Chief Reader Report on Student Responses:

2019 AP® Biology Free-Response Questions

- Number of Students Scored 260,816
- Number of Readers 712
- Score Distribution

Exam Score	N	%At
5	18,800	7.2
4	57,795	22.2
3	92,073	35.3
2	69,312	26.6
1	22,836	8.8

- Global Mean 2.92

The following comments on the 2019 free-response questions for AP® Biology were written by the Chief Reader, Nancy Morvillo, 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:** Work with models; make predictions; describe gene regulation and gene expression | **Topic:** Modeling Pathways Involved in Auxin Synthesis

Max. Points: 10 | **Mean Score:** 4.98

What were the responses to this question expected to demonstrate?

This question is based on a two-step enzymatic pathway in plants for the synthesis of the growth hormone indole-3-acetic acid (IAA) from the amino acid tryptophan. Students were provided with a model showing this pathway, including transcription and translation leading to production of the two enzymes needed for this pathway. The students were asked to interpret the model by circling an arrow on the diagram that represented the process of transcription and to identify the molecule that would be absent if one of the enzymes was nonfunctional. Students were then asked to apply concepts of gene mutation to predict the outcome of a specific mutation in the gene encoding one of the enzymes. The students were also asked to justify their prediction. Next, the students were asked to use their understanding of gene expression to explain a feedback mechanism that could lead to a reduction of one of the products of the pathway without affecting the production of an intermediate in the pathway. Students then considered ecological interactions involving populations of bacteria that live in root nodules of plants and produce IAA and fix nitrogen. Students were told that the plants release carbon-containing compounds into the nodule. Based on this information, students were asked to describe the type of symbiosis that occurs between the plant and bacterial species. Lastly, students were asked to describe the evolutionary advantage to "cheater" bacteria that did not produce IAA or fix nitrogen and to predict conditions in the bacterial population that would cause the plants to reduce the amount of carbon compounds released in the root nodules.

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

For part (a) most responses demonstrated correct circling of an arrow to represent transcription and identified IAA as the molecule that would be absent under the specified conditions. This demonstrates that students were able to interpret the model showing how genetic information is translated into proteins and to correctly identify the outcome of a perturbation in the system.

In part (b) most responses correctly predicted that the mutation described would cause a reduction in IAA. However, not all responses demonstrated correct justification of the prediction. This justification needed to include information on the production of the enzyme or how the pathway would be affected.

Some responses explained a negative feedback mechanism based on the prompt in part (c). As with part (b), this required students to engage with a perturbation of the model, which involves understanding the pathway and extending the understanding to include a disruption.

For part (d) most responses identified mutualism as the symbiotic relationship, correctly identifying this relationship based on a description. Most responses did not correctly describe one advantage to the bacteria producing IAA. This required students to apply concepts of ecological relationships to a novel situation.

In part (e) few responses correctly described the evolutionary advantage of bacterial cheaters, usually failing to identify a reproductive advantage to the bacteria. Few responses correctly predicted the change in the bacterial population that would cause the plant to reduce the release of carbon compounds. Students had difficulty making the connection between the amount of nitrogen available to the plant and the release of carbon to the root nodules.

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

Molecular biology, specifically gene expression (the Central Dogma), is a difficult concept for students. While students were able to use a model relating to this in part (a), they were less able to predict the outcome of a mutation in a pathway with a description in part (b). Though some students recognized how the mutation would affect the structure of the protein translated from the mutated gene, many were not as able to describe that the function of the enzyme would be disrupted.

Evolution is also another concept that is often difficult for students to fully explain. Most students did not extend the concept of saving energy to increased reproduction in part (e). Students also had difficulty applying changes in molecular processes to ecological relationships.

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Part (b): Correctly justifying that the reduction/lack of production of IAA is due to the mutation resulting in: • the translation of an inactive/nonfunctional Trp-T enzyme OR • no translation of the Trp-T enzyme OR • no/reduced production of I3PA	• "If a base pair in the fourth codon of the coding region of gene Trp-T was deleted, IAA would not be produced. The altered mRNA sequence for gene Trp_T would make a nonfunctioning/altered form of enzyme Trp-T." • "If deleted, when copied by mRNA it would not encode enzyme Trp-T the same way it would have if it had not been deleted. Thus Tryptophan will not be converted to I3PA which won't be converted to IAA."
Part (e): Description that cheaters/bacteria that benefit without producing IAA/fixing nitrogen have more energy for reproduction.	• "The advantage to being a "cheater" amongst noncheaters is that the "cheater" bacteria will multiply without having to use any energy to benefit the plant."
Part (e): Prediction that the change in the bacterial population that would cause the plant to reduce the amount of carbon-containing molecules to the nodules is due to the decrease in: • the nitrogen-fixing/noncheater bacteria OR • in the amount of nitrogen fixed by bacteria	• "A change in bacterial population that would cause the plant to reduce the amount of molecules provided could be if the cheater bacteria start to reproduce and have more successful cheater offspring, slowly out numbering the amount of non-cheater bacteria. Once the plant notices the decrease in nitrogen production, it can decrease the carbon molecules provided."

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?

Molecular biology, specifically gene expression (Central Dogma), is comprised of multiple complex pathways. The more practice teachers can provide for students, the better. Consider different ways to present the information; in the form of models, in experimental designs, in interpreting data, in having students draw diagrams based on narrative descriptions, etc.

Evolution often focuses on energy conversion. Help students to consider and integrate all the Big Ideas with evolution, including energy. Also, work with students to include the two notions of natural selection (survival AND reproduction) in their responses to evolution questions.

Use examples of changes in ecological systems to help students make predictions when considering how populations interact in communities. Invasive species are a good example of this, but also include examples of how natural interactions change when the environment changes.

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

- Refer to Unit 6 Instructional Approaches and Sample Activities in the 2019 Course and Exam Description
- See AP Central Biology Course Resources: From Gene to Protein–A Historical Perspective for another way to approach teaching the *Central Dogma*
- FRQ practice questions for teachers to use as formative assessment pieces are now available as part of the collection of new resources for teachers for the 2019 school year. These items begin with scaffolded questions that represent what students are ready for at the beginning of the school year and that continue on to present an increased challenge as teachers progress through the course. These resources are available on AP Classroom with the ability to search for specific question types and topics so that teachers are able to find the new collection of FRQ practice questions and the fully developed scoring guidelines that accompany each question.

Question #2 | **Task:** Graph data; experimental design; explain population interactions; predict changes in populations and cells | **Topic:** Investigating Protist Competition

Max. Points: 10 | **Mean Score:** 4.53

What were the responses to this question expected to demonstrate?

This question provided students with an experimental design where 10 individuals of two species of protist (A and B) were grown separately (group I) or 5 individuals of each species were grown together (group II). A data table was provided with the number of individuals of each species in each group over time. Students were asked to construct an appropriately plotted and labeled graph of the data on a template where half of the data had already been plotted. In an experimental design question, the students were asked to provide reasoning for why only 5 individuals of each species were placed in group II. Students were then asked to interpret the data to provide two pieces of evidence from the data that indicated species A and B were competing for the same food source. Students then considered basic ecological concepts when they were asked to predict two factors that most likely limited the population growth of species A in group I. Lastly, the students were required to use their understanding of tonicity and cellular organelles. They were provided with another scenario, where the growth medium had a lower solute concentration and were asked to predict how the activity of the contractile vacuole in the protists would be affected. They were also asked to justify their prediction.

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

In part (a) most responses demonstrated successful plotting of the data points on a graph and correct labeling of the lines. However, fewer responses earned a point for correctly labeling the axes. In most cases, where this point was not earned, the response did not include units.

In part (b) most responses correctly reasoned that the reduced population sizes kept the total number of organisms the same in all containers or that the reduction served as a control for population density.

Few responses earned two points for evidence that species A and B competed for the same food source in part (c). Most responses failed to compare the correct conditions. However, most responses did earn one point for providing evidence that species B grows to a higher population density in group I than in group II.

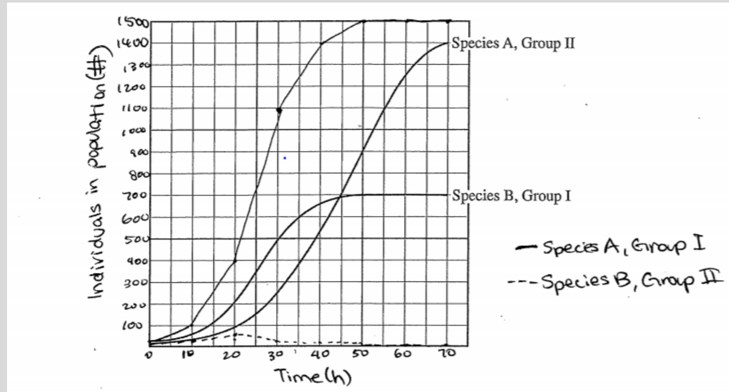
In part (d) most responses predicted that food and space would most likely limit the population growth of species A in group I.

Most responses correctly predicted the contractile vacuole will be more active, and most justified this prediction by correctly describing that water entered the cell in part (e). Other acceptable responses for this justification (the environment being hypotonic/the cell being hypertonic or that the cell has lower water potential than the environment/the environment has higher water potential than the cell) were less frequently seen.

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

In part (a) students labeled axes based on what they saw in the table. However, these labels were usually incomplete, and the students often left off the units on each axis.

In part (c) students had difficulty making the correct comparisons to provide evidence that species A and B competed for the same food source. Many responses focused only on comparing the numbers of individuals of each species in group II. Students presented as evidence the fact that species A increased and species B decreased in group II. However, without a comparison to group I (the control), the relevance of the increase and decrease cannot be correctly interpreted and applied to the claim of competition.

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Part (a): most responses showed correct plotting of points and labeling of lines, but the axes were less often correctly labeled with units (“number of individuals” on the Y axis and “hours” OR “h” OR “hr” on the X axis).	
Part (c): most responses did not correctly compare species A between the two groups to say that: • Growth rate for species A is faster in I/slower in II AND/OR • Species A grows to a higher population density in I/lower population density in II	• “The species compete for the same food because as shown in Group 1 both species grow exponentially and have a large number of individuals. In Group 2 species B’s populations falls drastically. Species A also goes lower in population signifying that they must compete with each other for food sources.”
Part (c): most responses did not correctly compare species B between the two groups to say that growth rate is faster in I/slower in II	• “One piece of evidence is that when grown together, populations of A and B were growing at a slower rate than when grown separately.”

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 opportunities to graph data, and to interpret data within a graph. These are two separate skills, and student who do well with one skill will not automatically perform well with the other. Have students consider different types of graphs (bar, line, dual Y axes, semi-log, etc.) to gain confidence in creating and interpreting graphs.

Stress the role of controls in experimental design, and encourage students to provide complete comparisons in their responses. Directionality is important in these comparisons: students should specifically state the change (e.g. an increase or decrease), not just indicate there will be a change.

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

- Refer to Units 3 (Energetics) and 8 (Ecology) Instructional Approaches and Sample Activities in the 2019 Course and Exam Description
- See AP Central Biology Course Resources: Quantitative Skills in the AP Sciences for support in teaching graphing skills.
- FRQ practice questions for teachers to use as formative assessment pieces are now available as part of the collection of new resources for teachers for the 2019 school year. These items begin with scaffolded questions that represent what students are ready for at the beginning of the school year and that continue on to present an increased challenge as teachers progress through the course. These resources are available on AP Classroom with the ability to search for specific question types and topics so that teachers are able to find the new collection of FRQ practice questions and the fully developed scoring guidelines that accompany each question.

Question #3 **Task:** Identify aspects of and explain energy conversion systems; calculate genetic probabilities **Topic:** Explaining the Effects of PDC Deficiency

Max. Points: 4 **Mean Score:** 1.68

What were the responses to this question expected to demonstrate?

Students were asked to consider the cellular location of pyruvate dehydrogenase complex (PDC), the enzyme that converts pyruvate to acetyl-CoA, and describe the consequences in the cell when the activity of the enzyme is greatly reduced in the genetic disorder PDC deficiency. Students used their understanding of cellular organelles to identify the location of the enzyme. They also used their understanding of glycolysis and aerobic respiration to make a claim (and justify it) about how PDC deficiency affects the amount of NADH produced by these two processes. Lastly, they used their knowledge of the inheritance of X-linked traits to determine the probability of a child inheriting PDC deficiency given information about the genotypes of the parents. Within the question, students needed to provide claims and reasonings as well as calculate a probability.

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?

For part (a) most responses correctly identified the location of PDC as being in the mitochondria or mitochondrial matrix. This required knowledge of where the Krebs cycle occurs in a eukaryotic cell.

Most responses did not correctly make the claim and provide reasoning that there would be no change in the amount of NADH produced in glycolysis in part (b). More responses correctly made the claim and provided correct reasoning that there would be a decrease in the amount of NADH produced by the Krebs cycle. However, this answer was not seen in the majority of responses.

For part (c) most responses correctly calculated that the probability of a male offspring inheriting the disorder was 0 if the parents were a male and a homozygous female with no family history of PDC.

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

- In part (b) many students confused the various processes in cellular respiration. Students also confused the reactants and products in the individual processes and the sequence of when these reactants were used and products were generated.

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Part (b): most responses did not make a correct claim that NADH production would not change in glycolysis and did not provide the correct reasoning that: • Glycolysis continues; PDC is not needed OR • Glycolysis occurs before conversion of pyruvate to acetyl-CoA	• " PDC deficiency will not affect the amount of NADH produced by glycolysis because PDC only catalyzes conversion of pyruvate, the product of glycolysis, to acetyl-CoA.

Part (b): many responses did not make a correct claim that NADH production would decrease in the Krebs cycle and did not provide the correct reasoning that • The Krebs cycle is greatly reduced/slowed down if there is no/less acetyl-CoA OR • The Krebs cyccle occurs after conversion of pyruvate to acetyl-CoA	• "PDC deficiency affects the amount of NADH produced by the Krebs cycle in a cell by causing a significant decrease in the amount of NADH produced. There will be a decrease because the Krebs cycle is one of the final steps in cellular respiration and without the PDC catalyzing the conversion of pyruvate to acetyl-CoA there is no substrate for the Krebs cycle so it will not occur."

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?

- Biochemical processes can be confusing for students. Show them different types of pathways to initially understand what molecules are substrates/reactants, what are products, what molecules are considered waste products, where products are used in the cell, where the processes occur in the cell, how the enzymes function in the pathway, etc. Importantly, students should consider what happens when there is a disruption to the pathway: how the disruption affects the progression of the pathway, the amount of products produced, the function of the cell, etc.
- As demonstrated in this question, disruptions to a pathway can be caused by a mutation in a gene. This type of scenario easily ties together biochemistry/energetics with molecular biology and inheritance. Have students trace through the central dogma, to describe how a mutation in a gene coding for an enzyme will impact the mRNA transcribed from the gene, and the impact the mutation will have on the protein (enzyme) translated from the mRNA. Also extend the mutation to a case study of inheritance, providing the genotype of some individuals in a family and asking students to predict the genotypes of other members in the family.

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

- Refer to Units 2 (Cell Structure and Function) and 3 (Energetics) Instructional Approaches and Sample Activities in the 2019 Course and Exam Description
- See AP Central Biology Course Resources: Quantitative Skills in the AP Sciences for support in teaching graphing skills.
- FRQ practice questions for teachers to use as formative assessment pieces are now available as part of the collection of new resources for teachers for the 2019 school year. These items begin with scaffolded questions that represent what students are ready for at the beginning of the school year and that continue on to present an increased challenge as teachers progress through the course. These resources are available on AP Classroom with the ability to search for specific question types and topics so that teachers are able to find the new collection of FRQ practice questions and the fully developed scoring guidelines that accompany each question.

Question #4 **Task:** Describe signaling in the nervous system **Topic:** Describing the Effect of a Neurotoxin

Max. Points: 4 **Mean Score:** 1.46

What were the responses to this question expected to demonstrate?

Students were provided with a figure showing the release of a neurotransmitter into a synapse and a graph showing a model of a typical action potential in a neuron. Information was provided that researchers were investigating the effect of a neurotoxin that causes the amount of the neurotransmitter, acetylcholine, released from presynaptic neurons to increase. Students were asked to describe the effect of the neurotoxin on the number of action potentials and to predict the effect of the neurotoxin on the maximum membrane potential of the postsynaptic neuron. Then students were asked to consider two models where acetylcholinesterase (AChE — an enzyme that degrades acetylcholine) was added to the system: In model A, AChE was added to the synapse, and in model B the enzyme was added to the cytoplasm of the post-synaptic neuron. Students were asked to predict the effectiveness of each model in preventing the effect of the neurotoxin and to provide reasoning for their predictions. This question required basic knowledge of the nervous system at the cellular level, specifically how signals are passed from cell to cell to cause action potentials. Students also needed to predict the effects of changes to the system.

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

In part (a) most responses correctly described that the number of action potentials would increase in response to the neurotoxin. However, not as many responses correctly predicted that the maximum membrane potential of the postsynaptic neuron would stay the same.

In part (b) few responses provided correct predictions and reasoning for the effectiveness of the two models.

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

Many responses in part (b) indicated that acetylcholine would enter the post-synaptic cell. Responses also indicated that many students were confused about the function of the toxin (causing the release of excess acetylcholine) in relation to the action of AChE (degradation of acetylcholine) and how this impacts action potentials.

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Part (b): Correctly predicting that Model A is effective and reasoning that acetylcholine is located in the synapse	• "In model A, AChE will degrade acetylcholine and prevent the effect of the neurotoxin because the neurotransmitter is activated in the synapse, so the addition of AChE to the synapse will degrade the neurotransmitter."
Part (b): Correctly predicting that Model B is not effective and reasoning that acetylcholine is not in they cytoplasm of the post synaptic cells.	• "AChE added to model B will not be effective because the neurotransmitters do not enter the postsynaptic cytoplasm, so AChE will not degrade any of the neurotransmitter."

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?

- Cell communication is an important topic in Biology. Emphasizing the connection between signaling molecules and cellular responses can be modeled in many different systems. Students should practice predicting what will happen in the system when changes or disruptions occur in the system.

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

- Refer to Unit 4 (Cell Communication and Cell Cycle) Instructional Approaches and Sample Activities in the 2019 Course and Exam Description
- See AP Central Biology Course Resources: Cell-to-Cell Communication - Cell Signaling
- FRQ practice questions for teachers to use as formative assessment pieces are now available as part of the collection of new resources for teachers for the 2019 school year. These items begin with scaffolded questions that represent what students are ready for at the beginning of the school year and that continue on to present an increased challenge as teachers progress through the course. These resources are available on AP Classroom with the ability to search for specific question types and topics so that teachers are able to find the new collection of FRQ practice questions and the fully developed scoring guidelines that accompany each question.

Question #5 **Task:** Construct and interpret cladograms **Topic:** Modeling Primate Evolution
Max. Points: 4 **Mean Score:** 1.88

What were the responses to this question expected to demonstrate?

This question provided a data table indicating the percent divergence of mitochondrial DNA sequences among five primate species. Students were asked to use the data to calculate the rate of mtDNA percent divergence per million years between humans and their most closely related species (chimpanzee). Then they were asked to construct a cladogram on a template and provide reasoning for the placement of one of the primate species (gibbon) that had been pre-populated as the outgroup on the cladogram. Lastly, students were asked to identify (by circling on the cladogram) all of the species that were descended from the species represented by a specific node on the cladogram. This demonstrated an understanding of evolutionary relationships as represented in a cladogram.

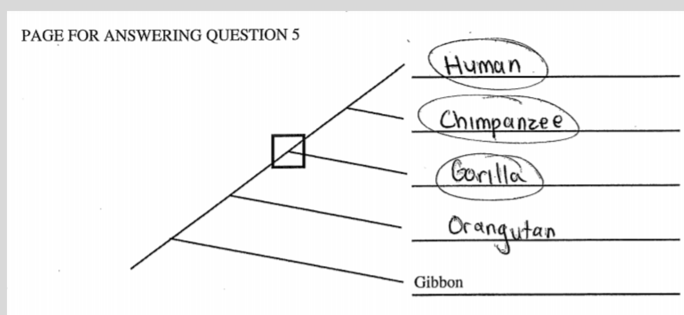
How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

In part (a) most responses correctly calculated the rate of 1.25 or 1.26 percent divergence per million years.

In part (b) most responses demonstrated a correct cladogram construction and correct reasoning that gibbon mtDNA is the least similar to (or most divergent from) all the other species in the study.

In part (c) few responses showed the correct circling of the three species that descended from the indicated node.

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

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Part (c): Correctly circling the three species in the first three positions (top to bottom) of the cladogram.	

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?

Constructing cladograms/phylogenetic trees and interpreting them are two different skills. Help students understand what these diagrams represent by having them practice both of these skills.

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

- Refer to Unit 7 (Natural Selection) Instructional Approaches and Sample Activities in the 2019 Course and Exam Description
- See AP Central Biology Course Resources: Visualizing Information

Question #6	**Task:** Experimental design; understand the outcome of mutations; predict the consequences of changing conditions	**Topic:** Investigating Yeast Complementation
	Max. Points: 3	**Mean Score:** 0.88

What were the responses to this question expected to demonstrate?

This question presented students with a data table indicating the growth of three different haploid strains of yeast: a wild-type strain and two different recessive mutants (Mutant 1 and Mutant 2). The table showed the growth (+) or no growth (−) of the yeast in four different treatment groups based on media containing: all amino acids, no amino acids, all amino acids except methionine, and all amino acids except leucine. Students were asked to identify the role in the experiment of growing all yeast strains in the medium with all amino acids present. Then they were asked to provide reasoning to explain how Mutant 1 could grow in a medium with all amino acids but not in a medium without methionine. Finally, students were asked to complete the table to predict if diploid cells produced by mating Mutants 1 and 2 would grow in the different media. The students used their understanding of experimental design to help respond to this question. They also needed a basic understanding that cells must obtain nutrients from the environment if they cannot synthesize them and that information about growth in specific environments can help determine what mutations are present. In addition, students needed to understand the inheritance of recessive traits and to apply an understanding of the expression of recessive mutations to haploid and diploid cells.

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

In part (a) most responses correctly identified that the treatment group of the medium containing all amino acids was the control group.

Few responses in part (b) correctly provided reasoning that mutant 1 could use the methionine provided in the medium, but could not synthesize methionine, which prevented it from growing on the medium lacking methionine.

In part (c) few responses correctly predicted the growth on all four media of the diploid strain created by mating mutants 1 and 2.

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

In part (b) students often missed earning this point because they did not provide a complete response that indicated mutant 1 could not synthesize methionine.

In part (c) students most often failed to indicate that the diploid strain would be able to grow in treatment II, on the medium that did not contain any amino acids.

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Part (b): Correctly reasoning that mutant 1 can use methionine when it is present in the medium, but mutant 1 cannot synthesize methionine	• “Mutant 1 has a mutation in the gene that encodes for the enzyme that synthesizes methionine that prevents mutant 1 from creating that enzyme. Therefore, the mutant cannot synthesize methionine (which is needed to start all peptide chains in translation) so cannot synthesize any proteins. Mutant 1 can grow on treatment I medium because this medium has all amino acids, including methionine. So mutant I can make proteins. Mutant 1 can’t grow on treatment III because it lacks methionine and mutant 1 can’t synthesize

	methionine on its own so it can't grow because it can't synthesize any proteins."
Part (c): Correctly predicting that the diploid would grow (+) on all four treatment groups/media.	

	MEDIUM	STRAINS: Wild Type (haploid)	Mutant 1 (haploid)	Mutant 2 (haploid)	Diploid Cells Produced by Mating Mutant 1 and Mutant 2
Treatment I	All amino acids present	+	+	+	+
Treatment II	No amino acids present	+	–	–	+
Treatment III	All amino acids present EXCEPT methionine	+	–	+	+
Treatment IV	All amino acids present EXCEPT leucine	+	+	–	+

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?

This question is based on biochemical pathways and an understanding that cells require amino acids that can either be synthesized by the cell or obtained from the environment. It can be difficult for students to envision pathways from a description. Help them practice drawing simple pathways from a narrative. Provide opportunities for students to consider how a disruption to a pathway, caused by a mutation, inhibitor or drug, would affect the products of the pathway, and ultimately how this disruption would affect the cell/organism.

This question required students to consider the end products of two different pathways, for two different amino acids. Many students were able to fill in the table correctly for the diploid cell in part (c) for all but treatment II. This indicates they understood how the synthesis of individual amino acids could be restored in a heterozygous state but could not extend this understanding to incorporate both mutations together. Provide opportunities for students to think deeply about processes and pathways, and to tie together inheritance with molecular pathways.

Provide different types of data representation to students. The "+" and "–" designations in this question are commonly used to represent when something happens ("+" to indicate growth) or when it does not happen ("–" to indicate no growth).

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

- Refer to Unit 6 (Gene Expression and Regulation) Instructional Approaches and Sample Activities in the 2019 Course and Exam Description
- See AP Central Biology Course Resources: From Gene to Protein – A Historical Perspective
- FRQ practice questions for teachers to use as formative assessment pieces are now available as part of the collection of new resources for teachers for the 2019 school year. These items begin with scaffolded questions that represent what students are ready for at the beginning of the school year and that continue on to present an increased challenge as teachers progress through the course. These resources are available on AP Classroom with the ability to search for specific question types and topics so that teachers are able to find the new collection of FRQ practice questions and the fully developed scoring guidelines that accompany each question.

Question #7 **Task:** Identify specific information from a data table; describe cellular processes; provide reasoning to explain an experimental result **Topic:** Investigating Patterns of mRNA Expression
Max. Points: 3 **Mean Score:** 0.69

What were the responses to this question expected to demonstrate?

This question provided students with a data table of relative expression levels of mRNA from six different genes in six different tissues. They were asked to identify the gene most likely to encode a protein needed for glycolysis and provide reasoning to support their answer. They were then given the observation that tissues with a high level of *gene H* mRNA did not always have gene H protein and were asked to provide reasoning for this situation. This question required students to interpret data and apply it to their understanding of glycolysis. Students also needed to have knowledge of the processes of transcription and translation to provide a complete answer.

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 responses correctly identified *gene G* as the gene that encoded a protein necessary for glycolysis. However, few responses provided correct reasoning to earn the second point.

In part (b) some responses provided correct reasoning for the lack of gene H protein in the cells where the mRNA was present.

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

In part (a) most students were able to see that *gene G* was expressed in every tissue type from the data table, but the reasoning was usually not specific. Often students would simply respond that the cells needed the gene and did not demonstrate understanding that glycolysis occurs in all the tissues listed.

Similarly, in part (b) students again were often not specific, stating that the tissue without gene H protein simply didn't need it. Students did not indicate that a specific biological process was blocked or modified to prevent the production of gene H protein. Students also stated that the gene was not in the tissues, instead of discussing the mRNA or the protein.

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Part (a): Correctly reasoning that *gene G* • is the only gene expressed in all six tissues AND that glycolysis occurs in all six tissues OR • is the only mRNA present in all six tissues AND glycolysis occurs in all six tissues.	• "Gene G has a high to moderate amount of mRNA in every tissue on the table. Because glycolysis is the first step of cellular respiration, which is ATP making, Gene G would most likely encode a protein essential for this energy bringing process which is done throughout the body."
Part (b): Correctly reasoning that g*ene H* mRNA:	• "Tissues with high gene H mRNA levels can have no gene H protein as unsuccessful translation can lead to a lack of gene H protein production."

• is not exported from the nucleus OR • is not translated/RNA interference prevents translation • undergoes post-transcriptional modifications	

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 answering FRQs. An important approach to help them is to have students closely examine the prompt and determine what is being asked. In all questions, students need to demonstrate and include biological concepts in their answers. In this question, students were asked to "[p]rovide reasoning to explain how tissues with high *gene H* mRNA levels can have no gene H protein." A reasoning might very well include that the tissues do not need the gene H protein. However, this response does not explain how the gene H protein would not be made in the tissues where the mRNA is present. It is the explanation that answers the prompt. The explanation requires students to use biological concepts (related to transcription and translation).

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

- Refer to Units 3 (Cellular Energetics) and 6 (Gene Expression and Regulation) Instructional Approaches and Sample Activities in the 2019 Course and Exam Description
- See AP Central Biology Course Resources: From Gene to Protein – A Historical Perspective
- FRQ practice questions for teachers to use as formative assessment pieces are now available as part of the collection of new resources for teachers for the 2019 school year. These items begin with scaffolded questions that represent what students are ready for at the beginning of the school year and that continue on to present an increased challenge as teachers progress through the course. These resources are available on AP Classroom with the ability to search for specific question types and topics so that teachers are able to find the new collection of FRQ practice questions and the fully developed scoring guidelines that accompany each question.

Question #8 **Task:** Use models to represent cellular processes; apply biological concepts to development **Topic:** Modeling Petal Cell Changes During Flower Opening

Max. Points: 3 **Mean Score:** 1.04

What were the responses to this question expected to demonstrate?

Students were provided with a model of petal cells in a bud and a fully opened flower. The models depicted a cell with a potassium ion channel in the plasma membrane and a proton pump and a K^+/H^+ transport protein in the vacuole membrane. Three main features of each cell were specified: the pH of the vacuole, the color of the flower, and the volume of the cell. The students were asked to identify the cellular component responsible for the increase in the pH of the vacuole during flower opening and to describe the component's role in changing the pH of the vacuole. Then students were asked to provide reasoning for a claim that the activation of the K^+/H^+ transport protein causes the vacuole to swell with water. Students needed an understanding of pH, osmosis/water potential, and membrane transport to correctly respond to this question. They also needed to interpret a model of a specific cell type, including how the cell changed during development.

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

In part (a) most responses correctly identified the K^+/H^+ transport protein as the component responsible for the increase in the pH of the vacuole during flower opening and correctly described that protons move out of the vacuole to increase the pH.

In part (b) some responses supported the claim that the K^+/H^+ transport protein caused the vacuole to swell with water by providing correct reasoning that the swelling is due to the increase in solute (K^+) concentration inside the vacuole.

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

Students often did not provide directionality in their responses; i.e., the protons moved out of the vacuole while the potassium ions moved in; potassium ion concentration increased in the vacuole, thereby decreasing water concentration, causing the water to move into the vacuole.

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Part (b): Providing correct reasoning to support the claim that the activation of the K^+/H^+ transport protein caused the vacuole to swell with water.	• "The activation of the K^+/H^+ transport protein does cause the vacuole to swell with water. This is because this transport protein pumps ions into the vacuole. By doing this, the vacuole now has a higher concentration of solutes. As a result, water flows down its concentration gradient (High → low) and fills up the vacuole."

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 to practice completing their thoughts within a prompt, “closing the loop,” to fully explain a concept. In this question students needed to include specific directionality when addressing the prompt. They had to clearly indicate in which direction the ions were moving. Also provide opportunities for students to see and interpret different models of cells, especially cells going through a dynamic process, such as the one depicted in this question.

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

- Refer to Unit 2 (Cell Structure and Function) Instructional Approaches and Sample Activities in the 2019 Course and Exam Description
- FRQ practice questions for teachers to use as formative assessment pieces are now available as part of the collection of new resources for teachers for the 2019 school year. These items begin with scaffolded questions that represent what students are ready for at the beginning of the school year and that continue on to present an increased challenge as teachers progress through the course. These resources are available on AP Classroom with the ability to search for specific question types and topics so that teachers are able to find the new collection of FRQ practice questions and the fully developed scoring guidelines that accompany each question.