Chief Reader Report on Student Responses:

2023 AP® Biology Free-Response Questions

- Number of Students Scored 239,470
- Number of Readers 1,003
- Score Distribution

Exam Score	N	%At
5	34,146	14.26
4	55,026	22.98
3	65,088	27.18
2	56,429	23.56
1	28,781	12.02

- Global Mean 3.04

The following comments on the 2023 free-response questions for AP® Biology were written by the Chief Reader, Amy Dykstra, Bethel University—Minnesota, with substantial assistance from the Operational Exam Leader, Jay Mager, Ohio Northern University, and Question Leaders, Geoff Gearner, Morehead State University (Question 1); Ross Sappenfield, Vail Mountain School, Vail, Colorado (Question 2); Jody Saxton West, Northfield High School, Northfield, Minnesota (Question 3); Leslie Haines, Walter Williams High School, Burlington, North Carolina (Question 4); Cynthia Beale, West Valley High School, Fairbanks, AK (Question 5); and Jeffrey Regier, Taylor University, Upland, Indiana (Question 6). The comments 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 with which students frequently have the most problems 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 with Experimental Design
Topic: PHO Pathway and Experiment with Yeast Mutants
Max Score: 9
Mean Score: 2.80

What were the responses to this question expected to demonstrate?

Question 1 described the PHO signaling pathway, which regulates phosphate homeostasis in yeast. The question stimulus presented a simplified model of the signal transduction pathway and a data table from an experiment designed to study the roles of Pho81 and Pho4, two proteins in the PHO pathway.

In part (a) students were expected to describe the effect of adding a charged phosphate group to a protein (Skill 1.A; Learning Objective [LO] SYI-1.C from the AP Biology Course and Exam Description [CED]). Students were also expected to explain how signals can be amplified in a signal transduction pathway (Skill 1.C; LO IST-3.D).

In part (b) students were expected to demonstrate understanding of experimental design by identifying a dependent variable, justifying the researchers' using a wild-type strain of yeast as the background for creating mutant strains, and justifying the use of mutant strains that each contained a mutation to a single component of the PHO pathway (Skill 3.C).

In part (c) students were expected to describe data from the table by identifying the yeast strain and growth conditions that led to the highest relative amount of *PHO1* mRNA (Skill 4.B). Students were then asked to calculate the percent change in APase activity in wild-type cells exposed to a high extracellular inorganic phosphate (high-Pi) environment compared with those exposed to a low-Pi environment (Skill 5.A).

In part (d) students were expected to predict the results of a follow-up experiment that tests the effects of a loss-of-function mutation to Pho85, another protein in the PHO pathway (Skill 3.B; LO IST-3.G). Students were then expected to justify their predictions (Skill 6.C).

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?

Protein Structure

- Many responses correctly described that the effect of the addition of a charged phosphate group to a protein is a change in shape/structure of the protein (Essential Knowledge [EK] SYI-1.C.1.d).

Signal Transduction Pathways

- Most responses did not explain that a signal can be amplified because each enzyme can act on many copies of a protein. Responses did not demonstrate an understanding of the term "amplification" (EK IST-3.D.2).

Experimental Design

- Many responses correctly identified a dependent variable (Skill 3.C.a).
- Most responses did not demonstrate the ability to clearly articulate the function of control and experimental variables in the specific context of the PHO experiment (Skill 3.C.c).

Evaluating Experimental Data

- Most responses correctly described data in the table (Skill 4.B.a) by identifying the wild-type yeast in a low-Pi environment as the yeast strain and growth conditions that resulted in the highest relative amount of *PHO1* mRNA.

Performing Mathematical Calculations

- Some responses correctly calculated the percent difference between two data points using the appropriate formula.

Predictions Based on Disruptions of Biological Systems

- When tasked with engaging with a visual representation of signal transduction and its associated cellular response (gene regulation), some responses made the correct prediction (Skill 3.B) as well as provided an appropriate justification (Skill 6.C).

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 (a) • Misconception: The concept of amplification as it relates to signal transduction. Many responses used the term “phosphorylation cascade,” which, by itself, does not indicate amplification.	Part (a) • “phosphorylating a protein in step 1 might activate 10 proteins in step 2”
Part (b) • Knowledge Gap: The inability to specifically elaborate on the function/purpose of control variables in an experimental design, with many simply stating that a particular experimental group “served as a control.”	Part (b) • “to ensure that no other variables would be changed other than the mutation.” • “by using mutant strains that had only a single component mutated, they could know that any significant differences in enzyme activity were for sure caused by that one mutation.” • “Only mutating a single component allows the researcher to determine the specific component that produced the results.”
Part (c) • Skill Gap: Miscalculation of percent change. Many students used this formula: $(V_2 / V_1) \times 100$, rather than $(V_2 - V_1 / V_1) \times 100$ where $V_1 = 0.5$ and $V_2 = 17.3$, $[(17.3 - 0.5) / 0.5] \times 100 = 3,360\%$. Note that it is not required that the students show their work.	Part (c) • “3360%”
Part (d) • Skill Gap: Connecting a loss-of-function mutation of *Pho85* to failure to phosphorylate Pho4 to expression of *PHO1*.	Part (d) • “if Pho85 is nonfunctional Pho4 will express the Pho target genes.”

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?

Signal Transduction

- This topic affords the opportunity to connect a number of concepts, e.g., cell communication, the cell cycle and its regulation, and mitosis.
- Start with general considerations of cell communication, including types (paracrine, endocrine, etc.) and the three stages of cell communication (receptor activation, signal transduction, and cellular response [metabolic, gene regulation, cytoskeletal]). Signal transduction involves cascades of protein activation and amplification (one component activates numerous copies of the next component in the cascade). Follow this up by exploring specific examples such as epidermal growth factor signaling and epinephrine signaling.

Experimental Design

- Teach students about the various types of controls (positive, negative, and a baseline for comparison). Provide students with descriptions of experiments and have them identify the various types of controls; additionally, provide students with an experimental question and have them design an experiment with appropriate controls.

Science Practices

- Give students opportunities to understand the relationship between claim, evidence, and reasoning. Give students a claim and ask them to identify the kind of evidence that would support their claim. Give students a claim with evidence and ask them to connect the two with reasoning. Provide students with journal articles about experiments or phenomena and have them determine the researchers'/authors' argument, identifying the claim, evidence, and reasoning components. Provide students with previous Free-Response Questions that contain the task verbs **explain**, **justify**, and **support a claim** to help students recognize that each of these task verbs requires elements of argumentation.

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

From AP Classroom:

- Progress Checks from Units 1 and 4
- AP Daily Videos, Topics 1.5, 4.2, 4.3, and 4.4 as well as Faculty Lectures 1 and 4
- Topic Questions from Topics 1.5, 4.2, 4.3, and 4.4 for formative assessments

From the AP Biology Online Teacher Community:

- Data resources outlined in the *Online Resources Recommended by AP Teachers*

Question 2

Task: Interpreting and Evaluating Experimental Results with Graphing
Topic: CO_2 Effects on Chloroplasts and Mitochondria
Max Score: 9
Mean Score: 4.10

What were the responses to this question expected to demonstrate?

Question 2 presented results, in a table, from an experiment designed to study the effect of elevated CO_2 on the density of mitochondria in the cells of six different species of plants.

In part (a) students were asked to describe the role of the inner mitochondrial membrane in cellular respiration (Skill 1.A; Learning Objective [LO] SYI-1.F from the AP Biology Course and Exam Description [CED]).

In part (b) students were expected to construct "an appropriately labeled graph that represents" the data in the provided table (Skill 4.A). Students were then expected to use the data to "determine which species show(s) a difference in the number of mitochondria between normal and elevated levels of CO_2" (Skill 5.B).

In part (c) students were asked to describe the relationship between the independent and dependent variables (Skill 4.B).

Part (d) presented information about a mutation in mitochondrial DNA that inhibits the development of chloroplasts and results in leaves with white stripes. Students were asked to predict the phenotype(s) of the offspring from a cross between white-striped and green plants (Skill 6.E; LO IST-1.J). Finally, students were asked to explain why plants with the same genotype could exhibit differences in the number of organelles in response to differences in environmental CO_2 levels (Skill 6.D; LO SYI-3.B).

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>Constructing an appropriately labeled graph and describing data in the graph</u>

- Many responses constructed a correctly labeled bar graph with data points and error bars correctly plotted (Skill 4.A).
- Many responses demonstrated proficiency in using error bars to determine whether there are significant differences among the means of the graphed data (Skill 5.B).
- Many responses correctly described the relationship between the independent variable and the dependent variable (Skill 4.B.c).

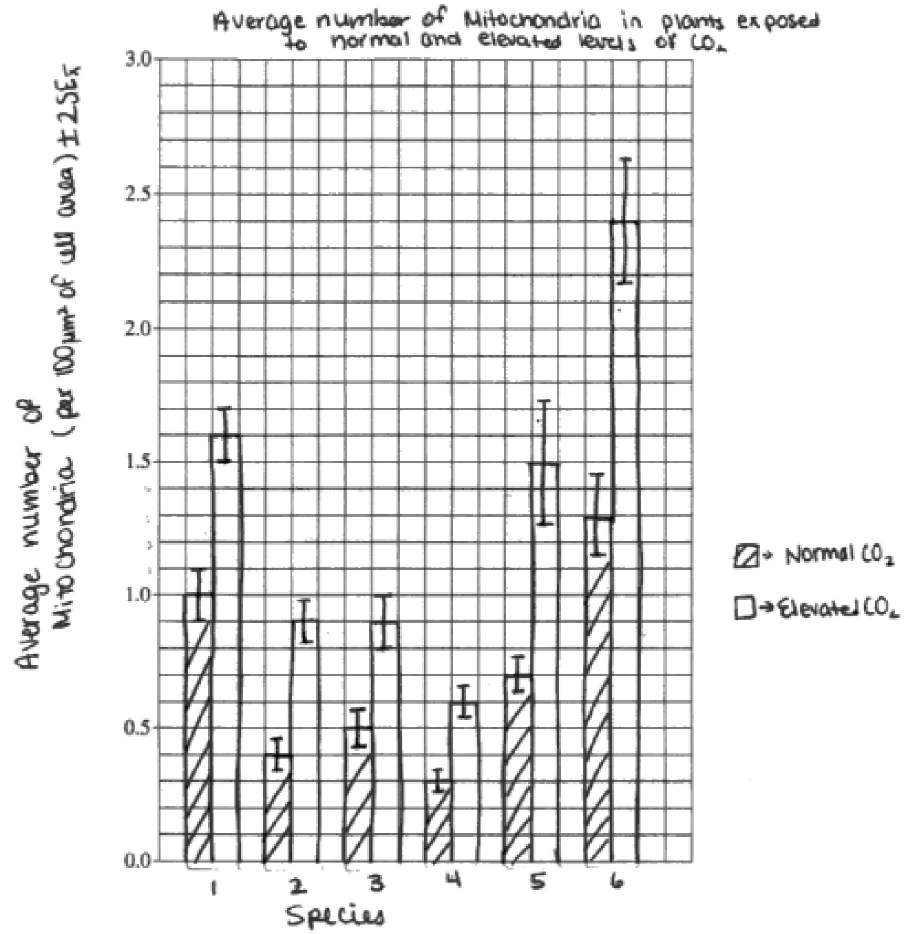
<u>Cellular Respiration and Environmental Effects on Phenotype</u>

- Many responses did not correctly describe the role of the inner mitochondrial membrane in cellular respiration (EKs SYI-1.F.9, ENE-1.K.3).
- Some responses correctly predicted the phenotype of a specific cross.
- Many responses did not justify the prediction using the correct mechanism of inheritance (EK IST-1.J.4.c).
- Many responses did not explain that phenotypic changes are due to environmental effects on gene expression (EK SYI-3.B.1).

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

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Knowledge Gaps	
• The location and role of the specific reactions in cellular respiration	• "The inner mitochondrial membrane is involved in the electron transport chain and creating a proton gradient. This provides energy for oxidative phosphorylation."
• Determining Statistical Significance	• "All of the plant species show a statistical difference in the number of mitochondria between normal and elevated CO_2 levels because no SEM bars overlap."
• mtDNA inheritance mechanism and pattern	• "The offspring will have green leaves because mitochondrial DNA comes from the mother, which had green leaves, not white."
• Different factors that can affect phenotypes	• "Different environmental factors, such as CO_2 levels, can alter gene expression. Although the plants may have the same genotype, the different environment will affect which genes are expressed."
• Experimental design (confusing the independent and dependent variables)	• "There is a positive correlation between CO_2 concentrations and the density of mitochondria in plant cells."
Misconceptions	
• All cellular respiration processes occur in the same place.	• "The electron transport chain (ETC) is located in the inner mitochondrial membrane."
• A line graph is appropriate for categorical data.	• See graph below.
• Mutations are always recessive.	• "Since the mutation is in the mitochondria and the mitochondrial DNA comes from the mother, the plant with unmutated ovules won't pass on mutated mitochondria."
• The most common phenotype is always dominant.	
• Maternal inheritance (of organelles) has the same mechanism as X-linked inheritance.	• "Mitochondrial DNA is only inherited from the mother through maternal inheritance."

Sample graph response:



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?

- Look at Science Practice 4.A, “Construct a graph, plot, or chart.” There are seven Skills related to constructing an appropriate graph; give students opportunities to practice each Skill.
- Be sure to provide unique data sets during the year, as well as collect data from authentic labs that address all the Skills and all the graph types listed.

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

From AP Classroom:
- Progress Checks from Units 2 and 5
- AP Daily Videos, Topics 2.2, 5.4, and 5.5 as well as Faculty Lectures 2 and 5
- Topic Questions from Topics 2.2, 5.4, and 5.5 for formative assessments

From the AP Biology Online Teacher Community:
- Data resources outlined in the *Online Resources Recommended by AP Teachers*
- For graphing supports and practice, utilize the resources within the Quantitative Skills Guide

Question 3

Task: Scientific Investigation
Topic: Sand Lances and Climate Change
Max Score: 4
Mean Score: 1.46

What were the responses to this question expected to demonstrate?

The stimulus of Question 3 described small fish called sand lances (*Ammodytes spp*.) that function as keystone organisms and are preyed upon by organisms at higher trophic levels. A scientific investigation into the effect of rising temperatures and CO_2 levels on sand lance development was presented.

In part (a) students were expected to describe that increased biodiversity results in increased ecosystem resilience (Skill 1.A; Learning Objective [LO] SYI-3.F from the AP Biology Course and Exam Description [CED]).

In part (b) students were asked to justify the use of the control conditions in the experiment (Skill 3.C).

In part (c) students were expected to write a null hypothesis for the experiment (Skill 3.B).

Part (d) described a claim of the scientists that "a reduction in the population size of the *Ammodytes* sand lances will affect the stability of the entire coastal ecosystem." Students were asked to provide reasoning to support the claim (Skill 6.B; LO SYI-3.G).

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>Biodiversity</u>

- Many responses correctly described the effect of increased biodiversity as increased resilience in an ecosystem (EK SYI-3.F.1), although some responses confused ecosystem biodiversity with genetic variation within a population.
- Many responses supported the claim that a reduction in the population size of a keystone species would negatively affect the ecosystem because other trophic levels would have a reduction in their food source or energy transferred to them (EK ENE-1.N.2), though some supports were incomplete.

<u>Experimental Design</u>

- Many responses correctly stated that $5°C$ and $400\ \mu atm$ were the typical conditions under which sand lance embryos develop; however, many responses did not justify the use of these typical conditions as a baseline for comparison to the experimental temperatures and atmospheric pressures.
- Many responses correctly stated a null hypothesis for the experiment (Skill 3.B), but some responses were not specific enough to the described experiment by not relating the null hypothesis to the experimental variables.

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: Biodiversity is measured as genetic variation; these genetic variations were described at the organismal, population, and community/ecosystem levels.	• "Increased biodiversity increases the resilience of an ecosystem." • "With an increase in biodiversity comes an increase in resilience, as if there is a disruption in the ecosystem, it is more likely to recover than a less biodiverse ecosystem."
• Skill Gap: Writing complete justifications	• "Scientists selected $5°C$ and $400\ \mu atm$ as the lowest temperature and CO_2 level because the embryos typically develop in those conditions. Therefore, the survivability of embryos in that condition can be compared to the survivability of embryos in the experimental conditions, allowing the scientists to see if the survivability of the sand lances is likely to be affected by climate change."
• Skill Gap: Writing complete supports to a claim, connecting the claim to the evidence with reasoning	• "The scientists' claim is accurate because the sand lance is a keystone species, meaning its presence is critical to stabilizing the ecosystem's food web. So if the sand lance population's size is reduced, the size of the population that feeds on it will likely be reduced, too, because there will be less energy available to the consumer."

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?

<u>Ecology</u>

- Teach students about the levels of organization in an ecosystem, from smallest to largest (organism → population → community → ecosystem); require them to use this vocabulary to add clarity to responses.
- Provide students with models of a food webs. Have them predict which species, if any, are likely the keystone species, and what would happen to the food web if that keystone species were removed, and then have students support their predictions with reasoning. Provide students with a journal article, video, or case study about a disruption to that ecosystem that allows them to evaluate their predictions and reasoning.
- Provide students with models or descriptions of food webs of various complexities, with arrows indicating transfers of energy. Ask the students to predict which ecosystem(s) would be the most resilient to a disruption and support their prediction with reasoning.

<u>Experimental Design</u>

- Teach students about the various types of controls (positive, negative, and a baseline for comparison). Provide students with descriptions of experiments and have them identify the various types of controls; additionally, provide students with an experimental question, and have them design an experiment with appropriate controls.

- Since experiments on ecological concepts may be difficult to carry out in classrooms, give students descriptions of ecology concept-based experiments and have them create labeled sketches of the design. This will allow them to practice visualizing experiments that they didn't perform, which can make them more understandable.

General

- When you feel that students are developing an understanding of a process or concept (such as interactions within an ecosystem), challenge them by introducing a disruption to the system. Ask them to predict the effect of the disruption, then support their prediction. Practice questions that have the processes/concepts and disruptions described in a text-based stimulus, as well as with processes/concepts and disruptions presented as a model.

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

From AP Classroom:

- Progress Checks from Unit 8
- AP Daily Videos, Topics 8.6 and 8.7 as well as Faculty Lecture 8
- Topic Questions from Topics 8.6 and 8.7 for formative assessments

From the AP Biology Online Teacher Community:

- Data resources outlined in the *Online Resources Recommended by AP Teachers*

Question 4

Task: Conceptual Analysis
Topic: Noncyclic and Cyclic Electron Flow
Max Score: 4
Mean Score: 1.17

What were the responses to this question expected to demonstrate?

This question presented a simplified model showing both noncyclic and cyclic electron flow in the light reactions of photosynthesis.

In part (a) students were expected to describe the role of chlorophyll in the photosystems of plant cells (Skill 1.A; Learning Objective [LO] ENE-1.J from the AP Biology Course and Exam Description [CED]).

In part (b) students were asked to explain why an increase in the ratio of NADPH to $NADP^+$ would cause an increased flow of electrons in the cyclic pathway (Skill 2.B; LO ENE-1.I).

Part (c) described a loss of function in the gene encoding CRR6, a component of photosystem I. Students were asked to predict the effect of this mutation on the rate of biomass accumulation in rice plants (Skill 6.E; LO ENE-1.J).

In part (d) students were expected to justify their prediction (Skill 6.C).

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?

Light-dependent reactions

- Many responses correctly described the role of chlorophyll as absorbing light (EK ENE-1.J.1).
- Few responses correctly explained that the increased ratio of NADPH to $NADP^+$ would result in lower amounts of $NADP^+$ available to accept electrons and an increase in the flow of electrons in the cyclic pathway.

Light-independent reactions

- Many responses correctly predicted that a disruption in the activity of photosystem I would result in a decrease in the rate of biomass accumulation (EK ENE-1.I.2).
- Many responses did not fully justify the prediction. While many responses noted that less ATP/NADPH would be produced, these responses often did not justify the resulting decrease in Calvin cycle activity (EK ENE-1.J.5).

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: Chlorophyll's role is to make plants green.	• "Chlorophyll captures light"
• Knowledge Gap: the role of the final electron acceptor, $NADP^+$. Responses focused on the increase in NADPH, not recognizing that a lack of available $NADP^+$ to accept electrons would shift the electrons on the noncyclic pathway over to the cyclic pathway. • Knowledge Gap: Some responses demonstrated a lack of understanding that the "food" produced in photosynthesis is used to build new plant structures (biomass), and these cannot be built if photosynthesis is disrupted. • Knowledge Gap: Many responses demonstrated a lack of understanding that when a ratio increases, the numerator (NADPH) increases AND the denominator ($NADP^+$) becomes proportionately smaller. • Skill Gap: Many responses demonstrated an inability to write a complete justification of a prediction, demonstrated when responses did not give both sides of the justification. • Skill Gap: Being able to analyze a diagram in order to understand the relationships between its component parts.	• "If NADPH concentration is already high, it would inhibit noncyclic electron flow because there is not enough $NADP^+$ to accept the electrons, so the electrons will be transferred back to the electron transport chain and photosystem I." • "Without photosystem I (or with reduced activity), the light-independent reactions where CO_2 is broken down to provide carbon to plants to grow and gain biomass cannot occur as quickly" • "If NADPH concentration is already high ... there is not enough $NADP^+$ to accept the electrons" • "This is because less $NADP^+$ will be reduced, which is needed for the energy to carry out carbon fixation in the Calvin cycle" • "With reduced photosystem I activity, less NADPH will be produced (in noncyclic pathway)"

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?

- Be careful to avoid getting so focused on helping students understand that plants are reflecting green light that this is all students remember about chlorophyll.
  - **TIP:** Do exercises with the absorption spectra for different types of photosynthetic organisms.
- Don't forget to include plants when you give examples of physiological processes. Do experiments and demos that use plants. Have real plants in class and reference them as often as you can to help students get used to the idea that plants actually do grow and produce new structures (i.e., biomass) even though they are not "eating."
- We sometimes assume students have mastered the Skills in Science Practice 5A in earlier courses, but they cannot always apply these Skills to new situations.
  - **TIP:** Practice working with ratios as applied to course concepts.
- Students often don't realize how much information a diagram really contains.
  - **TIP:** Model diagram exploration by talking your way through a complex diagram with your students: What does this part show? What is this arrow telling us? How does this part connect with that part, etc.? Have students practice diagram exploration with novel and complex diagrams.

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

From AP Classroom:

- Progress Checks from Unit 3
- AP Daily Video, Topic 3.5 as well as Faculty Lecture 3
- Topic Questions from Topics 3.5 for formative assessments
- Use analysis-level questions with visuals on assessments where appropriate and applicable.

Question 5

Task: Analyze Model or Visual Representation of a Biological Concept or Process
Topic: Cladograms of Ruminants
Max Score: 4
Mean Score: 1.19

What were the responses to this question expected to demonstrate?

Question 5 presented two cladograms of several ruminant families, one based on morphological data and another based on molecular data. The stimulus also presented a table of morphological characteristics for the ruminants.

In part (a) students were asked to describe how scientists would use comparisons of DNA sequences to determine the evolutionary relatedness of different organisms (Skill 1.A; Learning Objective [LO] EVO-1.N from the AP Biology Course and Exam Description [CED]).

In part (b) students were expected to interpret the cladograms to "explain why Bovidae is likely to be more closely related to Moschidae than it is to Giraffidae" (Skill 2.B; LO EVO-3.C).

In part (c) students were expected to use a cladogram template to represent the points at which a particular morphologic characteristic evolved (Skill 2.D; LO EVO-3.B).

In part (d) students were asked to explain why a trait found in only two families in the cladogram is likely evidence of convergent evolution. This question required students to apply their understanding of cladograms to the idea that selective pressures can result in the evolution of similar phenotypes in unrelated species (Skill 2.C; LO EVO-1.G).

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?

Interpreting cladograms and data tables

- Many responses were proficient in reading a cladogram to determine where characteristics arose and the common ancestry of families (Skill 2.B; EK EVO-3.C.1).
- Many responses were proficient in reading a data table to determine what traits were shared or lacking between families of ruminants (Skill 4.B).

Evolutionary biology

- Many responses demonstrated an understanding of convergent evolution (EK EVO-1.G.1).
- Many responses demonstrated an understanding of common ancestry (a concept that appears in many places in the CED, including EKs EVO-3.B.1 and EVO-3.C.1).
- Many responses did not use the evidence in the cladogram to explain why it is more likely that a trait present in only two families of a large clade is due to convergent evolution than to common ancestry (Skill 2.C).

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: DNA sequences are the equivalent of amino acid sequences or protein sequences.	• "A scientist would use similar DNA sequences in two species to determine that they must have had a recent common ancestor. Species pairs with more similar DNA shared a more recent common ancestor than species pairs with very different DNA."
• Misconception: When comparing cladograms based on morphological data and molecular data, comparing how close organisms are on the cladogram is a sufficient explanation of why one cladogram might be more reliable.	• "Bovidae is more likely to be related to Moschidae because molecular data was used to construct Figure 1B where Bovidae and Moschidae are the closest relatives. It is possible that Bovidae and Giraffidae have similar morphology due to convergent evolution, and therefore morphological data is less reliable than molecular data."
• Misconception: Branches at nodes on cladograms represent an organism that evolved from the previous one, rather than two groups/families sharing a common ancestor.	• "A characteristic found only in Cervidae and Bovidae is more likely evidence of convergent evolution than common ancestry because Bovidae and Cervidae aren't that close genetically. Were that trait to be found in a common ancestor of both, Moschidae would have to have lost that trait (and if using Cladogram A, Giraffidae and Antilocapridae would also have to lose that trait.) This seems unlikely."

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?

- Ask students to both construct and explain cladograms from data tables that are based on DNA sequences, amino acid sequences, and protein differences, as well as morphology.
    - **TIP:** Seek out data or examples that go beyond the most used examples. Make sure the students understand the implications of using DNA sequences versus amino acid sequences or proteins.
    - Have students explain how to back up their answers using scientific evidence found in cladograms.
    - Have students explain what cladogram nodes represent and what the families/species names at the end of each branch of the cladogram represent.

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

<u>From AP Classroom</u>:

- Progress Checks from Unit 7
- AP Daily Videos, Topics 7.3 and 7.6 as well as Faculty Lecture 7
- Topic Questions from Topics 7.3 and 7.6 for formative assessments

<u>From the AP Biology Online Teacher Community</u>:

- Data resources outlined in the *Online Resources Recommended by AP Teachers*

Question 6

Task: Analyze Data
Topic: Housekeeping Genes
Max Score: 4
Mean Score: 1.48

What were the responses to this question expected to demonstrate?

Question 6 described housekeeping genes that tend to be expressed at constant levels in all cells. The stimulus also described an experiment designed to determine whether the expression of four specific housekeeping genes was indeed constant across different developmental stages, sexes, and cell types of bees. Gene expression was measured by collecting mRNA, performing reverse transcription, and then using PCR to amplify the DNA. This process results in a Cq value, defined as "the number of PCR cycles needed to produce a specified number of DNA copies." Data from the experiment were presented in a box-and-whisker plot.

In part (a) students were asked to identify the gene that had the lowest median Cq value when comparing bees of different developmental stages (Skill 4.B).

Part (b) explained that the Cq value is inversely proportional to the amount of mRNA collected. Students were asked to identify the gene with the lowest level of gene expression (Skill 4.B; Learning Objectives [LOs] IST-1.N, IST-2.A from the AP Biology Course and Exam Description [CED]).

Part (c) described an investigation into the effect of pesticides on gene expression in male and female bees of the same developmental stage. Students were asked to use the data from the box-and-whisker plot to evaluate the scientists' hypothesis about the best control gene for the investigation (Skills 4.B and 5.D).

In part (d) students were asked to explain how expression of a specific gene can vary in different cell types of the same bee (Skill 6D; LO IST-2.D).

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 were proficient at identifying information provided in the graph (Skill 4.B).
- Many responses were proficient at converting information in the graph to gene expression levels (Skill 4.B).
- Some responses demonstrated a lack of understanding of box-and-whisker plots (e.g., the whiskers were thought to represent error bars).
- Few responses demonstrated an ability to use the details of the proposed experimental design to evaluate the provided hypothesis (Skill 5.D).

Molecular Genetics

- Many responses provided an explanation for differences in gene expression in different cell types in terms of the purposes they serve rather than of the molecular cause by which they arise (i.e., they explained why vs. explaining how gene expression could vary in different cell types).
- Many responses attempted to use data from the graph to explain how different cell types regulate gene expression, rather than providing an explanation based on their knowledge of biology (Enduring Understanding IST-2).
- Few responses demonstrated a proficient understanding of regulation of gene expression (LOs IST-2.A, IST-2.C, IST-2.D).

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: Mutations are the reason why expression of specific genes varies from one cell type to another. In fact, DNA sequences are essentially identical in different cell types, but which genes are expressed varies.	• "Every cell has the same DNA sequence, yet which genes get expressed varies ... Different transcription factors in the cells will lead to different genes being expressed in a cell."
• Misconception: Operons are found in eukaryotes. In fact, operons are a prokaryotic gene regulatory strategy.	• "Gene regulation in eukaryotes is controlled by promoters and transcription factors, which vary in quantity inside the organism's different cell types."
• Misconception: Promoters/enhancers (DNA sequences) differ in different cell types rather than the transcription factors differing.	• "Cells that have the correct transcription factors will ... express the GAPDH gene."
• Misconception: TBP-AF is the best control gene because it has the lowest expression level.	• "The scientists' hypothesis is correct, because in the variation being tested (sex), TBP-AF had the narrowest range of Cq values."

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

- Provide students with examples of box-and-whisker plots.
  - **TIP:** Ask students to compare ranges of data sets in box-and-whisker plots.

Molecular Genetics

- Have students identify the different stages of gene expression that are subject to regulation.
- Have students identify key proteins responsible for regulation at each stage.

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

From AP Classroom:

- Progress Checks from Unit 6
- AP Daily Videos, Topics 6.3, 6.5, and 6.6 as well as Faculty Lecture 6
- Topic Questions from Topics 6.3, 6.5, and 6.6 for formative assessments

From the AP Biology Online Teacher Community:

- Data resources outlined in the *Online Resources Recommended by AP Teachers*
- For graphing supports and practice, utilize the resources within the Quantitative Skills Guide.