Student Performance Q&A:

2009 AP® Biology Free-Response Questions

The following comments on the 2009 free-response questions for AP® Biology were written by the Chief Reader, John Lepri of the University of North Carolina at Greensboro. 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 performance 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

What was the intent of this question?

The understanding of experimental design and the analysis of numerical data underlie the development of scientific knowledge, including our understanding of the physiology and behavior of animals. In the setting for this question, behavioral observations of a particular species of fish showed that the fish were most likely to be observed in the water at 12–17°C, with fewer fish found at temperatures higher or lower than this range. Students were asked to graph the relationship between water temperature and fish distribution and to summarize the data. They were then asked to identify and describe two specific variables that were not controlled in the original experiment and to discuss two ways that temperature could affect the physiology of the fish in the experiment.

How well did students perform on this question?

Graphing data is a fundamental skill in science, and the answers to this question supported the proposition that this skill is well developed in AP Biology exam-takers, since most of the answers included an appropriate graph that earned 2 to 3 points. The ability to identify and discuss two uncontrolled variables (e.g., sex, circadian rhythms) not included in the experimental design was also evident in many answers, resulting in a mean score of 5.49 out of a possible 10 points. The highest-scoring answers demonstrated a good understanding of the effects of temperature on the physiology of ectotherms, with answers that included an optimization of heart rate, circulation, or respiration in response to decreased water temperature, relative to the temperature of the holding tank. An additional component in the highest-scoring responses was a description of the decrease in the concentration of dissolved oxygen in warmer waters.

What were common student errors or omissions?

In part (a) responses that did not earn full credit for the graph typically included an inappropriate line graph or placed temperature on the *y*-axis.

In part (b) the question asked for identification of uncontrolled variables within the experiment, but many responses implicated the species of fish and the temperature of the water as uncontrolled variables. Both of these variables, however, actually were controlled by the experimenters.

Also in part (b), some essays described strategies to naturalize the experimental tank, making it more like the fish's natural habitat. In such cases the testing apparatus was not distinguished from aquariums that one might have at home or in the classroom.

Some essays showed signs of confusion about the temporal aspects of the experiments, with predictions that the fish would evolve or adapt to the conditions in 30 minutes.

In part (c) the implications of an ectothermic lifestyle were occasionally a point of confusion, because some essays suggested that colder temperatures necessitate increased cell respiration in order to generate enough heat to keep the fish "warm." Descriptions of the effect of increased temperature on enzyme activity occasionally erred by suggesting that the fish would die in Section E (27° C) because the heat would cause their enzymes to denature.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

Classroom experimentation and descriptions of experimental scenarios provide rich opportunities for teachers and students to identify and discuss flaws in experimental designs and to try to improve them. By identifying the elements of experimental design—including the dependent and independent variables (in this case, fish location and water temperature, respectively) and the controlled variables (species of fish, water quality, light)—students will come to understand what is being measured, how, and at what intervals. Teachers should also emphasize clear understanding of the purpose of a control in an experiment.

Graphing continuous data is a different task from graphing discontinuous/discrete data. Teachers should have students use a combination of graphing both by hand and by using technology (e.g., Microsoft *Excel*) so that they will better understand how to illustrate their data (see the second appendix, "Constructing Line Graphs," in the *AP Biology Lab Manual for Students*).

Continued practice with essay writing based on data presentation will help students produce more in-depth responses.

Question 2

What was the intent of this question?

Energy transfer is a fundamental requirement of living organisms—and an AP Biology theme. This question tested student knowledge of the structure, production, and use of ATP in cells. Students were asked to describe the structure of ATP (or GTP) and explain ATP synthesis, including chemiosmosis. They were then asked to describe two cell processes that require ATP, including specific information on how ATP hydrolysis altered reactions at the molecular level. Students were then asked to identify the trophic levels through which ATP energy flows in a four-trophic-level system and to identify actual organisms that would be found at each level in a marine system. The question concluded by asking students to explain why there is less energy available at the top than at the bottom of the food chain.

How well did students perform on this question?

While understanding energy transfer is a clear objective in AP Biology, writing about ATP and system-level principles was more challenging than expected for students. The mean score for this question was 2.92 out of a possible 10 points. Many responses earned at least 1 point in part (a) for the structure of ATP, at least 1 point in part (b) for describing chemiosmosis, 1 to 2 points in part (c) for accurately describing one or both of the ATP-utilizing processes, and 1 to 2 points in part (d) for labeling the trophic levels and/or identifying organisms in each trophic level.

What were common student errors or omissions?

In part (a) one of the most common errors was describing the structure of ATP as an adenine (rather than an adenosine) and three phosphates. Many essays stated that "ATP is an adenosine triphosphate," without including specific details about the ribose (a sugar) in ATP; or they just called it "sugar" rather than ribose. A common misconception was reflected in the statement that the phosphate bonds of ATP are high-energy bonds and thus hard to dissociate, rather than a correct description of them as relatively weak, unstable bonds.

In discussing chemiosmosis in part (b), responses indicated significant confusion about which molecules or ions move through the ATP synthase channel, with many inaccurate descriptions that had electrons, ADP, or phosphates moving through the ATP synthase channels. Similar confusion as to what exactly passes along the electron transport chain was present in many answers. Another area of confusion was the question of where hydrogen ions are pumped, with some responses indicating they are pumped into the matrix, out of the mitochondria, or completely out of the cell.

In part (c), when describing two specific cell processes that utilize ATP, the most common mistake was to merely identify a process that requires energy from ATP hydrolysis. Many essays contained descriptions of the light-dependent reactions of photosynthesis or the Krebs cycle, although neither of these requires ATP.

The most difficult points to earn were the points for explaining *how* ATP is used in the processes that were described in part (c). Many essays simply stated that ATP "provides the energy" for whatever process was described. Students did not appear to understand that ATP does its "work" by inducing conformational changes via hydrolysis and by bonding to other molecules.

In part (d) the levels of the energy pyramid were often mislabeled, including the lack of a producer at the bottom of the pyramid. Some responses actually reversed the trophic levels, putting the producer at the top. When choosing examples of the trophic levels in a *marine* ecosystem, some essays wrongly focused on a terrestrial ecosystem example.

A common inaccuracy was in accounting for the dissipation of energy along the pyramid. Most essays simply said it was "lost," although many unsuccessfully cited the 10 percent rule without explaining what happened to the 90 percent of the energy that does not move directly into the succeeding trophic level.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

Teachers can help students improve their performance by:

- providing details at the molecular level of what is actually taking place when ATP hydrolysis drives specific molecular processes;
- exploring further the basic ecological concepts of ecosystems, an exercise that provides an opportunity to integrate details of energy transfer;
- making clear the distinction between memorizing molecular details and buzzwords like *electron transport chain* and demonstrating an integrated understanding of what molecular events actually take place, an approach that provides students with an opportunity to step back to see the overall process; and
- reminding students of the Internet-based animations that are readily available to provide visual perceptions of the increasingly complex concepts of molecular biology.

Question 3

What was the intent of this question?

A broad understanding of evolution by natural selection is a core principle for learning about phylogenetic relationships and a foundational theme in AP Biology. The first part of this question asked students to identify two ways that genetic change occurs and to explain how each mechanism affects genetic variability. The second part of the question provided details of amino acid differences in the protein known as cytochrome *c*; students were asked to develop a phylogenetic tree among five organisms—horse, donkey, chicken, penguin, and snake—and to identify the species most closely related to the chicken, as shown by the data. The final part of the question required students to discuss two additional (nonprotein) types of evidence that could be used in constructing a phylogeny or evolutionary history of organisms.

How well did students perform on this question?

Evolutionary mechanisms and phylogenetic relationships are broadly taught in AP Biology, and they are taught with success. The mean score for this question was 5.33 out of a possible 10 points. Many essays included mutations and crossing over as mechanisms of genetic change. Many essays correctly identified the evolutionary relationship between penguins and chickens and properly supported this conclusion by noting the very few amino acid differences in the cytochrome *c* of the two species. For nonprotein-based evolutionary analysis, there were frequent descriptions of homologous structures, including the wing–forelimb example, and evidence from the fossil record. However, essays often failed to appropriately link organisms via a common ancestor and frequently did not portray a clear understanding of the strengths of different types of evidence used to develop our understanding of phylogenetic organization.

What were common student errors or omissions?

- While essays often identified mutation as a mechanism of evolutionary change, it should have been more explicitly linked to changes in nucleotide and amino acid sequences.
- Although crossing over, independent assortment, and other details of meiosis increase the genetic diversity of an organism's gametes, many students thought the organism undergoing gametogenesis was itself changed.
- The colloquial phrase "survival of the fittest," used by most students to describe natural selection, would have been better stated as "differential reproductive success of offspring."
- Some students did not realize that Hardy–Weinberg analysis, while useful in allelic equilibrium (e.g., no change in genetic variation), does not specify or describe mechanisms of genetic change.
- Many students, while describing phylogenetic relationships, failed to include the common ancestor necessary to portray the included organisms in their proper evolutionary relationships.
- Some students continue to exhibit confusion about structures that are homologous (common ancestor) versus those that are analogous (convergent evolution).

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

Teachers should remind their students that:

- evolution produces *changes* over time in allelic frequencies, and this is most apparent at the population level of analysis;
- natural selection is more clearly understood within the context of differential reproductive success than by merely invoking differential survival; and
- comparing phylogenetic versus cladistic analyses in exploring evolutionary diversification and adaptive radiation is a great means of comparing insights via visual data and molecular evidence (e.g., look no further than the recent discovery that peregrine falcons are more closely related to parrots than to hawks).

Question 4

What was the intent of this question?

The question addressed the central dogma of biology, the flow of information from DNA to RNA to protein. In the first part of the question, students had to explain the *role* of five specified components—RNA polymerase, spliceosomes, codons, ribosomes, and tRNA—involved in transcription and translation in eukaryotic cells. The second part of the question asked students to describe two specific eukaryotic mechanisms that regulate protein synthesis and protein activity. In the third part of the question, students had to explain how the central dogma does not apply to some viruses, selecting a type of virus or a specific virus and explaining how it deviates from the central dogma.

How well did students perform on this question?

The broad scope of this question provided diverse pathways for describing the relationship between coding and proteins. Its mean score was 3.29 out of a possible 10 points. A few of the essays covered the material quite well, but about half of the students attempting to answer the question earned scores of 3 or below. Although the question requested the roles of the five specified components, some essays concentrated too much on structure rather than function. Not uncommon in the second part of the question was discussion of feedback mechanisms in the regulation of protein synthesis or protein activity. The description of methylation, acetylation, and DNA packaging was typical of high-scoring essays. Among viral exceptions to the central dogma, the retrovirus HIV was most often selected for exposition.

What were common student errors or omissions?

Students who performed poorly on this question experienced one or more of the following problems in their essays:

- There was confusion among these pairs of terms: *DNA* versus *RNA*, *introns* versus *exons*, and *transcribe* versus *translate*.
- Use of the term *replication* for making mRNA from DNA was a common error.
- Ribosomes were often correctly described, but spliceosomes were rarely described well.
- RNA polymerase was incorrectly described as using an RNA primer, converting DNA directly into RNA, or being the key enzyme in the polymerase chain reaction used to amplify DNA.
- Spliceosomes were incorrectly proposed to be active in cutting up codons and removing exons from mRNA.
- Codons were mistakenly described as coding for specific proteins, directing spliceosome cutting, or being composed of three amino acids.
- Ribosomes were mistakenly ascribed to protein packaging, codon, or tRNA synthesis.
- Incorrect definitions for the *t* in tRNA included *transduces*, *translates*, *transforms*, or *transports* mRNA from the nucleus to the ribosome.

- Responses occasionally discussed the regulatory functions of proteins, rather than the actual regulation of proteins.
- Surprisingly few mechanisms of regulating protein synthesis were discussed.
- The selection of a DNA virus was a frequent error in describing a virus that departs from the central dogma, and there were a few inappropriate descriptions of the lytic and lysogenic cycles in viral replication as a deviation from the central dogma.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

Teachers can help students improve their performance by:

- teaching the distinctions and similarities between prokaryotic and eukaryotic cells (better practice in noting distinctions of viruses, bacteria, prions, and genetic disorders would be equally useful);
- providing plenty of practice with the basics of the central dogma, especially protein synthesis, and including the addition of specific details;
- comparing codons and anticodons, and exons and introns;
- spending time on the distinctions of DNA and RNA, including the distinct structure and functions of rRNA, tRNA, siRNA, mRNA, and so on; and
- exploring the mechanisms (including feedback) of regulation, a key attribute of homeostatic maintenance.