chromosomes while two of the haploid cells will have five chromosomes. This is because if only three of the four pairs have crossing over then the fourth pair will not be properly seperated. Thus, at the first division one cell will get three chromosomes while the other cell gets five since one of the pairs were not properly seperated and instead both homologous chromosomes of the pair put into one cell. Now, at the second division, the cell with three chromosomes will have its sister chromatids seperate to make cells with three chromosomes each. On the other hand the cell with five chromosomes will have its sister chromatids seperate to divide into two cells with five chromosomes each.

Plant breeders can use the information in Table 1 to see which corn strains have the most number of double stranded breaks and thus the largest average number of crossovers. If the breeder breeds two strains of corn that both have high averages of the number of crossovers, the genes of the corns will mix and the offspring

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of the corn will be more genetically diverse. ~~With~~ The breeder can continue breeding corn to create offspring that are even more genetically ~~diverse, corn~~ diverse, which can then eventually become its own new variety of corn.

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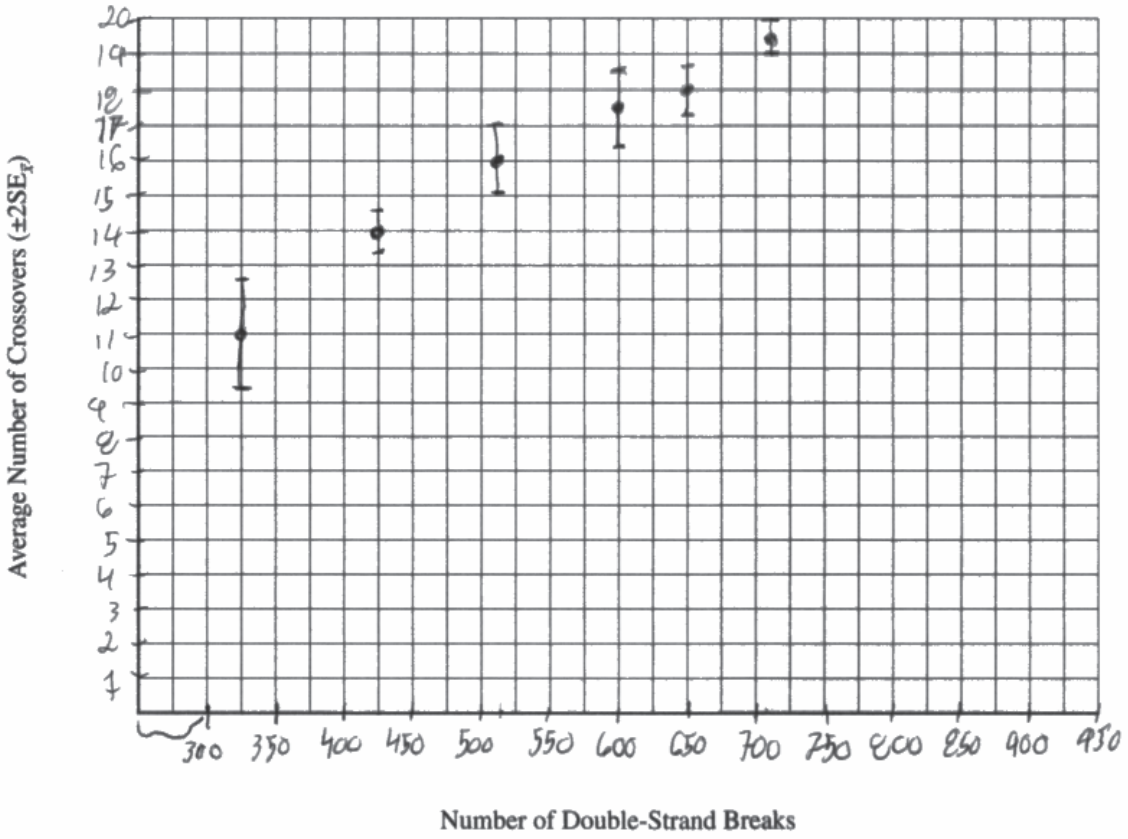

a) The breaks occur as hydrogen bonds are broken by Helicase which cause the double strand to break, into 2 sister chromatids.

b) Corn strains 1, 2, 3 do differ in their average number of crossovers.

c) Based on the data, there is a direct correlation with number of Double-Strand Breaks and Average Number of Crossovers since the more of one, cause the more of the other.

d) on the back

Additional page for answering Question 2

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d) There most likely will be 2 chromosomes in each haploid cell as long as no uneven tension in the spindle fibers cause the division of chromosomes to be off. Since there are 2 homologus chromosomes, those will replicate and create sister chromatids. Then it will go through Meiosis 1 and have 2 diploid cells, lastly, it will split and create 4 haploid cells with 2 chromosomes in each cell. Plant breeders can cause the number of double-strand breaks in the varieties of corn to increase, therefor causing average number of crossovers to increase, This will cause more genetic variation, creating new varities of corn.

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BEGIN Question 2

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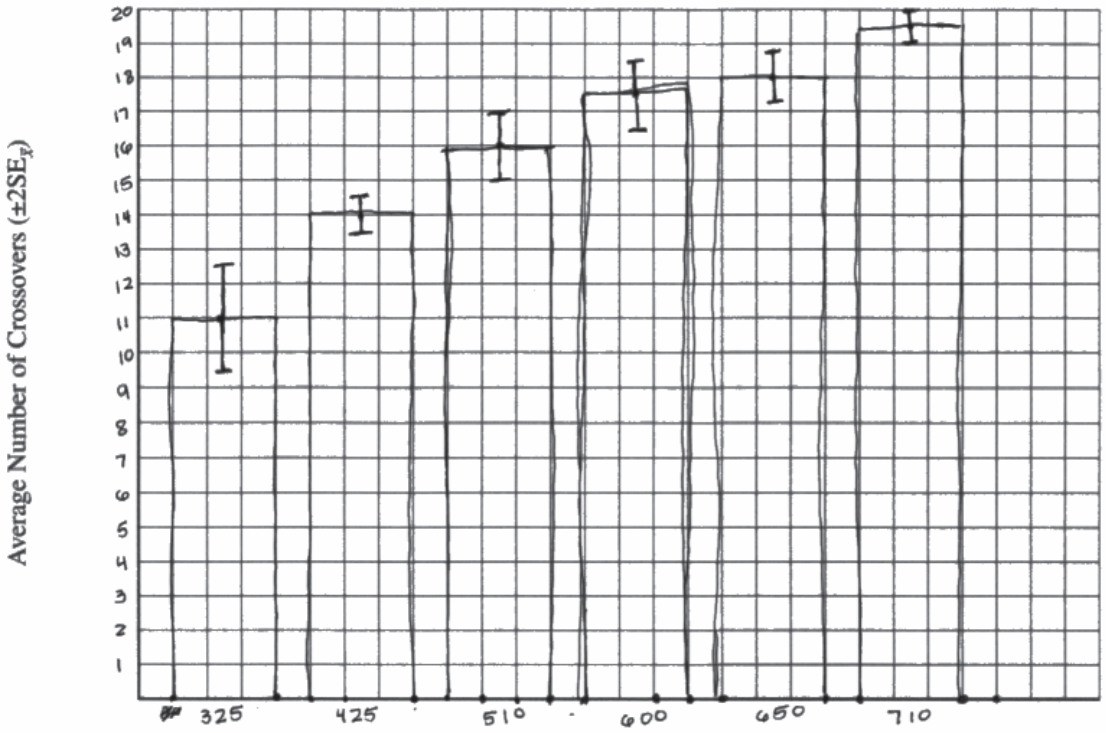

a. The breaks occur between the covalent bonds of the deoxyribose sugar, phosphate group and nucleotide that constitutes the DNA backbone.

b. strains I, II, and III do differ in their average number of crossovers.

c. The larger the average number of double-strand breaks observed, the larger the average number of crossovers observed in the strains of corn.

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d. There will still be 1 chromosome in each of the four haploid cells. Even though crossing over ~~occure~~ occurred between 3, the number of chromosomes present remains the same because crossing over does not affect chromosome number. Plant breeders can use the information in Table 1 by understanding effects of crossing over. Because crossing over increases genetic diversity, more crossovers could help develop new varieties of corn.

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Question 2

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

Question 2 presented a figure showing that double-strand breaks in chromatids may result in crossing over or may be repaired without crossing over. The stimulus also included a table of data comparing the number of double-strand chromatid breaks with the average number of crossovers in several strains of corn.

Responses to part (a) were expected to describe that enzymatic hydrolysis between nucleotides is the process by which the double-strand breaks occur (Learning Objective SYI-1.B).

In part (b) responses were expected to graph the data from the table in an X,Y plot, using appropriate axis scaling and accurate error bars (Science Practice 4.A). Responses were also expected to use the error bars to determine whether three of the strains of corn differed in their average number of crossovers (Science Practice 5.B).

Responses to part (c) were expected to describe the positive relationship between the average number of double-strand breaks and the average number of crossovers in the strains of corn analyzed in the experiment (Science Practice 4.B).

The prompt of part (d) explained that physical connections between homologous chromosomes are required for their proper separation. Responses were expected to demonstrate understanding of chromosomal inheritance by predicting that, if crossing over only occurs among three of four pairs of homologous chromosomes in a diploid cell, two daughter cells will have three chromosomes and two daughter cells will have five chromosomes. Responses were also expected to justify the prediction by providing the reasoning that one pair of homologous chromosomes would not separate during meiosis I, and all chromatids would separate normally during meiosis II (Learning Objective SYI-3.C). Finally, responses were expected to explain that plant breeders could breed strains with high numbers of crossovers to increase genetic variation (IST-1.H).

Sample: 2A
Score: 9

The response earned 1 point in part (a) for describing the breaking of the "covalent phosphodiester bond between the deoxyribose sugar and phosphate groups." The response earned 1 point in part (b) for appropriately scaling the axes. The response earned 1 point in part (b) for correctly plotting the means on an X,Y graph. The response earned 1 point in part (b) for appropriately plotting error bars. The response earned 1 point in part (b) for correctly determining that strains II and III do not differ in the number of crossovers and that strain I differs from both II and III. The response earned 1 point in part (c) for describing "as the average number of double-strand breaks increases, the average number of crossovers ... increase as well." The response earned 1 point in part (d) for predicting that two of the cells will have three chromosomes and two of the cells will have five chromosomes. The response earned 1 point in part (d) for justifying that during "the first division one cell will get three chromosomes while the other cell gets five." Then during the "second division, the cell with three chromosomes will have its sister chromatids separate" and the "cell with five chromosomes will have its sister chromatids separate." The response earned 1 point in part (d) for explaining the link between double-stranded breaks and crossing-over frequency and further explaining that by breeding strains with high numbers of crossovers, the "offspring of the corn will be more genetically diverse."

Question 2 (continued)

Sample: 2B
Score: 5

The response did not earn a point in part (a) because it incorrectly describes that hydrogen bonds are broken and apparently confuses the structure of DNA with that of chromatids. The response earned 1 point in part (b) for appropriately scaling the axes. The response earned 1 point in part (b) for correctly plotting the means on an X,Y graph. The response earned 1 point in part (b) for appropriately plotting error bars. The response earned 1 point in part (c) for describing a "direct correlation" between the number of double-stranded breaks and the number of crossovers. The response did not earn a point in part (d) because it does not correctly predict the number of chromosomes in each haploid cell. The response earned 1 point in part (d) for explaining that "Plant breaders can cause the number of double-strand breaks … to increase," thus increasing the number of crossovers, which "will cause more genetic variation."

Sample: 2C
Score: 2

The response did not earn a point in part (a) because it describes that the breaks occur between the "sugar, phosphate group and nucleotide." The response did not earn a point in part (b) because the X-axis is not scaled appropriately. The response did not earn a point in part (b) because it does not plot the means on an X,Y graph. The response earned 1 point in part (b) for appropriately plotting error bars. The response earned 1 point in part (c) for describing that the larger number of double-stranded breaks correlates with a larger number of crossovers. The response did not earn a point in part (d) because it does not correctly predict the number of chromosomes in each haploid cell. The response did not earn a point in part (d) because it does not explain the requirement to breed strains with high crossover numbers.