2024

AP® Biology

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 1

- ☑ **Scoring Guidelines**
- ☑ **Student Samples**
- ☑ **Scoring Commentary**

Question 1: Interpreting and Evaluating Experimental Results with Experimental Design — 9 points

Crossing over in meiosis I is required for homologous chromosomes to properly align during metaphase and segregate during the first cell division.

Some regions of a chromosome called hotspots display a higher frequency of crossing over than other regions do. Crossing over is suppressed in chromosomal regions near the centromeres. The centromere region of a duplicated chromosome includes a collection of proteins that form a structure called the kinetochore. Scientists hypothesized that one or more of these kinetochore proteins are responsible for suppressing crossing over around the centromere.

To investigate their hypothesis, scientists modified chromosome 8 in yeast such that, in each cell, one chromosome from the pair of homologous chromosome 8s contained the gene encoding red fluorescent protein (RFP), while the other chromosome from the pair contained the gene encoding green fluorescent protein (GFP). Cells expressing RFP emit (give off) red light, and cells expressing GFP emit green light. Models of the modified chromosome 8 both before and after crossing over are shown in Figure 1.

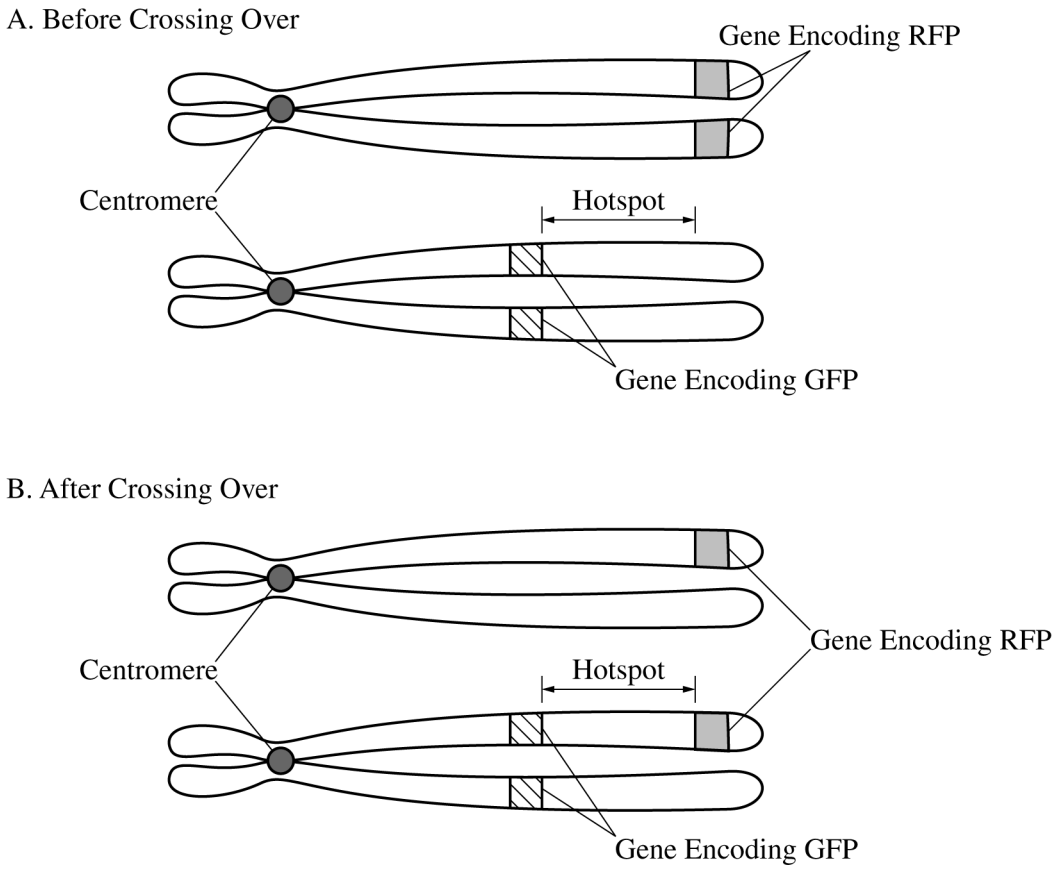

Figure 1. Models of modified chromosome 8 used in the experiment (A) before and (B) after crossing over occurs at the hotspot

The scientists then investigated whether attaching individual kinetochore proteins to a specific DNA sequence present in a known crossing-over hotspot on chromosome 8 affected the frequency of crossing

over at this location. In their first experiment, they examined three groups of yeast cells containing the modified chromosome 8. Group 1 contained no kinetochore proteins attached to the hotspot, group 2 contained the kinetochore protein CTF attached to the hotspot, and group 3 contained the kinetochore protein IML attached to the hotspot. For each group, the scientists determined the frequency of crossing over between the RFP and GFP genes. To determine the frequency, the scientists added the number of cells emitting both red and green light to the number of cells that emitted no light and divided by the total number of cells (Figure 2).

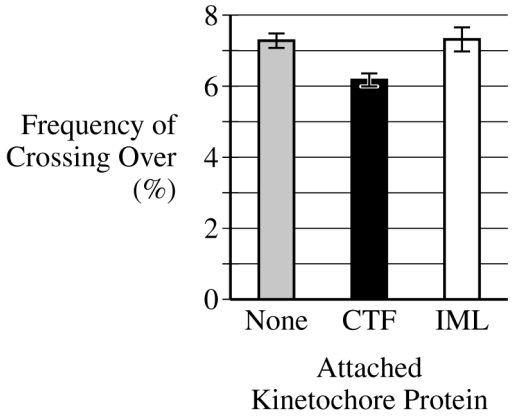

Figure 2. The frequency of crossing over in a hotspot on yeast chromosome 8 for cell groups treated with different kinetochore proteins. Error bars represent $\pm 2\mathrm{SE}_{\bar{X}}$.

(a)	**Describe** the function of S phase of interphase. Accept one of the following: • (The function of S phase is to) replicate/duplicate/synthesize the DNA/chromosomes. • (The function of S phase is to) double the amount of DNA.	**1 point**
	Explain why some haploid cells formed after meiosis in this experiment will have only one fluorescent marker. Accept one of the following: • Some cells will receive a chromosome/(sister) chromatid that did not undergo crossing over/recombination (in the hotspot). • Two (or a multiple of two) crossing-over events occurred (in the hotspot). • Each daughter cell will receive one of the four sister chromatids. Two of the sister chromatids shown in Figure 1 have only one fluorescent protein gene. • The two chromosomes that were not involved in crossing over will have only the RFP gene or the GFP gene. After meiosis II, a gamete with one of these chromosomes will have only the RFP or the GFP gene.	**1 point**
		Total for part (a) 2 points
(b)	**Identify** the control group for the scientists' first experiment, shown in Figure 2. Accept one of the following: • Group 1 • (The group called) None • Cells with no (kinetochore) protein (attached to the chromosome)	**1 point**

	In a follow-up experiment, the scientists created a modified version of CTF in which the DNA-binding portion had been removed. They compared the frequency of crossing over in yeast cells in the presence and absence of unmodified CTF with that in yeast cells in the presence and absence of the modified CTF protein (data not shown). In the follow-up experiment, **justify** why the scientists used a modified CTF protein that is unable to bind to DNA as a control. Accept one of the following: • (Using a modified CTF enabled the scientists) to determine whether DNA binding of the CTF/kinetochore protein affects/inhibits crossing over/recombination. • (Using a modified CTF enabled the scientists) to determine whether just the presence of the CTF/kinetochore protein is enough to affect/inhibit the crossing over/recombination frequency.	**1 point**
	Identify the independent variable in the follow-up experiment. Accept one of the following: • The type of CTF used • The presence or absence of (modified/unmodified) CTF	**1 point**
		Total for part (b) 3 points
(c)	Based on Figure 2, **describe** the effect on the frequency of crossing over when CTF is attached to the chromosome 8 hotspot compared with the effect when IML is attached to the hotspot. Accept one of the following: • CTF attachment results in a decreased/lower frequency of crossing over/recombination, (whereas IML had no effect). • IML attachment results in an increased/a higher frequency of crossing over/recombination (compared with CTF attachment).	**1 point**
(d)	**Predict** the effect on the number of copies of chromosome 8 likely to be present in the resulting daughter cells when CTF is attached to the hotspot. Accept one of the following: • There will be zero/two (copies). • There will be one less/one extra (copy).	**1 point**
	Provide reasoning to **justify** your prediction. • Cells (with attached CTF molecules) undergo crossing over/recombination at a lower frequency, so it is more likely that nondisjunction would occur/chromosomes would not separate properly.	**1 point**
	Explain how the presence of hotspots (Figure 1) could increase the likelihood that a population will survive in the presence of selective pressures. • Hotspots would increase genetic diversity; therefore, it would be more likely that some individuals would survive and reproduce.	**1 point**
		Total for part (d) 3 points
		Total for question 1 9 points

BEGIN Question 1

Begin your response to **QUESTION 1** on this page. Do not skip lines.

(a)(i) The S phase of interphase is where the DNA is replicated in preparation for cell division. The helicase enzyme will come and bind at the origin site, unzipping the two strands of DNA. Then RNA primase will build primers where the DNA polymerase enzyme can synthesize both the lagging and leading strands. By duplicating it's geneme, during the S phase of interphase, the cell then has two identical copies of its DNA which then can be separated during cell division.

(a)(ii) Some haploid cells formed after meiosis will only have one fluorescent marker and not both because not all chromatids experience crossing over. In the two homologous chromosome 8's, only the two close together chromatids experienced crossing over, where the other 2 didnt. During meiosis 2, when the sister chromatids separate to create haploid gamete cells, some will have chromosomes with both markers, some will have neither and some will have just one fluorescent protein marker.

(b)(i) Group 1 - with no kinetochore proteins attached to the hotspot - is the control group for the scientist's first experiment

(b)(ii) The scientists used a modified CTF protein that is unable to bind to DNA as a control because it can

Additional page for answering Question 1

Continue your response to **QUESTION 1** on this page. Do not skip lines.

show them that it is the CTF protein binding to the DNA that is causing the decrease in frequency of crossing over and not another variable.

(b)(iii) The independent variable in the follow up experiment is the presence or absence of the either modified or unmodified CTF protein.

(c) There is a decrease in ~~the percentage of~~ the frequency of crossing over when CTF is attached to the chromosome 8 hotspot compared to the frequency relatively not changing (because its error bars overlap with the no protein group) when IML is attached to the hotspot. CTF's frequency ~~decrease~~ is less than when there is no protein attached, where as IML's crossing over frequency is almost the same as when there is no protein attached

(d)(i) When CTF is attached to the hotspot, the number of copies of chromosome 8 is likely to be ~~rearranged~~ different and not the usual one chromosome 8 per haploid daughter cell.

(ii) This is because crossing over is required in meiosis I for homologous chromosomes to properly align. Since CTF protein decreases the frequency of crossing over, there is then a higher chance that the chromosomes

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dont align properly, leading to potential nondisjunction events where some daughter cells can get more or less chromosomes than normal.

(iii) The presence of hotspots could increase the likelihood that a population will survive in the presence of selective pressures because crossing over leads to genetic variation. Hotspots, where crossing over happens more frequently, help mix up the alleles on the chromosomes, resulting in each haploid gamete carrying a completely new and different genome. With this increased genetic variation, populations are better able to ~~select~~ adapt to selective pressures because one individual might be fitter than another

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BEGIN Question 1

Begin your response to **QUESTION 1** on this page. Do not skip lines.

a) The function of S phase of interphase is to replicate the DNA of the cell. Some haploid cells formed after meiosis in this experiment will only have one florescent marker because not all genes are transferred from one homologous chromosome to another in crossing over.

b) The control group for the scientists first experiment is group 1 which contains no kinetochore proteins attached to the hotspot.
In the follow up experiment, the modified CTF protein that is unable to bind to DNA is the control because that is the normal effect of CTF. In a normal ~~cell~~ yeast cell with CTF, it is unable to bind to the hotspot of a DNA sequence making this condition the normal/epected result. The independent variable is the presence or absence of unmodified and modified CTF protein in different yeast cells.

c) The frequency of crossing over is statistically significantly lower ~~in~~ when CTF is attached compared to when IML is attached to the hotspot.

D) When CTF is attached to the hotspot, there is likely to be 2 daughter cells with 2 copies of chromosome 8, ~~are with no copies of chromosome 8~~ and 2 with no copies of chromosome 8. This is because with a lack of crossing over, the homologous chromosomes are going to not be seperated properly during meiosis 1. Therefore nondisjunction will occuur in which 2 of the daughter cells will recieve one sister chromatid of each homologous chromosome and the other 2

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will recieve no chromatids.

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Q5218/3

BEGIN Question 1

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a) i) the function of the S phase of interphase is for DNA replication.

ii) Some haploid cells will only have one fluorescent marker because during crossing over the Gene encoding RFP, one of them crossed over to the other chromosome.

b) i) The control group is the group of yeast cells that contained no kinetochore proteins attatched to the hotspot. So group 1.

ii) they used a modified CTF protein that can't bind to DNA as a control so no crossing over would occur.

iii) the independent variable is the frequency of crossing over.

c) When CTF is attached to the hotspot there is less frequency of crossing over than when IML is attached to the hotspot.

d) i) If CTF is attached to the hotspot then there will be more Chromosome 8 copies

ii) Reasoning to this would be the graph showing that when there is no extra proteins attached

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in group 1, there is a higher frequency of crossing over.

iii) the presence of hotspots could increase the populations survival rate because the hotspots allow for more crossing over meaning more genetic variation to survive.

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0013592

Q5218/3

Question 1

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

Overview

The stimulus of Question 1 explained that crossing over is necessary for proper alignment and segregation of chromosomes during meiosis I, and that crossing over frequency is higher in chromosomal regions called hotspots. Figure 1 showed a pair of homologous chromosomes labeled with fluorescent proteins. The primary experiment measured crossing-over frequency in the presence of different kinetochore proteins. A follow-up experiment then tested modification of one of these proteins to determine what function/domain of the protein might be affecting the crossing-over frequency.

In part (a)(i) responses were expected to describe the function of the S phase of interphase (Science Practices Skill 1.A; Learning Objective [LO] IST-1.B from the AP Biology Course and Exam Description [CED]). In part (a)(ii) responses were expected to explain why some of the haploid cells resulting from meiosis in this experiment would have only one fluorescent marker (Skill 1.C; LO IST-1.F).

In part (b) responses were expected to demonstrate an understanding of experimental design (Skill 3.C). In part (b)(i), responses were expected to identify a control group. In part (b)(ii), responses were expected to justify the purpose for a control treatment in the context of the follow-up experiment, and in part (b)(iii), responses were expected to identify the independent variable in this follow-up experiment.

In part (c) responses were expected to describe data from a graph (Figure 2) that presented results of the first experiment (Skill 4.B).

In part (d)(i), responses were expected to predict that, when a kinetochore protein that reduces crossing over is attached to the chromosomal hotspot, resulting daughter cells would be more likely to have a missing or extra chromosome (Skill 3.B; LO SYI-3.C). In part (d)(ii) responses were expected to justify the prediction by reasoning that nondisjunction would be more likely (Skill 6.C; LO SYI-3.C). In part (d)(iii) responses were expected to explain the relationship between the experimental results and a broader biological theory by explaining that crossing over could increase the likelihood of a population surviving "in the presence of selective pressures" (Skill 6.D; LOs EVO-1.E, SYI-3.D, and IST-1.H).

Sample: 1A
Score: 8

The response earned 1 point in part (a)(i) for describing the function of S phase as "DNA is replicated." The response earned 1 point in part (a)(ii) for explaining that "not all chromatids experience crossing over" and some gamete cells "will have chromosomes with...just one fluorescent protein marker." The response earned 1 point in part (b)(i) for identifying Group 1. The response earned 1 point in part (b)(ii) for justifying that "it can show them that it is the CTF protein binding to the DNA that is causing the decrease in frequency of crossing over." The response earned 1 point in part (b)(iii) for identifying "the presence or absence of either modified or unmodified CTF protein." The response earned 1 point in part (c) for describing that "There is a decrease in the frequency of crossing over when CTF is attached to the...hotspot." The response did not earn a point in part (d)(i) because it does not predict a specific difference in the number of copies of chromosome 8. The response earned 1 point in part (d)(ii) for justifying… that "Since CTF protein decreases the frequency of crossing over, there is then a higher chance... [of] nondisjunction." The response earned 1 point in part (d)(iii) for explaining that hotspots increase "genetic variation" and, as a result, "one individual might be fitter than another."

Question 1 (continued)

Sample: 1B
Score: 6

The response earned 1 point in part (a)(i) for correctly describing the function of S phase. The response did not earn a point in part (a)(ii) because even though it explains that "not all genes are transferred," this will not necessarily produce a sister chromatid with only one copy of the fluorescent marker. There is no mention that the chromatid that did not cross over was the one passed on to the cell. The response earned 1 point in part (b)(i) for identifying group 1 as the control group. The response did not earn a point in part (b)(ii) because it does not justify that the control determines whether the binding of CTF to the DNA inhibits crossing over frequency. The response earned 1 point in part (b)(iii) for correctly identifying the independent variable. The response earned 1 point in part (c) for describing the effect on the frequency as "lower." The response earned 1 point in part (d)(i) for predicting that there will be "2 daughter cells with 2 copies of chromosome 8" (and at least one cell with zero copies of chromosome 8). The response earned 1 point in part (d)(ii) justifying the prediction because of the increased probability of nondisjunction due to lower crossing over frequency.

Sample: 1C
Score: 3

The response earned 1 point in part (a)(i) for describing that the function of the S phase "is for DNA replication." The response did not earn a point in part (a)(ii) because it does not explain why some cells will have only one fluorescent marker. The response earned 1 point in part (b)(i) for identifying the control group as "the group...that contained no kinetochore proteins." The response did not earn a point in part (b)(ii) because it does not correctly justify why the modified CTF was used as a control. The response did not earn a point in part (b)(iii) because it incorrectly identifies the independent variable. The response earned 1 point in part (c) for describing the effect as a lower frequency of crossing over when CTF is attached. The response did not earn a point in part (d)(i) because it incorrectly predicts "more chromosome 8 copies." The response did not earn a point in part (d)(ii) because it does not correctly justify the prediction. The response did not earn a point in part (d)(iii) because it does not explain that an increase in genetic variation increases the likelihood of individuals surviving and reproducing,