AP® CollegeBoard

Chief Reader Report on Student Responses:

2017 AP® Biology Free-Response Questions

- Number of Students Scored 254,270
- Number of Readers 686
- Score Distribution

Exam Score	N	%At
5	16,346	6.4
4	53,341	21.0
3	93,282	36.7
2	69,871	27.5
1	21,430	8.4

- Global Mean 2.90

The following comments on the 2017 free-response questions for AP® Biology were written by the Chief Reader, Nancy Morvillo, Professor and Chair, Department 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:** Graph and interpret data; design an experiment; propose benefits and costs to an organism	**Topic:** Effects of caffeine on memory in bees
	Max. Points: 10	**Mean Score:** 3.83

What were responses expected to demonstrate in their response to this question?

This question was based on investigations of the effects of caffeine on memory in bees. Caffeine is often produced by plants in their nectar, and researchers studied the effect of caffeine on the probability of bees remembering and, therefore, revisiting a nectar source. Students were presented with a data table indicating the average probability of bees revisiting caffeinated and caffeine-free (control) nectar sources after 10 minutes and after 24 hours. The data included inferential error bars to compare groups. Students were asked to construct an appropriate graph based on the data provided. Students were then asked to describe the effect of caffeine on the short-term (10 minute) and long-term (24 hour) memory of a nectar source. Next, students were asked to design an experiment using artificial flowers to investigate potential negative effects of increasing caffeine concentrations in nectar on the number of floral visits by bees. As part of their experimental design, students were asked to identify the null hypothesis, an appropriate control treatment, and the predicted results that could be used to reject the null hypothesis. Finally, students were told that nectar with caffeine often has a lower sugar content than nectar without caffeine, and plants expend less energy to produce caffeine than to produce sugar. Based on this information, students were asked to propose one benefit to plants that produce nectar with caffeine and to propose one cost to bees that visit the flowers of the plants that produce nectar with caffeine.

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 students were able to earn points for correctly identifying a bar graph, or modified bar graph, as the appropriate type of graph for the representation of categorical data. Many students were also able to correctly plot the categorical data, appropriately labeling axes, providing units and using appropriate scaling. Some students were able to correctly draw error bars that represented ±2 standard errors of the mean.

In part (b), most students earned a point for correctly identifying that caffeine improves or increases the long-term memory of bees.

In part (c), many students were able to earn a point by identifying the control as nectar containing no caffeine.

In part (d), most students earned the point for proposing a benefit to the plant, usually by identifying that the plant would store energy or have more energy available for other uses.

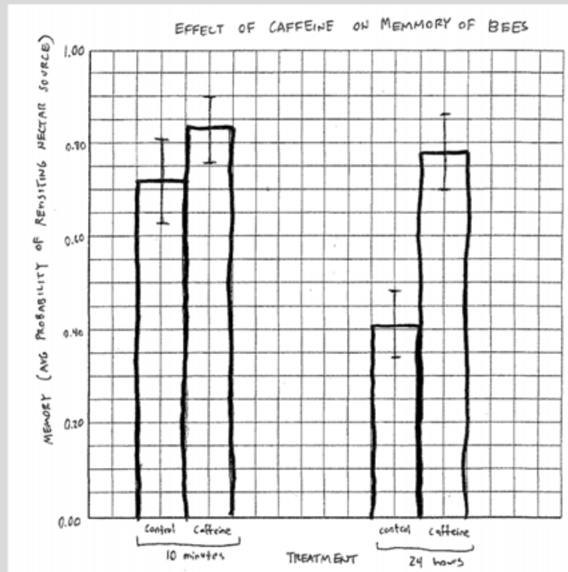
What common student misconceptions or gaps in knowledge were seen in the responses to this question?

In part (a), when students did not earn points for graphing, it was commonly due to omission of units on the Y-axis label, or for representing the categorical data (treatment/time) as continuous data. Many students did not earn the point for correctly drawing error bars. Students who attempted to draw the error bars, but did not earn the point, constructed error bars that represented either ±1 or ±4 standard errors of the mean.

In part (b), many students were not able to use the error bars to conclude that caffeine does not have a short-term impact on memory. Students incorrectly described the effect of caffeine by analyzing the means of the data (e.g. there was a little difference or less difference than the long-term memory), instead of interpreting the significance of the overlap of the error bars between the control and caffeine groups in the short term (10 minutes).

In part (c), many students failed to earn a point for identifying the null hypothesis (H0), instead identifying an alternate hypothesis (Ha or H1). Consequently, students often did not earn a point for predicting the results that could be used to reject the null hypothesis.

In part (d), most students did not earn a point for proposing a cost to bees. Students often predicted the bees would die from eating the toxic nectar.

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Graphing errors	• 
• Correctly identifying short term effects of caffiene	• "On a short-term (10 minutes) scale, caffeine has no significant effect on the bees' memory of nectar source. The standard deviation of the control and the experimental (caffeine) group overlapped."
• Identification of null hypothesis and results to reject	• "A null hypothesis would be that varying caffeine concentrations in nectar will have no effect on floral visits by bees….Predicted results would be that the greatest concentration solution (0.9 M caffeine) will yield a drastically lower number of floral visits by bees that the control solution (no caffeine)."
• Cost to bees	• "As for the bees, a cost of the low sugar content is that the bee will have to visit more flowers to get enough sugar to make honey. This is an extra energy expenditure for the bees."

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?

Teachers should provide students with case studies and practice questions based on journal articles that focus on content they may have not previously studied in order to practice applying scientific thinking to a wide-range of topics. This approach will help to build confidence when students are faced with question prompts that provide a novel context for biological concepts.

Teachers should expose students to a variety of types of graphs and data tables that provide multiple opportunities for students to determine the type of data they are graphing and the appropriate graphical representation. Particular emphasis should be given to correctly describing data (descriptive statistics) by providing students with figures, including different types of error bars. This will help students learn how to correctly draw error bars and how to use and interpret error bars to communicate data and inform conclusions.

Teachers should emphasize all aspects of experimental design, including the significance and format of a null hypothesis (H0). Teachers should stress the importance of identifying measurable results and provide students with opportunities to practice predicting the quantitative data that would lead them to reject, as well as fail to reject, null hypotheses.

Teachers can utilize the Materials and Methods sections of primary source literature to provide students with novel experimental designs and opportunities to evaluate and refine investigations.

Question #2

Task: Interpret data; describe a competitive advantage

Topic: Effect of compounds found in smoke water on germination of seeds in areas that experience frequent forest fires

Max. Points: 10

Mean Score: 4.04

What were responses expected to demonstrate in their response to this question?

This question was based on a laboratory experiment to determine the effect of compounds found in smoke water on germination of seeds in areas that experience frequent forest fires. Two types of compounds, karrikins (KAR) and trimethylbutenolides (TMB), bind to receptor proteins on Lactuca seeds and affect two aspects of germination. Students were presented with a line graph describing the timing of germination and the percent of seeds that germinated in various treatments (a control treatment and treatments with KAR alone, TMB alone, or KAR and TMB together). Students were asked to use the data to provide support for the claims that KAR alone and TMB alone affect both timing and percent of seed germination. Students were provided with data that described the results of a second investigation to determine the effect of a water rinse on seeds after exposure to KAR and TMB. Students were then asked to interpret the data to make a claim about the effect of rinsing on the binding of KAR and TMB to the protein receptors in the seeds. Students were also asked to support their claims by comparing the appropriate control and treatment groups. Finally, students were asked to describe a competitive advantage for plants that use KAR regulation and for plants that use TMB regulation in an area prone to fires.

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 students were able to analyze and interpret the data from the various treatment groups and earn points for supporting the claims about the effects of the KAR and TMB on timing and percent of seed germination.

In part (b), some students earned points for making the claims that KAR binding was not affected by rinsing but that TMB binding was affected.

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

In part (a), students would occasionally confuse timing results with percent seed germination results.

In part (b), many students described the effects of a water rinse on seed germination, instead of focusing on the molecular impact of a water rinse on binding of the compound to a receptor. When providing support for their claims, students frequently did not reference the results from the appropriate treatment groups, referred to only one of the treatment groups, or did not identify both control groups when necessary. Some students used results from the graph rather than the results given in the table to support their claims.

In part (c), few students earned points for describing an advantage of KAR and an advantage of TMB regulation to plants in a fire-prone ecosystem. Students often simply restated the claims made in part (a) or failed to describe the advantage as compared to plants without KAR or TMB regulation. Many students were unable to describe an advantage of TMB regulation, as they did not make the connection between TMB-regulated plants and the importance of water for germination. Students frequently confused germination with reproduction. Students often broadly linked the advantage of regulation to overall success of the ecosystem, or diversity within the ecosystem, instead of describing the advantage of regulation to individual plants. Students also often incorrectly described that plants with TMB regulation would have an advantage because they would germinate “later” when there would be less competition.

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Confusing timing results with percent seed germination results	• "KAR affects the timing of seed germination, as seeds germinated 12 hours sooner than the control group. KAR also affects the percentage of seeds that germinate, as 20% more seed germinate than the control group."
• Lack of focus on the molecular impact of a water rinse on binding of the compound to a receptor	• "Rinsing doesn't affect the binding of KAR to receptors."
• Innappropriate reference to control groups	• "Rinsing does affect binding of TMB to receptors. Treatment groups 3 and 6 are treated with TMB. Treatment group 3 is unrinsed and behaves differently than control group 1. Group 6 is rinsed and behaves the same as control group 4."
• Inncorrect identification of an advantage to KAR and TMB regulation	• "One advantage of KAR regulation in plants is that seeds germinate and begin to grow quickly after a wildfire, giving them first access to nutrients. One advantage of TMB regulation is that seed grow again in the presence of water, so the seeds wait until a vital nutrient is present, in order for them to grow better, is present.

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?

Teachers should expose students to a variety of different types of tables and graphs to provide opportunities for students to interpret and analyze data. Teachers should emphasize the role of positive and negative controls as part of an experimental design, and the importance of comparing appropriate treatment groups with the appropriate controls.

Teachers should find opportunities within the course of the year to connect the role of cell signaling at the molecular and cellular levels to the responses of organisms and the impact on ecosystems.

Question #3	**Task:** Relate changes in the DNA to changes in proteins and phenotypes	**Topic:** The molecular biology behind the inheritance of stem growth in plants
	Max. Points: 4	**Mean Score:** 1.10

What were responses expected to demonstrate in their response to this question?

This question focused on the genetics behind the inheritance of stem growth in plants. Students were presented with a description of the role of the plant growth hormone gibberellin in stem elongation and an explanation of how the presence of GA3H, an enzyme, results in the biochemical synthesis of gibberellin. Students were then provided with a description of a cross between GA3H wild type and GA3H mutant plants and the outcome of the cross, as well as a description of a specific amino acid substitution that occurred in the GA3H mutant enzyme. Students were also supplied with a genetic code chart. Students were asked to describe the effect of the mutation on the enzyme and to provide reasoning to support the observed results from the cross. Then the students were asked to predict the change in the codon sequence that resulted in the change in the amino acid sequence of the enzyme. Students were also asked to describe how both individuals who are heterozygous and individuals who are homozygous for the wild type GA3H allele could have the same phenotype.

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), many students were able to describe that the mutation changed the structure or function of the protein.

In part (b), most students were able to identify the change from G to A.

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

- In part (a), most students were not able to provide reasoning that connected a mutation (a molecular change) to the organismal level (a decrease or nonexistent gibberellin production). Some common misconceptions were that the change to a polar amino acid affected the attraction of the GA3H to water, or prevented GA3H from crossing the cell membrane. Some students also described that the mutation caused denaturation of the protein, and that a point mutation caused a frameshift mutation.

- In part (b), few students deemed it necessary to identify that the change would have had to occur in the first position of the codon.

- In part (c), few students were able to describe that enough gibberellin was produced from the wild type allele to allow for the heterozygous plants to have the same phenotype as the homozygous wild type plants. A common response was that the wild type was dominant, which did not address the relative activity of GA3H or the quantity of the enzyme produced.

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Incorrect reasoning connecting a mutation to the organismal level	• "In homozygous recessive plants, neither copy of the allele encodes functional GA3H; therefore gibberellin is not synthesized and the plant is short."
• No identification of the location of the mutation in the codon	• "Alanine was changed to threonine by changing the first nucleotide in the codon from G to A."

• No description that enough gibberellin was produced from the wild type allele to allow for the heterozygous plants to have the same phenotype as the homozygous wild type plants.	• "If an individual is heterozygous for wild-type GA3H, they still have one functional copy of GA3H that encodes the functional enzyme. This may be sufficient to synthesize enough gibberellin to stimulate the same amount of stem elongation, therefore showing the same phenotype."

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?

Teachers should present multiple opportunities for students to practice using the genetic code chart and consider how different types of mutations in the DNA (nucleotide substitutions, deletions and additions) impact the sequence of the resulting proteins. As many students described all mutations as having a negative effect, teachers should include examples of mutations that do not significantly alter the phenotype of organisms.

Teachers should also emphasize how the flow of information at the molecular level (including how changes in DNA sequences lead to changes in mRNA sequences that can lead to changes in protein sequence) and how these changes affect the phenotype of an organism (including how changes in protein sequences can affect the activity of a protein which in turn affects phenotype of the organism). Teachers should make a concerted effort to connect the study of genetics with evolution to stress how the natural selection of phenotypes can change the genetic makeup of a population.

Question #4

Task: Construct a food web; predict the impact of a change on an ecosystem

Topic: A quantitative food web involving an aquatic ecosystem

Max. Points: 4

Mean Score: 2.05

What were responses expected to demonstrate in their response to this question?

This question focused on a quantitative food web involving an aquatic ecosystem. Students were presented with a data table quantifying the interactions between species by showing the percentage each species relied on others in the ecosystem as a food source. Students were asked to use this information to construct a food web by writing in the names of the organisms in the appropriate trophic levels on the template provided. Students were also asked to draw arrows to indicate the direction of energy flow between the organisms in the ecosystems. Then, students were told that an area within ecosystem was sprayed with a fungus that eliminated one of the species. Students were then asked to predict which population of organisms would experience the greatest short-term impact due to the elimination of this species and 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?

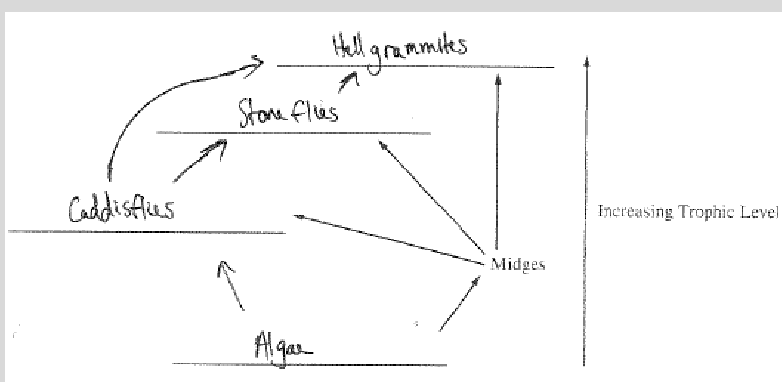
In part (a), most students were able to analyze the data in the table in order to correctly place the four species in the appropriate trophic levels of the food web. Most students were also able to draw the appropriate arrows to indicate energy flow between the species in the food web.

In part (b), most students were able to predict that the population of stoneflies would experience the greatest short-term impact.

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

In part (a), when students did not earn points it was usually because they were unable to infer the correct relationships between the organisms in the food web or were unfamiliar with how those relationships translated to placement on the correct trophic levels. Some students also failed to include arrows to indicate energy flow.

In part (b), in some cases, students interpreted "greatest" to mean best or ideal, which cause them to not earn the point. Few students were able to justify this impact to the stoneflies because they did not address the comparison with both the caddisfly and hellgrammite populations, as indicated in the stem of the question.

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Incorrect relationships between the organisms in the food web	

• Misinterpretion of "greatest" to mean best or ideal	• "The spraying of midges will have the greatest short-term impact on the stoneflies because 90% of the stoneflies diet is midges, and if midges are being killed then stoneflies are losing food."
• No comparison with both the caddisfly and hellgrammite populations	• "The spraying of the fungus will have the greatest short-term impact on the stoneflies because, in comparison to the caddisflies or hellgrammites, midges comprise of a larger percentage of the stoneflies diet."

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?

The study of ecological systems is a logical unit to make connections between organisms and their environment, and it needs to be emphasized in the classroom. Students need practice with both analyzing and constructing food webs, describing energy transfer and making predictions about how environmental changes can impact ecosystems. These ecological concepts should be integrated with other topics taught across the curriculum throughout the year. Ecology is also a unit where quantitative reasoning can be introduced and developed.

Teachers should emphasize that, in a comparative analysis, students must address all component parts indicated in the question to complete their argument.

Question #5

Task: Analyze data; identify cause and effect relationships

Topic: Changes in oxygen levels in a pond community

Max. Points: 4

Mean Score: 1.81

What were responses expected to demonstrate in their response to this question?

This question focused on analyzing data to identify the causes of change in oxygen levels in a pond community. Students were presented with a graph showing the relative concentrations of cyanobacteria, decomposers, and oxygen in a pond ecosystem over time. Students were asked to identify the metabolic pathway and the organism that was primarily responsible for the change in oxygen levels between time points.

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?

Most students were able to analyze the data to identify the organisms responsible for an increase in oxygen level (cyanobacteria) between times I and II and for a decrease in oxygen level (decomposers) between times III and IV.

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

A common misconception of students was that plants are the only organisms capable of photosynthesis.

Not as many students were able to identify the metabolic pathway that caused oxygen levels to increase (photosynthesis) between times I and II and oxygen levels to decrease (cellular respiration) between times III and IV. Many students identified cell division and decomposition as metabolic pathways. Students also identified general types of pathways (anabolic or catabolic) rather than the specific pathway.

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Only plants are capable of photosynthesis	• "The metabolic pathway of cyanobacteria that is responsible for the change between I and II is photosynthesis."
• Inncorect identification of metabolic pathways	• "The metabolic pathway used by decomposers and responsible for the change between III and IV is cellular respiration."

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?

Teachers should be sure to clarify what is meant by a metabolic pathway, and provide students with opportunities to predict the impact on the pathway if a change occurred (e.g. increase or decrease of a reactant) and explain how this change could affect the organism and the ecosystem.

Teachers should have students practice analyzing different types of graphs, especially graphs where there are multiple types of data presented along the same axes. Once students have analyzed the data, teachers should provide opportunities for students to not only describe what they see in the graph, but also to construct an explanation from the data and to predict (with justification) how a change in one of the variables will affect another variable.

Question #6	**Task:** Identify properties of a macromolecule; predict the result of a mutation	**Topic:** Analysis of DNA using a comet assay
	Max. Points: 3	**Mean Score:** 0.75

What were responses expected to demonstrate in their response to this question?

This question focused on the analysis of DNA using a comet assay. Students were presented with a diagram demonstrating the results of a comet assay in a cell with DNA damage and a written description of the assay. Students were asked to identify one property of DNA and to provide reasoning to support how this property contributed to the movement of DNA in the comet assay. Students were also asked to predict the results of a comet assay in an experiment in which cells were treated with a mutagen that causes only nucleotide substitutions.

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), many students were able to identify that DNA is negatively charged. More students identified that DNA is charged as opposed to those who identified that DNA can be different sizes.

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

In part (a), students often identified that DNA has either a positive charge, is uncharged or polar or has both negative and positive ends. Some students thought that the charge of DNA depended on whether it is damaged or not and that negatively charged molecules were attracted to the negatively charged end of the gel.

In part (b), many students were unsuccessful at predicting the results of the comet assay. Some students predicted that the results of the assay would "be the same" or that they would "be different" but failed to provide a comparison. A misconception commonly seen was that the lack of a tail would mean the comet assay is inconclusive.

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Incorrect identification of charges in DNA	• "DNA is negatively charged, therefore during electrophoresis it moves toward the positive end of the gel."
• Inncorrect prediction	• "There will only be a head and no tail, since the DNA isn't broken in nucleotide substitution."

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?

Teachers should present opportunities where students consider the role that unique structural features of the subunits of macromolecules play in predicting the overall properties, including the electrostatic charge, of those macromolecules. Furthermore, teachers should provide students with opportunities to connect this essential knowledge to unique technological applications.

Teachers should provide students with ample opportunities across the curriculum to practice analyzing, interpreting and making predictions from data, including diagrams and models. Teachers should also recognize that interpreting diagrams and models and constructing diagrams and models are related, but unique skills, and both require attention throughout the course.

Question #7 | **Task:** Identify and describe biochemical pathways; predict how population growth will change | **Topic:** Growth of two bacterial species found in biofilms in the mouth

Max. Points: 3 | **Mean Score:** 0.76

What were responses expected to demonstrate in their response to this question?

This question focused on the growth of two bacterial species (*S. mutans* and *S. sanguinis*) found in biofilms (plaque) on teeth. Students were provided a description of the optimal growth environment for each bacterial species. Students were asked to identify the biochemical pathway used by *S. mutans* for metabolizing sugar and to describe how the pathway contributes to the low pH of the environment. Students were then asked to predict how the population size of each species would change if the pH in the mouth were raised due to the alkaline composition of toothpastes.

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 students earned a point for identifying a correct biochemical pathway for sugar metabolism Some students earned a point for describing an acid as the product of the pathway.

In part (b), most students were able to predict the environmental change would decrease *S. mutans* population size and increase *S. sanguinis* population size.

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

In part (a), students wrote that anabolic pathways or photosynthesis were used. Incorrect products of the pathways were commonly identified as H+, NADH, NAD+, and ethanol. Students sometimes described the proton gradient created during electron transport as being responsible for the acidic pH. Some students were confused about the relationship between high/low pH and more/less acidic (e.g., describing that the presence of an alkaline toothpaste increased the acidity in the mouth).

In part (b), students sometimes used vague language such as "thrive" rather than using more definitive terms such as "increase."

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Incorrect identification of pathway and description of product	• S. mutans metabolizes sugar through fermentation. Fermentation requires no oxygen and produces lactic acid, which can break down the enamel of the tooth."
• Confusion over relationship between pH and acidity	• "S. mutans undergo lactic acid fermentation, causing low pH (acidic) conditions which can damage enamel."
• Vague language	• "…*S. mutans* will decrease in population as the acidity is lowered, as they cannot receive as many nutrients.

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?

Teachers should place their efforts on emphasizing the reactants and products of key metabolic pathways used by organisms, instead of having students memorize inconsequential intermediate reactions. Teachers should compare and contrast different energy-yielding pathways used by organisms so students recognize that organisms extract energy from their environment in different ways. Teachers should find creative ways to help students conceptualize the similarities and differences among these complex pathways.

Teachers should reinforce basic principles, such as pH, throughout the curriculum.

Teachers should make more connections to ecology in their curriculum, and help students recognize how changes at a molecular level can affect cells and, in turn, organisms and how those changes might manifest at the population and ecosystem levels.

Teachers should emphasize the use of specific and descriptive language in responses.

Question #8

Task: Describe characteristics of cells and molecules; relate these characteristics to interactions

Topic: Selective permeability of cellular membranes

Max. Points: 3

Mean Score: 0.60

What were responses expected to demonstrate in their response to this question?

This question focused on the selective permeability of cellular membranes. Students were asked to describe one characteristic of the plasma membrane that allows estrogens to passively cross the membrane. Students were then presented with an experiment where antibodies that bind to purified estrogen receptors extracted from cells were ineffective in the treatment of estrogen-dependent cancers. Students were asked to explain the ineffectiveness of the antibodies for treating estrogen-dependent cancers.

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), many students correctly described the hydrophobic nature of the cell membrane as the characteristic which allowed estrogen to passively cross the membrane. Fewer students described the space between phospholipids as the characteristic.

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

In part (b), few students were able to explain the ineffectiveness of antibodies at treating estrogen-dependent cancers. Instead, many students incorrectly explained that antibodies were supposed to bind with estrogen molecules instead of the intracellular estrogen receptors. Students were unable to make the connection that proteins, including antibodies, are too large to cross cell membranes, preventing them from binding to intracellular estrogen receptors. Some students incorrectly explained that antibodies attacked foreign molecules and would not be able to bind to natural molecules, in this case, estrogens. Students also provided reasoning that cancer cells were too strong, grew too quickly, or mutated too quickly for the antibodies to be effective. Occasionally, students reasoned that antibodies were the same as antibiotics.

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Incorrect explanation of molecules crossing the membrane	• "The antibody is ineffective as they are too big or incompatible to diffuse across the membrane to attack cancer."
• Incorrect description of antigen/receptor binding	• "The size and polarity of the antibody proteins prevent them from effectively crossing the bilipid membranes and binding to the estrogen receptor in the cytoplasm."

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?

Teachers should provide students with opportunities to explain how structure determines function at the molecular, cellular, and organismal levels.

The immune system provides a framework for integration of big ideas, through the discussion of complex concepts including cell structure and function, signal transduction, molecular specificity, and biochemistry. Teachers should revisit these concepts throughout the year to scaffold both content and skill development.