Chief Reader Report on Student Responses:

2018 AP® Biology Free-Response Questions

- Number of Students Scored 259,663
- Number of Readers 712
- Score Distribution

Exam Score	N	%At
5	18,594	7.2
4	55,964	21.6
3	85,175	32.8
2	73,544	28.3
1	26,386	10.2

- Global Mean 2.87

The following comments on the 2018 free-response questions for AP® Biology were written by the Chief Reader, Nancy Morvillo, Ph.D., Professor and Chair of Biology, Florida Southern College. They give an overview of each free-response question and of how students performed on the question, including typical student errors. General comments regarding the skills and content that students frequently have the most problems with are included. Some suggestions for improving student preparation in these areas are also provided. Teachers are encouraged to attend a College Board workshop to learn strategies for improving student performance in specific areas.

Question #1

Task: Interpret data; identify evolutionary relationships; predict the effects of natural selection and genetic manipulation

Topic: Investigating the evolution of polar bears

Max. Points: 10

Mean Score: 4.73

What were the responses to this question expected to demonstrate?

This question is based on recent investigations into the evolutionary history of polar bears. Students were presented with a phylogenetic tree created from mitochondrial DNA (mtDNA) data for five populations of bears. Using this phylogenetic tree, students were asked to estimate the age of the most recent common ancestor of all brown bears, to identify what population of brown bears was most closely related to polar bears, and to identify two populations of bears whose positions on the phylogenetic tree could be switched without altering the proposed relationships. Students were presented with a data table indicating the number of amino acid differences in the lysosomal trafficking protein LYST among four species of bears. Using these data, the students were asked to construct a cladogram on a provided template and circle the outgroup position on that cladogram. Students then were asked to provide one piece of reasoning to support a claim that mtDNA sequence comparisons provide a more accurate prediction of bear phylogeny. The students were then asked to predict the most likely difference in the phenotype of a mouse that was genetically altered to contain the polar bear-specific *lyst* allele. The students were asked to justify their prediction. Finally, students were asked to describe how the *lyst* allele became common in the polar bear population and to predict what percentage of the offspring resulting from a mating between a brown bear and a polar bear would be white.

The key understandings and skills students were expected to demonstrate included the following:

- Basic concepts of evolution were used to evaluate and interpret data and to describe evolutionary relationships and processes.
- Knowledge of Mendelian and molecular genetics was used to predict the outcomes of a genetic alteration and a mating based on experimental design.

How well did the response address the course content related to this question? How well did the responses integrate the skills required on this question?

In part (a), most students correctly estimated the age of the most recent common ancestor of all brown bears to be between 310 and 350 thousand years ago, and correctly identified European brown bears to be most closely related to polar bears based on the mtDNA sequence data. Most students were also able to correctly identify that either the European brown bear and polar bear positions could be switched or the Asian and Western (North American) brown bears positions could be switched on the phylogenetic tree without affecting their relationships.

Course content highlighted in this part included a basic understanding of evolutionary relationships among taxa. Skills highlighted in this part included extrapolating a data point from a graphical representation and interpreting the representation to determine evolutionary relationships.

In part (b), many students were able to correctly construct the cladogram and to identify the position of the outgroup.

Course content highlighted in this part included a basic understanding of evolutionary relationships among taxa. Skills highlighted in this part included drawing a cladogram from the data provided and identifying where on the cladogram the outgroup is located.

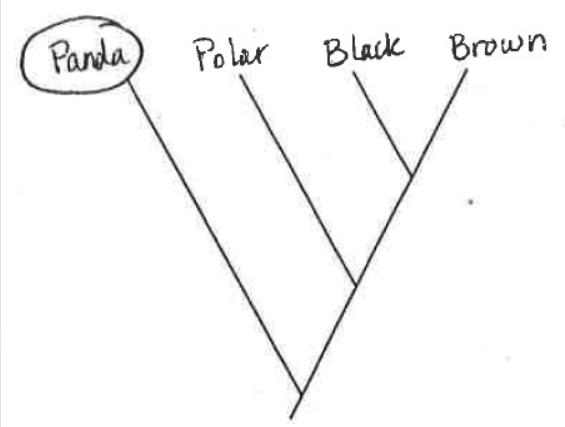
In part (c), it was difficult for students to provide reasoning to support that the mtDNA sequence comparisons were more accurate that the LYST protein sequence comparisons to construct a phylogenetic tree. Responses did not often articulate that there was more variability in DNA sequences than in protein sequences or that there is more information from multiple mitochondrial genes than from only one *lyst* gene, or that phenotypes associated with the *lyst* gene might be under selection and less likely to show variation.

Course content highlighted in this part included an understanding of the structure of macromolecules (DNA and proteins) and fundamental understandings of the central dogma (notably that genes can contain different DNA sequences that could result in proteins of the same amino acid sequence). Skills highlighted in this part included applying fundamental knowledge of basic biology to provide reasoning for the choice of the type of data that would be most accurate to answer a question.

In part (d), students were often able to predict that the phenotype of the transgenic mice with the polar bear *lyst*-specific allele would be white or produce less pigment. Students were often able to predict that 0% of the offspring from a mating between a brown bear and a polar bear would be white.

Course content highlighted in this part included a basic understanding that a transgene will be expressed and can confer a new phenotype to the organism. Mendelian genetics were also highlighted. Skills highlighted in this part included predicting the phenotype that would be produced in a transgenic organism, and calculating the percentage of a specific phenotype that would be predicted from a given cross between bears.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Incorrectly constructing a cladogram and identifying the outgroup (part b) • Student responses often demonstrated a misinterpretation of the data table, causing incorrect placement of the species on the cladogram. • Students were asked to identify (circle) the *position* of the outgroup, not the species. Some responses had a circle around the panda even though the panda was incorrectly placed on the cladogram. • Some responses had not just the outgroup, but also the entire branch, including the common ancestor, circled.	

Misunderstanding of the use of types of genetic data (part c) Some student responses incorrectly used the following as lines of reasoning to support that mtDNA was more accurate to determine evolutionary relatedness: • mtDNA is only inherited from the maternal line • mtDNA inheritance is highly conserved • protein (amino acid) sequence data cannot be used to determine evolutionary relatedness • mtDNA was used to construct the phylogenetic tree and was able to separate three types of brown bears, but the amino acid data only grouped the brown bears into one clade	• "The student's reasoning is valid because multiple codons can code for the same amino acid. Thus, simply comparing the differences in the amino acids on the LYST protein could indicate that two species are equally similar to another where one could actually be less similar due to a different base sequence."
Lack of or irrelevant specificity (part d) • Predictions did not include a specific phenotype (e.g., "The mice would be like polar bears") • Predictions included traits associated with polar bears (e.g., thick fur) that were not provided by the question • Justifications included genes other than the *lyst* gene	• "The most likely change is that the mouse will appear white due to a lack of pigment in its fur."
Misunderstanding of natural selection (part e) • Some responses included discriptions of natural selection acting on a genotype rather than a phenotype • Some responses included descriptions of the phenotype conferring a specific advantage for	• "The LYST gene became common through the process of natural selection. After the mutation appeared, white individuals gained an advantage in their environment-hunting became easier since they were blending in with the snow and ice. Because these individuals were more successful in eating, therefore surviving more, they were able to reproduce and carry on the mutation. The mutation was so advantageous it eventually became commonplace."

survival without connecting survival to reproduction	
Misreading (part e) • Some responses indicated that the *lyst* allele causing white fur would be present in heterozygous brown bears when the information in the question indicated that the allele was ONLY present in polar bears • Some responses indicated the percentage of brown offspring, not the percentage of white offspring from the cross	• "The percent of white offspring (assuming the offspring survive/could be conceived) should be zero, since the similar mutation of LYST in humans is recessive."

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Help students with reading and addressing the prompt. Encourage them to underline key words and phrases, and to re-read the information.
- Interpreting and constructing models (including phylogenetic trees and cladograms) are different skills. Be sure to practice both with students, and do not assume that if students are proficient in one skill they are proficient in the other.
- Help students understand that natural selection has two components: survival and reproduction. Students do not often extend the notion of survival to reproductive fitness. Provide practice with different scenarios.
- Help students develop their reasoning skills with "explain" questions. Students can follow the popular model of "claim-evidence-reasoning" with these types of questions. Have students break down an argument into these three components, to help them articulate their ideas. Have students write their responses to practice clear communication of their ideas.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

AP Central, Visualizing Information, Lessons Two and Three: Modeling Evolution; https://apcentral.collegeboard.org/pdf/biology-visualizinginformation.pdf?course=ap-biology

AP Central, Investigative Labs: Comprehensive Links: https://apcentral.collegeboard.org/courses/ap-biology/classroom-resources/investigative-labs-comprehensive-links?course=ap-biology, Investigation 3

Question #2

Task: Modeling a cell signaling pathway; identification of cellular localization of macromolecules based on data; explaining key aspects of an immune response

Topic: Modeling cell signaling leading to pyroptosis

Max. Points: 10

Mean Score: 2.68

What were the responses to this question expected to demonstrate?

This question required students to consider a cell signaling enzymatic pathway that involved caspase-1 in cells that had been infected by pathogenic bacteria. Background information was provided as a narrative and in the form of an illustration. Prior to infection, inactive caspase-1 precursors are formed that can be activated by cleaving the inactive caspase-1. Once activated, caspase-1 cleaves interleukin, an immune system cytokine, thereby activating it and allowing it to be released from the cell. Caspase-1 also cleaves gasdermin, which allows the N-terminal portion of the protein to form large pores in the plasma membrane. The students were provided with a diagram illustrating these steps. Students were asked to describe the impact of inhibiting gasdermin cleavage on pore formation and on interleukin release. Students made a claim about how inactive caspase-1 becomes activated by cleaving. They were further asked to provide reasoning for why having inactive caspase-1 precursors formed prior to infection speeds the response after a cell is infected. In addition, the question contained a table that shows the location of five cellular proteins after fractionating the cell. Using these data, students justified a claim that the NF-*k*B protein is located in the cytoplasm of the cell. They identified two fractions where N-terminal gasdermin would be located based on both the image and information found in the table. Students were then asked to describe how the formation of gasdermin pores would affect water balance on cells in a hypotonic environment. Finally, students were asked to explain how gasdermin pore formation and interleukin release contribute to an organism's defense against a bacterial pathogen.

The key understandings and skills students were expected to demonstrate included the following:

- The scientific method and quantitative skills were used to interpret a diagram and data presented in a table.
- Knowledge of cell signaling, organelle function, molecular activation, osmosis and water potential, apoptosis, and specific components of the immune system were integrated and used to interpret a model.

How well did the response address the course content related to this question? How well did the responses integrate the skills required on this question?

In part (a), many students were able to describe the impact of inhibiting gasdermin activation and relate it to a loss of pore formation. Some students were able to describe that the step involving release of interleukin would not be impacted.

Course content highlighted in this part included the process of cell signaling and the structure and function of the cell membrane involving transport of molecules. Skills highlighted in this part included describing the consequences of a disruption of a cellular process.

In part (b), many students were able to make a claim indicating that activation of caspase-1 involved the removal of a part of the protein serving as an inhibitor or that the protein would become activated due to a conformational change. Some students were able to provide reasoning that cell response time would decrease if there were inactive precursors made prior to infection because then the cell would not require time, after infection, to go through the process of transcription and translation, or that cleaving an inactive precursor is faster than producing the proteins after infection.

Course content highlighted in this part included the relationship between structure and function of proteins and, in a very general and broad sense, an understanding of the processes involved in protein production. Skills highlighted in

this part included describing how structure and function are related and providing reasoning as to how cells may be able to speed up their responses to environmental changes (in this case infection by bacteria).

In part (c), many students were able to justify that NF-*k*B was located in the cytoplasm if it was found in the presence of glycolytic protein GAPDH, since glycolysis occurs in the cytoplasm. Many were able to identify that N-terminal gasdermin would be found in Fractions 3 and 4, since those fractions represented the cytoplasm and the cell membrane, respectively.

Course content highlighted in this part included understanding of the sub-cellular localization of specific metabolic processes. Skills highlighted in this part included inferring where proteins required for specific processes would be located in the cell and interpreting a data table to identify the expected experimental results when a new element is included.

In part (d), many students were able to describe that in a hypotonic environment, water would move into a cell with gasdermin pores.

Course content highlighted in this part included the understanding of water movement across a membrane. Skills highlighted in this part included constructing a model of water movement given specific environmental conditions.

In part (e), some students were able to explain that interleukin would initiate a specific immune response and were able to describe cells and components of the immune system that would help defend an organism from a bacterial pathogen. Fewer students were able to explain that gasdermin pores would allow for lysis of infected cells and help prevent bacterial replication.

Course content highlighted in this part included knowledge of the basic components of an immune response and that cell lysis will occur when water rushes into a cell. Skills highlighted in this part included constructing an explanation of how signaling between cells allows for a coordinated response.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Misinterpretation of the diagram (part a) Some student responses mistakenly tied the inhibition of pore formation to interleukin not being released, despite a diagram showing it as a separate step.	• "The inhibition of step 3 would stop the formation of pores." • "Inhibiting step 3…will not affect the release of interleukin from the cell because interleukin does not require pores to leave the cell."

Repetition of the prompt/inappropriate reasoning (part b) • Some responses repeated the prompt (pre-infection production of inactive precursors shortened the cellular response time to infection) without further providing reasoning as to why that would shorten response time. • Some responses mistakenly equated the shortened response time to an immune system response, and provided reasoning pertaining to memory cells responding to an infection. • Some responses equated having more protein precursors speeding the reaction, failing to provide the pre-and post-infection comparison.	• "If the cell did not constantly produce inactive caspase-1, the protein would have to be transcribed and translated before performing its function, a process which requires more enzymes and more time than a simple cleavage of a polypeptide."
Inability to integrate information in the table and diagram (part c) • Some responses only provided information for either NF-*k*B or N-terminal gasdermin. • Many responses indicated the students incorrectly read the table: a "+" in Fractions 2 and 3 for NF-*k*B was applied to N-terminal gasdermin. • Some responses failed to provide enough information from the table to justify that NF-*k*B was found in the cytoplasm.	• "The student's claim is correct because the NF-*k*B protein was found in fraction 3 along with the glycolytic protein." • "N-terminal gasdermin is found in Fractions 3 and 4."

Confusing hypotonic and hypertonic and the effect on water balance (part d) • Some responses incorrectly described which direction water would move in relation to the cell in a hypotonic environment. • Some responses described movement of solutes rather than water. • Some responses described what would happen to the cell (swelling, lysing, etc.) without addressing water balance specifically.	• "In a hypotonic environment, the pores would help facilitate movement of water from outside the cell (hypotonic) to the hypertonic inside of the cell."
Misconception regarding the function of pores and interleukin (part e) • Some responses failed to explain that gasdermin pores would result in the lysing and death of infected cells. • Many responses equated the presence of pores with the release of interleukin, or with a portal to allow the passage of immune cells, bacteria, antibodies, and other immune components. • Some responses were not specific enough as to the immune cells or components of the immune system, or simply repeated the background information that interleukin initiated an immune response.	• "Gasdermin pore formation causes the flow of water into the cell, which may cause the infected cell to burst. This would prevent the spread of the infection because phagocytes could then digest the components of the cell along with the pathogens." • "The release of interleukin activates the adaptive immune response by stimulating B and T leukocytes to divide and produce antibodies or kill infected cells, respectively."

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Provide students with samples of several cell signaling pathways. Have students describe each step in the pathway and predict what would happen if a step were inhibited or activated.
- Provide samples of different kinds of tables, including "+/-" tables, and have students practice creating their own tables from data.
- Provide opportunities for students to make, and justify, a claim based on evidence from data. Also encourage students to incorporate evidence from their own knowledge of biological concepts.
- Allow students the opportunity to apply concepts such as water potential to a variety of systems and circumstances. Provide opportunities for students to consider the functions of organelles under different circumstances/environmental conditions.
- Stress the importance of different immune responses.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

From AP Central: Cell-to-Cell Communication and Cell Signaling; https://apcentral.collegeboard.org/pdf/ap-sf-bio-cell-cell-communication.pdf?course=ap-biology

Question #3

Task: Experimental design; predicting results

Topic: Pollination of aquatic plants

Max. Points: 4

Mean Score: 2.38

What were the responses to this question expected to demonstrate?

The first part of the question focused on experimental design. The prompt described natural sea grass fertilization, which depends on circulating water, and presented a claim by a researcher that mobile aquatic invertebrates could provide an alternative method of transferring pollen in the absence of circulating water. The question asked the students to design an experiment appropriate to test the scientist's claim. Students were provided with symbols for both male and female flowers and invertebrates and told to place the symbols in two template aquarium drawings to represent the experiment. The second part of the question asked students to identify the dependent variable in the experiment and to predict the results that would support the researcher's claim.

The key understandings and skills students were expected to demonstrate included the following:

- The scientific method was used to design an experiment, identify the dependent variable, and predict results.
- Knowledge of how organisms interact and how biotic and abiotic factors affect life processes such as sexual reproduction was used to predict the results of an experiment.

How well did the response address the course content related to this question? How well did the responses integrate the skills required on this question?

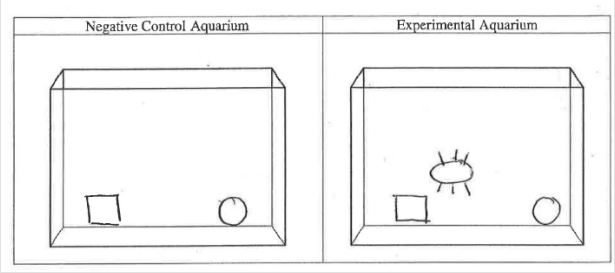
In part (a), many students were able to draw the negative control aquarium containing only the male and female flowers, and most students were able to draw the experimental aquarium with male and female flowers and invertebrates.

Course content highlighted in this part included a basic understanding of biotic and abiotic interactions among living things. Skills highlighted in this part included experimental design.

In part (b), many students were able to identify the dependent variable as pollination, fertilization or reproduction, and to predict an appropriate experimental result to support the researcher's claim; that there would be an increase in the dependent variable in the experimental aquarium.

Course content highlighted in this part included a basic understanding of biotic and abiotic interactions among living things. Skills highlighted in this part included experimental design and predicting the results of an experiment.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Misconception of the nature of a negative control (part a) • Some responses included the variable being tested (the invertebrates) in the control aquarium, indicating a misunderstanding that the control includes the variable being tested.	

• Some responses indicated a misunderstanding of what a negative control is used for; as a comparison where the expected result is unlikely to occur.	
Misconception of the nature of the dependent variable (part b) • Incorrect responses for identification of the dependent variable included circulating water, complete lack of water, absence of one type of flower, and invertebrates.	• "The dependent variable is pollination (or absence of it)."
Incorrect prediction (part b) • Some predictions did not align with the dependent variable • Some responses failed to make a comparison between the experimental aquarium and the control aquarium	• "The negative control would have no pollination but the experimental would."

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Practice reading the question carefully with students. The prompt indicates there is an absence of circulating (moving) water in both the control aquarium and in the experimental aquarium. Some responses indicated there was no water in the experimental aquarium. Some responses included circulating water in the negative control, or specifically deleted all water in the experimental aquarium so that circulating water or just water could be the dependent variable.
- When practicing experimental design, emphasize the difference between a positive and a negative control. Have students think about ways to set up an experiment that could include both types of controls (it may not always be possible- help them see this as well).
- When practicing experimental design, emphasize the difference between a dependent variable and an independent variable. Help students to understand that, while there may be several independent variables, there is only one dependent variable in the design. One way to approach this is to critique different experimental designs that attempt to answer the same question.
- Provide opportunities for students to make predictions about the results of an experiment. Emphasize that a prediction must compare the experimental group to the control group. Relative terms such as "more" or "less" are often appropriate to clearly indicate the predicted outcome.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

AP Central, AP Biology Lab Manual Resource Center: Matrix for Assessing and Planning Scientific Inquiry; https://apcentral.collegeboard.org/pdf/bio-appendixd-mapsi.pdf?course=ap-biology

Question #4

Task: Experimental design; data analysis; explain molecular interactions within metabolic processes

Topic: Investigating the genetic components of insecticide resistance in bedbugs

Max. Points: 4

Mean Score: 1.41

What were the responses to this question expected to demonstrate?

The first part of the question focused on the interpretation of data presented both in graphic and tabular form. Students were provided with the results of an experiment involving five different strains of genetically altered bedbugs. The presence or absence of three different genes, *P450*, *Abc8*, and *Cps*, was given for each strain. The corresponding graph showed the average percent survival, with corresponding 95 percent confidence intervals, when each of the strains was exposed to the insecticide beta-cyfluthrin. Students were asked to identify the control strain and to justify the claim that *Abc8* is effective at providing resistance to the insecticide. Next, the students were provided with information on how each gene product functions in contributing to insecticide resistance. The students were then asked to explain the relationships among the functions of the gene products in providing resistance when either: 1) *P450* and *Abc8* are both deleted, or 2) When only *Cps* is deleted.

The key understandings and skills students were expected to demonstrate included the following:

- Knowledge of how organisms are affected by abiotic factors was used to investigate insecticide resistance.
- The understanding that expression, or lack thereof, of genes can alter phenotypes was used in an experimental investigation to help determine the function of the gene products in a biological process (insecticide resistance).
- Knowledge of experimental design and statistics were used to interpret the results of an experiment.

How well did the response address the course content related to this question? How well did the responses integrate the skills required on this question?

In part (a), most students were able to identify that Strain I, the strain with all genes present, was the control. Some students could justify the claim that *Abc8* is effective at providing resistance by indicating that the response of Strain III (lacking *Abc8*) showed a statistically significant difference from Strain I (the control).

Course content highlighted in this part included the basic concepts of how organisms are affected by abiotic factors and the results of genetic manipulation of organisms. Skills highlighted in this part included experimental design and the use of statistics to interpret the results of an experiment.

In part (b), many students were able to explain the effect of deleting both *P450* and *Abc8*, thereby eliminating the ability of the bedbugs to detoxify and pump out the insecticide, compared to deleting *Cps*, alone in lowering bedbug survival. Some students were able to explain that the effect of deleting *Cps* alone, compared to *P450* and *Abc8*, was the increased probability of survival.

Course content highlighted in this part included the basic concepts of how organisms are affected by abiotic factors and the results of genetic manipulation of organisms. Skills highlighted in this part included experimental design and the use of statistics to interpret the results of an experiment.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Misconceptions of experimental design (part a) Responses that did not demonstrate understanding of experimental design included: • Identification of one of the genes or the insecticide as the control • Failure to compare the correct strain (strain III) with the control (strain I) **Misinterpretation of figures (part a)** • Some responses indicated the students misread the table and thought *P450*, *Abc8*, and *Cps* were the strains	• "The control strain in this experiment is strain I."

Misconceptions of statistical analysis (part a) • Some responses demonstrated a lack of understanding that no overlap between error bars indicates a statistically significant difference. • Some responses incorrectly stated a wide confidence interval indicates high confidence while a narrow confidence interval indicates lower confidence.	• "We can conclude that Abc8 is effective at providing resistance to beta-cyfluthrin because the highest value in the 95% confidence interval for strain III (all genes present except Abc8) is significantly lower than the lowest value of the 95% confidence interval for strain I (control)."
Misconception regarding genetic manipulation (part b) • Some responses indicated that deleting two genes was always more detrimental than deleting only one. **Incomplete comparison (part b)** • Many students did not complete the explanation of how deletion of *P450* and *Abc8* resulted in decreased bedbug survival compared to deletion of *Cps*. • Most students did not complete the explanation of how deletion of *Cps* only resulted in increased bedbug survival compared to deletion of *P450* and *Abc8*.	• "The deletion of both P450 and Abc8 results in lower survival in bedbugs compared with a deletion of Cps only because depleting P450 and Abc8 prevents the bedbugs from detoxifying insecticides and from getting the insecticides out of their cells, so once the insecticide is in their system it remains in their system until the bedbug dies." • "While on the other hand, deleting Cps only results in the bedbugs absorbing the insecticides at an increased rate, they can still detoxify the insecticides and pump them out of their cells, so the bugs are able to survive even if they absorb the insecticides."

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Provide opportunities for students to practice using statistical analysis. Students need to understand the meaning and use of error bars; whether they are standard errors, standard deviations, or confidence intervals. If bars do not overlap, there is a statistically significant difference between the values being compared.
- Have students practice correct comparisons. In part (a), some responses identified Strain V, which had both *Abc8* and *P450* deletions. The question was specific for the role of Abc8. The inclusion of another deletion does not allow for a direct comparison with the control.
- Have students practice complete comparisons. Responses often did not "close the loop" in part (b). Many responses simply restated information from the prompt or question stem but did not indicate how a particular deletion(s) affected survival, compared to deletion of the alternative gene(s).

- Emphasize the relationship between genes and their functions. Responses in part (b) often mentioned the genes that were deleted, but did not connect these deletions to bedbug survival.
- Provide opportunities for students to evaluate what question they answered. In part (b), many responses said the same thing twice. To practice, students can critique their work and the work of their peers to ensure all parts of the question are addressed.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

AP Central, AP Biology Course Planning and Pacing Guide, 1; https://apcentral.collegeboard.org/pdf/ap-biology-planning-pacing-guide-massey-2012.pdf?course=ap-biology

Question #5

Task: Describe symbiotic relationships; predict the outcome of an experiment

Topic: Relationships between bird species in two different environments

Max. Points: 4

Mean Score: 2.66

What were the responses to this question expected to demonstrate?

This question was about nest predation and the conditions under which a nest is successful. The prompt described the relationship between warbler chicks and cuckoo chicks that are raised in the same nests by warbler parents. In an environment without predators, nest success (where at least one warbler chick survives to adulthood) is reduced. Students were asked to describe the interaction between cuckoos and warblers in this environment. The prompt went on to describe an experiment in areas where predators are present, with the results of the experiment shown in a bar graph. The students were asked to predict the probability of nest success in the presence of predators under two different conditions: a warblers-only nest where cuckoos are added and a warblers-and-cuckoos nest where the cuckoos are removed. Finally, students were asked to identify the symbiotic relationship between the two bird species in the nest in the presence of predators.

The key understandings and skills students were expected to demonstrate included the following:

- Basic concepts of symbiotic relationships among organisms were used to consider how these relationships are affected by biotic factors and to identify patterns and relationships when provided with different variables and environmental conditions.
- Knowledge of experimental design was used to predict the results of an experiment.

How well did the response address the course content related to this question? How well did the responses integrate the skills required on this question?

In part (a), many students were able to describe that cuckoos were parasites of the warblers in an environment without predators.

Course content highlighted in this part included an understanding of symbiotic relationships among organisms. Skills highlighted in this part included identifying patterns and relationships in a defined environment.

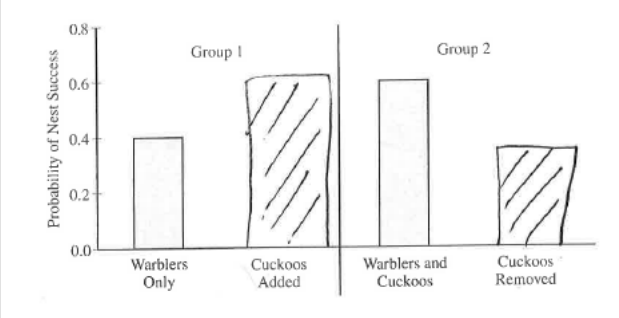
In part (b), most students were able to construct a graph to correctly indicate that, in the presence of predators, nest success would increase when cuckoos were added to the warblers-only nest (group 1), and that nest success would decrease if cuckoos were removed from the warblers-and-cuckoos nest (group 2).

Course content highlighted in this part included an understanding of symbiotic relationships among organisms. Skills highlighted in this part included predicting results of an experiment when changes in patterns and relationships occurred.

In part (c), most students were able to identify mutualism as the symbiotic interaction between cuckoos and warblers in the presence of predators.

Course content highlighted in this part included an understanding of symbiotic relationships among organisms. Skills highlighted in this part included identifying patterns and relationships in a defined environment.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Misconceptions regarding parasitic interactions (part a) • Some responses confused competition with symbiotic associations. • Some responses confused predation with parasitism. • Responses that only identified the relationship as (+/-) were not detailed enough to indicate understanding of the relationship: The question asked for a description, and the species needed to be identified based on their role in the relationship (i.e., the cuckoos benefited and the warblers were harmed).	• "The symbiotic relationship is parasitic because the cuckoos take the food from the warblers and lower the success rate of the nest overall when there are no predators."
Misreading/incorrect drawing of the graph (part b) • Some responses switched Group 1 and Group 2 to show a decrease in Group 1 and an increase in Group 2.	
Misconceptions regarding mutualistic interactions (part c) • Some responses misidentified the interaction as commensalism.	• "In the presence of predators, there is a mutualistic symbiotic relationship since both bird species benefit."

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Provide many examples of interactions among different species so students can practice identifying and describing relationships. Emphasize to students that they should clearly define the role of each species in a symbiotic relationship.
- Help students understand that plus/minus comparisons can be made for both competition and symbiotic relationships, so it is important to be clear about which organisms are doing what.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

AP Central: Quantitative Skills Guide, Chapter 1: https://apcentral.collegeboard.org/pdf/chapter-1-quantitative-skills-ap-sciences.pdf?course=ap-biology

Question #6

Task: Model the cellular location of proteins during and after their synthesis

Topic: Modeling the production and cellular localization of the CFTR protein

Max. Points: 3

Mean Score: 0.89

What were the responses to this question expected to demonstrate?

This question presented students with information about CFTR, a gated ion channel that requires ATP binding to allow ions to diffuse across the plasma membrane. Students were shown a diagram of a cell with numerous subcellular structures drawn and labeled. Students were asked to draw arrows to describe the pathway for production of a CFTR protein from gene expression to final location in the cell. The students were then asked to identify the most likely cellular location of the ribosomes that synthesize this protein. The question then provided information about a particular mutation in the CFTR protein, and students were asked to identify the most likely final cellular location of that protein.

The key understandings and skills students were expected to demonstrate included the following:

- Knowledge of subcellular structures and organelles was used to predict the process of synthesizing a specific protein.
- Knowledge of protein domains was used to determine the impact of mutations on the structure and function of a protein.
- Representations and models were used to describe the interactions of cellular organelles and to predict the consequences of a mutation.

How well did the response address the course content related to this question? How well did the responses integrate the skills required on this question?

In part (a), many students were able to draw arrows on the diagram to indicate the correct pathway from the nucleus through the endoplasmic reticulum through the Golgi apparatus to the plasma membrane.

Course content highlighted in this part included knowledge of the basic functions of cell organelles and the process of protein synthesis. Skills highlighted in this part included interpreting models and using them to represent processes.

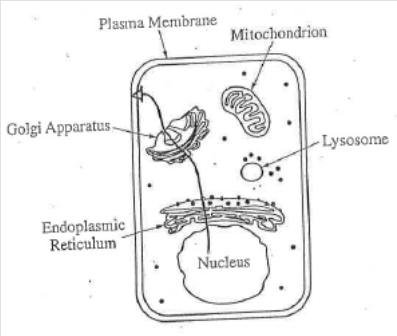
In part (b), most students correctly identified the rough endoplasmic reticulum as the site of CFTR protein synthesis.

Course content highlighted in this part included knowledge of the basic functions of cell organelles and the process of protein synthesis. Skills highlighted in this part included reasoning to conclude the most likely location of a subcellular structure.

In part (c), many students were able to correctly identify the plasma membrane as the most likely cellular location of the mutant CFTR protein.

Course content highlighted in this part included knowledge of protein structure and how that structure relates to function. Skills highlighted included prediction of the impact of a specific mutation on the structure and function, and ultimately the location, of a protein.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Incorrect pathway indicated for protein production (part a) • The most common error included the mitochondrion in the pathway of protein production.	
Incorrect location of the mutated protein (part c) • The most common error indicated the mutant CFTR protein would go to the lysosome to be broken down.	• "The mutant CFTR protein would still be embedded in the plasma membrane, just likely not functional."

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Provide opportunities for students to integrate information. While it is important that students are able to identify the function of each subcellular component, it is equally as important that students are able to describe how the subcellular components work together to carry out processes. Teachers might consider teaching the normal pathway for a process, and then using examples of what results when there is an error in the pathway.
- Help students understand the significance of changes to specific regions in a polymer. For example, have students consider what any one specific amino acid change would do for a protein: Would one amino acid substitution in a particular domain mark a protein for destruction in the cell, or change its function, or change its location?

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

AP Central: From Gene to Protein-A Historical Perspective; https://apcentral.collegeboard.org/pdf/cm-bio-gene-protein.pdf?course=ap-biology, Lessons 4 and 5

Question #7

Task: Apply Mendelian and non-Mendelian patterns to inheritance of a specific trait; connect genotype to phenotype and fitness

Topic: Genetic and environmental effects on sex determination in a fish species

Max. Points: 3

Mean Score: 1.10

What were the responses to this question expected to demonstrate?

This question presented students with information about how environmental temperatures can impact sex determination in a species of fish. Information was provided on the ZW sex determination system in the tongue sole fish (males are ZZ, and females are ZW). If fish are raised at 28°C instead of 22°C, the Z chromosome is modified (Z*) and Z*W individuals develop as phenotypic, fertile males. The students were shown a Punnett square of a cross between a Z*Z male and a ZW female and asked to predict the percent of phenotypic males that might result from that cross. Further information was provided that all fish must have a Z or Z* chromosome to survive, and the results of another genetic cross were given. Students were asked to use those results to identify the genotype of the male in the cross and to describe one fitness cost to the female in the cross as a result of that particular mating.

The key understandings and skills students were expected to demonstrate included the following:

- Concepts of Mendelian and non-Mendelian inheritance patterns, along with the impact of abiotic factors, were used to determine outcomes of a cross and to indicate the genotypes of the individuals involved in a cross.
- The relationship between genotype, phenotype, and the environment was used to describe the reproductive fitness of an individual.

How well did the response address the course content related to this question? How well did the responses integrate the skills required on this question?

In part (a), most students were able to use the Punnett square to correctly predict that 75% of the offspring would be phenotypically male.

Course content highlighted included the basic concepts of the inheritance of traits from one generation to another. Skills highlighted included predicting phenotypes from genotypes and applying non-Mendelian patterns of inheritance to a specific system.

In part (b), most students could identify the likely genotype of the male parent as Z*W. Some students were able to describe the fitness cost to the female parent as having fewer offspring or that some of her offspring would have the Z* chromosome.

Course content highlighted included the basic concepts of the inheritance of traits from one generation to another and the concept of evolutionary fitness. Skills highlighted included predicting phenotypes from genotypes, applying non-Mendelian patterns of inheritance to a specific system, and predicting the fitness consequences of an altered chromosome.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Incorrect description of a fitness cost to an individual female (part b) • Some responses focused on the potential implications of an imbalanced proportion of males to females in subsequent generations.	• "A cost to the female of mating with this particular male is that ¼ of her offspring will likely be WW, and those offspring won't survive." • "A fitness cost to this female is that some of her offspring will carry a Z* chromosome, which they will pass on to future generations, meaning more WW could be formed, further reducing the amount of her DNA that is represented."

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Provide opportunities to help students explore the implications of fitness at an individual level, as well as at a population level.
- Provide practice in using Punnett squares both when given information about the parent generation and when given information about the F_1 generation.
- Create opportunities for students to describe the predicated outcomes in different ways; as percentages and ratios, as genotypes, and as phenotypes.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

AP Central: AP Biology Course Planning and Pacing Guide, 4; https://apcentral.collegeboard.org/pdf/ap-biology-planning-pacing-guide-zedalis-2012.pdf?course=ap-biology, Unit 5

Question #8

Task: Connect structure and function of receptors to cell signaling and response

Topic: Investigating the structure and function of acetylcholine receptors

Max. Points: 3

Mean Score: 0.95

What were the responses to this question expected to demonstrate?

This question focused on molecular interactions at a neuromuscular junction. Students were provided with information on acetylcholine receptor (AChR) proteins and the series of events that occurs upon the binding of acetylcholine to an AChR. A data table showed the results of an investigation that exposed two types of AChR proteins (type 1 and type 2) to two different stimuli. Students analyzed the data to describe a structural and functional difference between the two AChR proteins. Information was given about the action of acetylcholinesterase, and the students were asked to describe the effect of inhibiting the enzyme on muscle cells with type 2 AChR proteins.

The key understandings and skills students were expected to demonstrate included the following:

- The relationship between structure and function was used to describe the activation of a specific signaling system and transmission of a signal in the nervous system.
- Data analysis was used to describe molecular interactions.
- Reasoning skills were needed to predict how inhibition of a pathway will alter the propagation of a signal.

How well did the response address the course content related to this question? How well did the responses integrate the skills required on this question?

In part (a), many students were able to use the information provided in a data table to describe that, while there are differences in the binding of molecules to the two receptors, there is no difference in the function/response of the receptors.

Course content highlighted included the basic concepts of how the structure of macromolecules is related to function. Skills highlighted included data interpretation.

In part (b), some students were able to describe the effect of inhibiting acetylcholinesterase as causing continued activation of the muscle cells.

Course content highlighted in this section included the basic concepts of molecular interactions and transmission of information in the nervous system. Skills highlighted included describing the predicted results when a process is inhibited.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Incomplete response (part a) • Some responses were incomplete and did not contrast the two required items. The responses described a quality of one item, but did not describe the differing quality of the second item.	• "A structural difference between AChR type one and AChR type two is that AChR type 1 has binding sites for both acetylcholine and nicotine, and type 2 only has a binding site for acetylcholine." • "AChR proteins type 1 and 2 differ in their function in that type 1 is stimulated to depolarize and then contract by both acetylcholine and nicotine, but only acetylcholine stimulates that response in a type 2 protein."
Misconsecption of how inactivation of an enzyme impacts a pathway (part b) • Some responses included an incorrect description of the effect of inhibiting an enzyme that acts in a catabolic capacity.	• "The effect of breaking down acetylcholinesterase is that the acetylcholine will remain in the synapse for a longer time, and so the sodium channels will remain open, resulting in continuous activation of muscle cells."

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Help students focus on regulation of biological processes by having them consider what happens when there are variations in a system (more of one component, less of another, failure of a regulatory mechanism earlier versus later in the process, etc.).
- Present students with examples of when changes to a molecule do have an impact, as well as when those changes do not.
- Provide students with many opportunities to practice stating differences fully, detailing the qualities of both items being contrasted.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

AP Central: AP Biology Lab Manual Resource Center, https://apcentral.collegeboard.org/pdf/bio-lab13-enzymeactivity.pdf?course=ap-biology, Lab 13 Enzyme Activity