Chief Reader Report on Student Responses:

2021 AP® Biology Free-Response Questions

- Number of Students Scored 230,527
- Number of Readers 1,000
- Score Distribution

Exam Score	N	%At
5	17,048	7.4
4	44,766	19.4
3	74,683	32.4
2	69,165	30.0
1	24,865	10.8

- Global Mean 2.83

The following comments on the 2021 free-response questions for AP® Biology were written by the Chief Reader, Amy Dykstra, Professor of Biological Sciences, Bethel University, St. Paul, MN, based on input from Exam Leader Robert Benedetto, Central Catholic High School, Lawrence, MA. 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:** Interpreting and Evaluating Experimental Results	**Topic:** Polycystic kidney disease and ouabain
	Max. Points: 10	**Mean Score:** 3.68

What were the responses to this question expected to demonstrate?

This question was based on polycystic kidney disease (PKD), which results in water loss from the body and affects cell division in kidney cells. The question described two experiments in which normal human kidney (NHK) cells and PKD cells were treated with increasing concentrations of the steroid hormone ouabain. Experimental results were presented in two graphs: Figure 1 showed the number of NHK and PKD cells in various ouabain concentrations, and Figure 2 showed the percent Na^+/K^+ ATPase activity in the various ouabain treatments. A third figure illustrated a hypothesized signal transduction pathway initiated by ouabain binding to Na^+/K^+ ATPase .

In part (a) students were asked to describe characteristics of the plasma membrane that prevent simple diffusion of Na^+ and K^+ across the membrane and to explain why ATP is required for the activity of the Na^+/K^+ ATPase . Responses were expected to demonstrate an understanding of the structure of plasma membranes (Topic 2.4 in the *AP Biology Course and Exam Description*), membrane permeability (Topic 2.5), active transport (Essential Knowledge ENE-2.E.3 in Topic 2.6), and the function of the Na^+/K^+ ATPase (ENE-2.G.4 in Topic 2.7).

In part (b) students were asked to identify an independent variable in the experiment represented in Figure 1, to justify the use of NHK cells as a control, and to justify the range of ouabain concentrations used. Responses were expected to demonstrate proficiency in identifying experimental procedures (Science Practice 3.C).

In part (c) students were asked to describe the relationship between concentration of ouabain and Na^+/K^+ ATPase activity in both NHK and PKD cells. Responses were expected to demonstrate proficiency in describing data from a graph (Science Practice 4.B). Students were also asked to perform a mathematical calculation based on the data presented (Science Practice 5.A).

Part (d) described a third experiment in which scientists added an inhibitor of one of the components of the signal transduction pathway. Students were asked to predict the effect of the inhibitor and justify their prediction. Responses were expected to demonstrate an understanding of signal transduction pathways (Topics 4.2, 4.3, and 4.4 of the CED) and proficiency in scientific argumentation (Science Practices 6.E and 6.C). Finally, students were asked to explain why the concentration of cyclin proteins may increase in PKD cells treated with a specific concentration of ouabain. Responses were expected to demonstrate an understanding that the signaling pathway stimulates gene expression (IST-3.D.2 in Topic 4.2) and that cyclins regulate the cell cycle (IST-1.D.1 in Topic 4.7).

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?

<u>Membranes and Transport</u>

- Many responses correctly described membrane structure – membranes are composed of lipid bilayers; phospholipids are composed of hydrophilic heads and hydrophobic tails – but some responses did not demonstrate understanding of how the structure of the membrane is related to its function or how hydrophilic and hydrophobic molecules interact with their environments.
- There was some confusion about the differences between simple diffusion, facilitated diffusion, and active transport.

Experimental Design

- Many responses correctly identified a dependent variable, but some responses confused independent and dependent variables.
- Many responses correctly justified the use of normal human kidney cells as a control.
- Some responses correctly justified the use of a range of ouabain concentrations in the experiments, but some responses confused using a range of concentrations with replication (performing multiple trials).

Data Analysis

- Many responses correctly described data from a graph, namely a decrease in ATPase activity with increasing concentrations of ouabain. However, some responses compared ATPase activity in NHK and PKD cells while neglecting to describe that, in both types of cells, the ATPase activity declined at high concentrations of ouabain.
- Some responses correctly calculated the expected Na^+/K^+ ATPase activity in PKD cells treated with 10^6 pM ouabain. However, some responses performed calculations based on incorrect data selection.
- Some responses indicated an incomplete understanding of mathematical ratios.

Signal Transduction Pathways

- Some responses demonstrated an understanding of signal transduction pathways and made correct predictions of the effect of a disruption to the ouabain pathway. However, there were many errors in interpreting the roles of various molecules in the pathway.
- Few responses demonstrated an understanding of the role of cyclins in regulating the cell cycle.

Integrating the Skills Required on this Question

- Many responses demonstrated an ability to handle complex stimuli and multiple data sets.
- Students appeared willing to work through and answer all parts of the question.

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: Na^+ and K^+ are too large to get through the pores in the membrane.	• "Since Na^+ and K^+ are ions (they have an electric charge) they must enter the cell through transport proteins since can't diffuse through membrane."
• Misconception: The Na^+/K^+ ATPase is required, not because Na^+ and K^+ are moving against their concentration gradients, but because they are ions.	• "Since the cell is bringing in more K^+ ions against their concentration gradient and pumping out Na^+ ions against their concentration gradient, energy in the form of ATP is necessary."
• Misconception: Using a range of concentrations of ouabain will increase the accuracy of the experiment.	• "A range of concentrations are used since PKD cells bind more ouabain to their Na^+/K^+ ATPase , so scientists are looking to see how the increased binding affects cells at varied concentrations."

• Knowledge gap: Understanding of the role of cyclins in regulation of the cell cycle.	• "Ouabain is a signaling molecule that causes the transcription of target genes…it can be inferred that ouabain increases transcription of cyclin genes, which promote cell growth and division."

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

Membranes and Transport

- Have students interact with the fluid mosaic model and its role in transporting various substances.
- Connect cell transport across topics and units.

Experimental Design

- Expose students to various types of data and require them to understand why certain data were collected and how these data tell a complete story.

Data Analysis

- Have students make multiple types of calculations from data.
- Have students describe the relationships among variables in various types of data.

Signal Transduction Pathways

- Expose students to multiple signal transduction pathways and models.
- Ask students to make predictions based on disruptions of these models.

General

- Make connections across topics and units.

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

- Teachers should direct students to AP Daily Videos from Topics 2.4 and 2.6 as well as Topic 4.4.
- Teachers should direct students to Higher Ed Faculty Lecture number 4.
- Teachers should assign topic questions, as well as personal progress check items to monitor progress being made in the mastery of content.
- To prepare students to meaningfully interact with data and experimental design, teachers should utilize the suggested data resources outlined in the Online Resources Recommended by AP Teachers.

Question #2	**Task:** Interpreting and Evaluating Experimental Results with Graphing	**Topic:** Pedigree – glucose metabolism disorder
	Max. Points: 8	**Mean Score:** 3.17

What were the responses to this question expected to demonstrate?

This question presented a pedigree of a family in which some individuals are affected by a "rare disorder that alters glucose metabolism and first shows symptoms in adulthood." Data on average blood glucose levels of individuals in one generation of the pedigree were presented in a table. A second table provided phenotypic classifications based on blood glucose levels.

In part (a) students were asked to describe the atoms and types of bonds in a glucose molecule. Responses were expected to demonstrate an understanding of the structure of carbohydrates (SYI-1.B.2.c in Topic 1.4).

In part (b) students were asked to construct a graph based on the blood glucose data. Responses were expected to demonstrate proficiency in constructing a bar graph (Science Practice 4.A). Students were asked to determine one individual both at risk of developing the disorder and with a significantly different blood glucose level from a specified individual. Responses were expected to demonstrate proficiency in describing data from a table or graph (Science Practice 4.B) and using error bars to determine whether means are statistically different (Science Practice 5.B).

In part (c) students were asked to identify all individuals in generation IV of the pedigree who can pass on the mutation to their offspring. Responses were expected to demonstrate proficiency in analyzing a visual representation of biological concepts and processes (Science Practice 2) and an understanding of a mitochondrial inheritance pattern (IST-1.J.4 in Topic 5.4).

Part (d) presented a claim that the inheritance pattern is X-linked recessive. Students were asked to predict which individuals of generation III would be affected by the disorder, based on the claim, and to justify why the data do not support the claim. Responses were expected to demonstrate an understanding of X-linked and mitochondrial inheritance patterns (IST-1.J.2 and IST-1.J.4 in Topic 5.4) and proficiency in argumentation (Science Practice 6).

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?

<u>Biochemistry</u>

- Many responses correctly identified the atoms in a glucose molecule. However, some responses incorrectly identified the types of bonds.
- Some responses indicated that glucose is a polymer.
- Some responses demonstrated confusion between atoms and molecules.

<u>Graphing and Data Analysis</u>

- Many responses demonstrated proficiency in labeling axes, plotting points on a graph, and plotting error bars.
- Some responses incorrectly connected the points on the graph, even though the instructions were to construct a bar graph.
- Many responses demonstrated proficiency in using error bars to identify an individual with a significantly different blood glucose level from another specified individual.

Genetics

- Many responses demonstrated a lack of understanding of non-Mendelian patterns of inheritance, including X-linked inheritance and mitochondrial inheritance.
- Many responses demonstrated a lack of proficiency in reading and interpreting pedigrees.

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: Hydrogen bonds hold the atoms in a glucose molecule together.	• "Glucose is made of carbon, hydrogen, and oxygen…the bonds found between these atoms in a glucose molecule are covalent bonds."
• Misconception: All individuals listed in a generation in a pedigree (including mates of the offspring) can inherit traits from the previous generation.	• "Every male individual of generation III that came from Individual II-2 would be affected if this claim was true…This is not true, since the females that came from II-2 were also affected even though their father wasn't affected."
• Misconception: Males can pass on mitochondrial DNA.	• "The data does not support the students claim because the trait is found in mitochondrial DNA which is passed down by the mother and not autosomal DNA which is from both parents."

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

Biochemistry

- If biochemistry is taught early in the course, continue to reintroduce these concepts throughout the year in other units.
- The basics of chemistry (e.g., bonding) need to be (re)introduced.

Graphing

- Have students practice graphing different types of data in different ways.

Genetics

- Teach beyond Mendelian patterns of inheritance, and have students make predictions based on non-Mendelian patterns.
- Have students interact with various models presenting inheritance patterns.

General

- Make connections across topics and units.

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

- Teachers should direct students to AP Daily Videos from Topics 1.1, 1.4, and 5.4.
- Teachers should direct students to Higher Ed Faculty Lecture numbers 1 and 5.
- Teachers should assign topic questions, as well as personal progress check items to monitor progress being made in the mastery of content.
- For graphing supports and practice, utilize the resources within the Quantitative Skills Guide.
- To prepare students to meaningfully interact with data and experimental design, teachers should utilize the suggested data resources outlined in the Online Resources Recommended by AP Teachers.

Question #3	**Task:** Scientific Investigation	**Topic:** Mitochondria and resveratrol
	Max. Points: 4	**Mean Score:** 1.54

What were the responses to this question expected to demonstrate?

This question described an experiment in which mammalian muscle cells were treated with resveratrol dissolved in dimethyl sulfoxide (DMSO).

In part (a) students were asked to describe the advantage of aerobic respiration over fermentation in mammalian muscle cells. Responses were expected to demonstrate an understanding of the ATP yields of fermentation and aerobic respiration (Learning Objective ENE-1.K in Topic 3.6).

In part (b) students were asked to identify an appropriate negative control. Responses were expected to demonstrate proficiency in identifying experimental procedures (Science Practice 3.C).

In part (c) students were asked to predict the effect on short-term ATP production if resveratrol-treated cells are grown in the absence of sugar. Responses were expected to demonstrate an understanding of the process of cellular respiration (ENE-1.K in Topic 3.6).

In part (d) students were asked to justify the claim that, because resveratrol stimulates the production of the components of the electron transport chain, treatment with resveratrol will increase oxygen consumption by the cells. Responses were expected to demonstrate an understanding that oxygen acts as the terminal electron acceptor in the electron transport chain (ETC) in mitochondria (ENE-1.K.3 in Topic 3.6).

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?

Cellular Respiration

- Many responses demonstrated an understanding of the advantage of aerobic respiration over fermentation. However, some responses demonstrated misconceptions (see table in next section).
- Many responses demonstrated a lack of understanding of the inputs and outputs of the steps of cellular respiration.
- Many responses demonstrated a lack of understanding about the role of oxygen in the mitochondrial electron transport chain.

Experimental Design

- Many responses did not correctly identify an appropriate negative control.

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: Glycolysis is the same as anaerobic respiration.	• "Aerobic respiration with glycolysis + Krebs cycle produces more ATP than fermentation using only glycolysis."

• Misconception: Aerobic respiration and fermentation differ in speed of ATP production, not amount of ATP produced.	• "Aerobic respiration can produce up to 36 ATP from a single glucose molecule, while fermentation produces only two ATP."
• Misconception: Molecular oxygen pulls hydrogen ions across the mitochondrial membrane.	• "Oxygen is the highly electronegative anchor/magnet that pulls electrons down the ETC. Likewise, increase usage of ETC promoted by resveratrol would result in more electrons moving down, and likewise more O_2 input."

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

Cellular Respiration

- Clearly distinguish glycolysis and fermentation from anaerobic respiration.
- Model the ETC and the role of all components. Have students predict the effects of disruptions to these components.

Experimental Design

- Have students identify, design, and justify the use of positive and negative controls.
- Teach experimental design early and often.

General

- Practice writing responses to FRQs.
- Require students to justify their conclusions.

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

- Teachers should direct students to AP Daily Video from Topic 3.6.
- Teachers should direct students to Higher Ed Faculty Lecture number 3.
- Teachers should assign topic questions, as well as personal progress check items to monitor progress being made in the mastery of content.
- To prepare students to meaningfully interact with data and experimental design, teachers should utilize the suggested data resources outlined in the Online Resources Recommended by AP Teachers.

Question #4 **Task:** Conceptual Analysis **Topic:** Finch evolution

Max. Points: 4 **Mean Score:** 1.60

What were the responses to this question expected to demonstrate?

This question described the establishment of a hybrid lineage of finches, dubbed "Big Bird," on the Galápagos island Daphne Major. Data on beak length and depth were presented in a scatterplot graph (Figure 1).

In part (a) students were asked to describe a prezygotic mechanism that contributed to the reproductive isolation of the Big Bird lineage from *Geospiza fortis*, one of the species of finches that lives on Daphne Major. Responses were expected to demonstrate an understanding of prezygotic mechanisms (EVO-3.F.3 in Topic 7.10).

In part (b) students were asked to explain why the Big Bird population has been able to survive and reproduce on the island. Responses were expected to demonstrate an understanding of niche partitioning (ENE-4.B.3 in Topic 8.5).

Part (c) posited a disruption caused by a virus that infects and kills all *G. magnirostris* on Daphne Major but does not affect the other finch species. Students were asked to predict the most likely change in the beak phenotype of the Big Bird population after six generations.

In part (d) students were asked to justify the predictions they made in part (c). Responses were expected to demonstrate an understanding of natural selection in response to selective pressures in the environment (Topic 7.2).

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?

Speciation

- Many responses correctly identified a prezygotic mechanism; however, some responses did not describe the mechanism or demonstrate understanding of how a prezygotic mechanism can lead to speciation.
- Many responses demonstrated an understanding of the biological concept of species.

Niche Partitioning

- Many responses demonstrated understanding that competition is minimized when niches do not overlap.

Using Data

- Some responses did not use the data provided to justify their predictions.

Evolution

- Many responses demonstrated an understanding that avoiding competition is advantageous.
- Some responses demonstrated misconceptions about evolution (see next section).

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: Evolution is goal-oriented.	• "Big Bird's beak will increase in size because it provides a selective advantage. By having a larger beak, Big Bird will be able to expand their ecological niche into G. magnirostris's former niche. This will increase food supply, so natural selection will favor the Big Bird variations with larger beaks."
• Misconception: Individuals can identify open niches and exploit them by making phenotypical changes.	• "With g. magnirostris gone, their food source will become extremely plentiful. Therefore, the Big Birds with longer and deeper beaks will be able to take advantage of this. With an abundance of food, most of them will live to reproduce, and pass on longer and deeper beaks."

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

Speciation

- Provide scenarios where students can observe pre- and postzygotic barriers leading to speciation.

Using Data

- Have students practice incorporating data into their understanding of a biological system or phenomenon.

Evolution

- Work with students to ensure they understand the role of chance in phenotypical shifts in a population.
- Use population changes to model the modes of selection.
- Distinguish between Lamarckian processes and natural selection.

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

- Teachers should direct students to AP Daily Videos from Topic 7.10.
- Teachers should direct students to Higher Ed Faculty Lecture number 7.
- Teachers should assign topic questions, as well as personal progress check items to monitor progress being made in the mastery of content.
- To prepare students to meaningfully interact with data and experimental design, teachers should utilize the suggested data resources outlined in the Online Resources Recommended by AP Teachers.

Question #5	**Task:** Analyze Model or Visual Representation	**Topic:** Ragweed and biodiversity
	Max. Points: 4	**Mean Score:** 1.62

What were the responses to this question expected to demonstrate?

This question described a field experiment in which all germinating seedlings of the invasive weed *Ambrosia trifida* (giant ragweed) were removed from some experimental plots, while other plots were left untouched. Figure 1 showed the plant identity and distribution in typical plots (plot A and plot B) by representing *A. trifida* and other annual plant species with different symbols.

In part (a) students were asked to describe a cause of logistic growth of the ragweed population. Responses were expected to demonstrate an understanding that resource availability limits population growth (SYI-1.H.2 in Topic 8.4).

In part (b) students were asked to explain why plot B would be more resilient than plot A if exposed to a sudden environmental change. Responses were expected to demonstrate an understanding that more diverse ecosystems are more resilient to environmental changes (SYI-3.F.1 in Topic 8.6) and proficiency in analyzing a visual representation (Science Practice 2).

Part (c) described a third group of plots in which researchers removed all seedlings that emerged prior to June 1, then left untouched the plants that emerged after June 1. Students were asked to represent the plant species that would be expected to emerge in these plots, using the same symbols used in Figure 1. Responses were expected to demonstrate an understanding of how interactions among populations can influence community structure (ENE-4.B.4 in Topic 8.5) and proficiency in representing relationships with a diagram (Science Practice 2.D).

In part (d) students were asked to explain how an invasive species such as ragweed affects ecosystem biodiversity. Responses were expected to demonstrate an understanding of how invasive species affect ecosystem dynamics (SYI-2.A in Topic 8.7).

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?

Population Growth

- Many responses demonstrated a lack of understanding of logistic growth, carrying capacity, and factors that limit population growth.

Community Ecology

- Many responses demonstrated a lack of understanding of ecological succession and ecosystem stability.
- Many responses equated species biodiversity with genetic diversity.

Interactive Modeling

- Many responses demonstrated a lack of proficiency in analyzing visual representations.
- Many responses demonstrated a lack of proficiency in representing relationships with a diagram.
- Many responses demonstrated an understanding that explanations require reasoning.

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: Logistic growth results in an exponential growth curve.	• "The ragweed population grows very quickly at first, but slowing steadily as it approaches carrying capacity. A limiting resource that slows the growth could be available space, whereas at the beginning there was enough space for the population to grow exponentially."
• Misconception: Invasive species attack/kill off/pursue native species.	• "An invasive species can decrease the community's biodiversity because it can out-compete the native species for resources, such as space or light."

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

Population Growth

- Emphasize different models of population growth and the mathematics underlying these models.
- Use simulations to demonstrate different growth patterns.
- Model carrying capacity and its causes and impacts on population growth.

Community Ecology

- Provide varying examples of the roles and impacts of introduced and invasive species.
- Distinguish between genetic diversity and (species) biodiversity.
- Explain how species biodiversity leads to ecosystem stability.

Interactive Modeling

- Use models often.
- Have students manipulate models and use them to make predictions.
- Emphasize that predictions/explanations of effects often require a direction (i.e., "it will change" is not sufficient – does it increase or decrease?).

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

- Teachers should direct students to AP Daily Videos from Topics 8.4-8.7.
- Teachers should direct students to Higher Ed Faculty Lecture number 8.
- Teachers should assign topic questions, as well as personal progress check items to monitor progress being made in the mastery of content.
- To prepare students to meaningfully interact with models and simulations, teachers should utilize the suggested data resources outlined in the Online Resources Recommended by AP Teachers.

Question #6 **Task:** Analyze Data **Topic:** Temperature and krill *hsp* mRNAs

Max. Points: 4 **Mean Score:** 1.26

What were the responses to this question expected to demonstrate?

This question was based on a species of krill, *Thysanoessa inermis*, that is adapted to cold seawater. The question described experiments used to detect changes in expression of *hsp* genes that code for heat-shock proteins (HSPs). Average concentrations of mRNAs transcribed from three *hsp* genes in krill before, during, and after a heat shock treatment were presented in a graph (Figure 1).

In part (a) students were asked to identify the *hsp* mRNA that has the slowest rate of concentration increase in response to the heat shock treatment. Responses were expected to demonstrate proficiency in describing data from a graph (Science Practice 4.B).

In part (b) students were asked to describe the trend in average concentration of mRNA I throughout the experiment. Responses were expected to demonstrate proficiency in describing data from a graph (Science Practice 4.B).

In part (c) students were asked to use experimental data to support the scientists' claim that the HSP translated from mRNA I plays a greater role in refolding proteins than does the HSP translated from mRNA II. Responses were expected to demonstrate proficiency in describing data from a graph (Science Practice 4.B), that gene regulation results in differential gene expression (IST-2.D.1 in Topic 6.6), and an understanding of how heat can denature proteins (ENE-1.F.1 in Topic 3.3).

In part (d) students were asked to explaian how a cell can produce two different mRNAs from the same gene. Responses were expected to demonstrate an understanding of alternative splicing (IST-1.N.6 in Topic 6.3).

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?

Data Analysis

- Many responses demonstrated proficiency in identifying data points on a graph.
- Some responses demonstrated proficiency in describing trends in data presented in a graph. However, some responses did not distinguish among different rates of change presented graphically.
- Some responses demonstrated a lack of mathematical understanding of graphical rates.

Environmental Impacts on Enzyme Function

- Many responses demonstrated an understanding that heat can denature enzymes.

Molecular Genetics

- Many responses demonstrated a lack of understanding of the specific processes involved in RNA processing.
- Many responses demonstrated an understanding of the processes of transcription and translation. However, some responses confused processes involved in DNA replication, transcription, and translation.
- Some responses demonstrated a lack of understanding of the roles of alleles, genes, DNA, and RNA in determining 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*
• Misconception: Both strands of DNA in a gene code for proteins (albeit different proteins).	• "A cell can produce two different mRNAs from the same gene through a process called alternative RNA splicing. Genes contain coding regions called exons that alternate with noncoding regions called introns. When transcription occurs, the pre-mRNA transcript has both exons and introns. The transcript then has its introns removed by a spliceosome and the exons are joined together. In alternative RNA splicing, different mRNAs can be produced depending on which regions are treated as exons and which are treated as introns."

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

Data Analysis

- Have students practice describing the nuances of data trends. Relate those trends to cellular processes and hypotheses.
- Incorporate mathematics into graphical discussions.
- Teach students to examine legends carefully.

Molecular Genetics

- Have students model the steps of post-transcriptional control. Ask them to predict the effects of modifying an aspect of these controls.
- Go beyond the basics of DNA → RNA → Protein.
- Include details about alternative splicing and its implications.
- Avoid teaching DNA replication alongside the Central Dogma.

General

- Have students practice using evidence to support a claim.

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

- Teachers should direct students to AP Daily Videos from Topic 6.3.
- Teachers should direct students to Higher Ed Faculty Lecture number 6.
- Teachers should assign topic questions, as well as personal progress check items to monitor progress being made in the mastery of content.
- For graphing supports and practice, utilize the resources within the Quantitative Skills Guide.
- To prepare students to meaningfully interact with models and simulations, teachers should utilize the suggested data resources outlined in the Online Resources Recommended by AP Teachers.