

Question 4: Conceptual Analysis**4 points**

Existing isolated brook trout populations in Newfoundland, Canada, were once part of a larger population that was fragmented at the end of the most recent glaciation period about 10,000 to 12,000 years ago. Researchers investigated 14 naturally separated stream populations of brook trout. They found that the populations are all genetically distinct and show differences in morphology.

- | | | |
|------------|--|----------------|
| (a) | Describe the prezygotic barrier that results in these genetically distinct populations. | 1 point |
| | <ul style="list-style-type: none"> • Geographic isolation prevents gene flow between the populations. | |
| (b) | Brook trout with longer fins are able to swim faster than brook trout with shorter fins. In one of the Newfoundland streams, the main prey of the brook trout evolved to move faster. For brook trout living in this stream, explain why there is a difference in fitness between longer-finned individuals and shorter-finned individuals. | 1 point |
| | <ul style="list-style-type: none"> • Individuals with longer fins are more likely to capture prey and reproduce. | |
| (c) | If two morphologically and behaviorally distinct populations of brook trout remain isolated for many generations, predict the likely impact on both populations. | 1 point |
| | Accept one of the following: <ul style="list-style-type: none"> • The two populations will become separate species. • The two populations will continue diverging (behaviorally/morphologically/genetically). | |
| (d) | Researchers claim that there are more genetic differences between any two current brook trout populations than there are between any single current population and the ancestral brook trout population from which all the trout are descended. Provide reasoning to justify their claim. | 1 point |
| | Accept one of the following: <ul style="list-style-type: none"> • Each single population has <u>accumulated mutations/experienced genetic drift</u> (distinguishing it from the ancestral population). The mutations each population accumulated are likely to differ (as a result of different selective pressures). • Allele production (as a result of random mutation) and <u>genetic drift/selection by local environmental conditions</u> has resulted in a collection of alleles unique to each population. | |

Total for question 4 4 points

AP[®] Biology

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Question 1

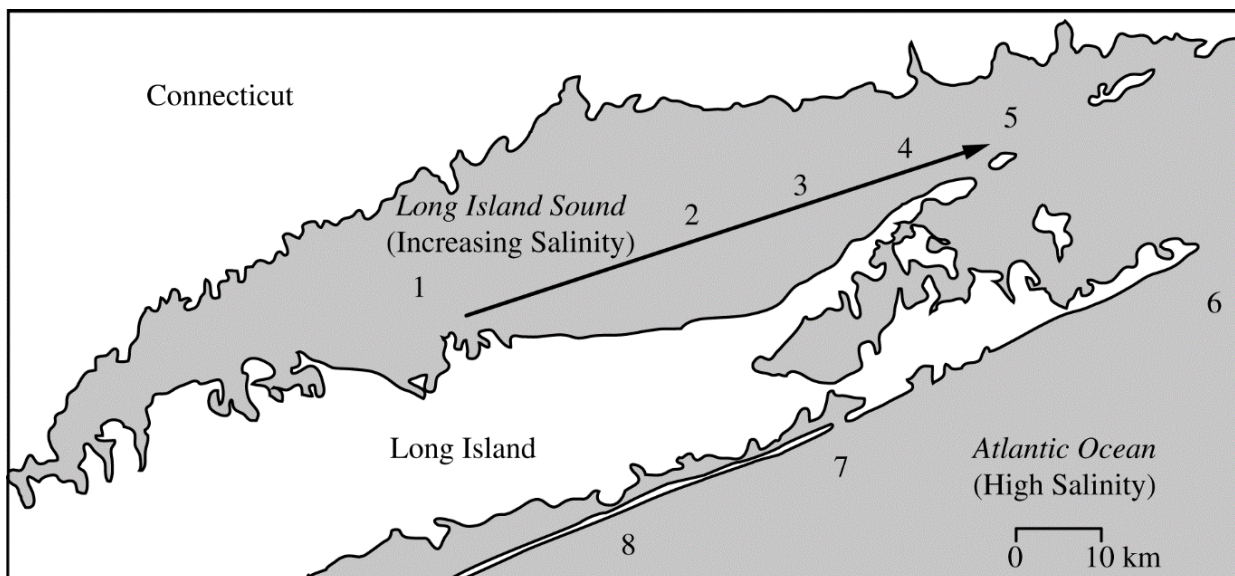


Figure 1. Sampling sites of marine mussels at various locations (1-8) in Long Island Sound and the Atlantic Ocean

TABLE 1. PERCENT OF INDIVIDUALS POSSESSING *lap*⁹⁴ ALLELE

	Long Island Sound					Atlantic Ocean		
Site	1	2	3	4	5	6	7	8
<i>lap</i> ⁹⁴ frequency (%)	13	16	25	37	55	59	59	59
Salinity	Low → High					High		

Leucine aminopeptidases (LAPs) are found in all living organisms and have been associated with the response of the marine mussel, *Mytilus edulis*, to changes in salinity. LAPs are enzymes that remove N-terminal amino acids from proteins and release the free amino acids into the cytosol. To investigate the evolution of LAPs in wild populations of *M. edulis*, researchers sampled adult mussels from several different locations along a part of the northeast coast of the United States, as shown in Figure 1. The researchers then determined the percent of individuals possessing a particular *lap* allele, *lap*⁹⁴, in mussels from each sample site (table 1).

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Question 1 (continued)

- (a) On the axes provided, **construct** an appropriately labeled bar graph to illustrate the observed frequencies of the *lap*⁹⁴ allele in the study populations. **(3 points)**

Construct graph (3 points)

- Correctly plotted bar graph that accurately represents the trend
- Correct axis labeling
- Correct scale and units

- (b) Based on the data, **describe** the most likely effect of salinity on the frequency of the *lap*⁹⁴ allele in the marine mussel populations in Long Island Sound. **Predict** the likely *lap*⁹⁴ allele frequency at a sampling site between site 1 and site 2 in Long Island Sound. **(2 points)**

Description (1 point)	Prediction (1 point)
• As salinity increases <i>lap</i>⁹⁴ frequency increases • As salinity decreases <i>lap</i>⁹⁴ frequency decreases	Between 13 and 16 percent (or a selected value between 13 and 16 percent)

- (c) **Describe** the most likely effect of LAP⁹⁴ activity on the osmolarity of the cytosol. **Describe** the function of LAP⁹⁴ in maintaining water balance in the mussels living in the Atlantic Ocean. **(2 points)**

Describe effect of LAP ⁹⁴ activity (1 point)	Describe function of LAP ⁹⁴ in maintaining water balance (1 point)
• LAP⁹⁴ increases osmolarity/solute concentration of the cytosol • LAP⁹⁴ decreases water potential of the cytosol	Prevents water loss to the environment

- (d) Marine mussel larvae are evenly dispersed throughout the study area by water movement. As larvae mature, they attach to the rocks in the water. **Explain** the differences in *lap*⁹⁴ allele frequency among adult mussel populations at the sample sites despite the dispersal of larvae throughout the entire study area. **Predict** the likely effect on distribution of mussels in Long Island Sound if the *lap*⁹⁴ allele was found in all of the mussels in the population. **Justify** your prediction. **(3 points)**

Explanation (1 point)	Prediction (1 point)	Justification (1 point)
• Mussels with <i>lap</i>⁹⁴ allele are more likely to survive in high salinity/less likely to survive in low salinity. • Mussels without <i>lap</i>⁹⁴ allele are less likely to survive in high salinity/more likely to survive in low salinity.	• Mussel population will increase in high salinity. • Mussel population will decline in low salinity.	• Mussels in high salinity with <i>lap</i>⁹⁴ allele will osmoregulate. • Mussels in low salinity with <i>lap</i>⁹⁴ allele will not osmoregulate.

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Question 2

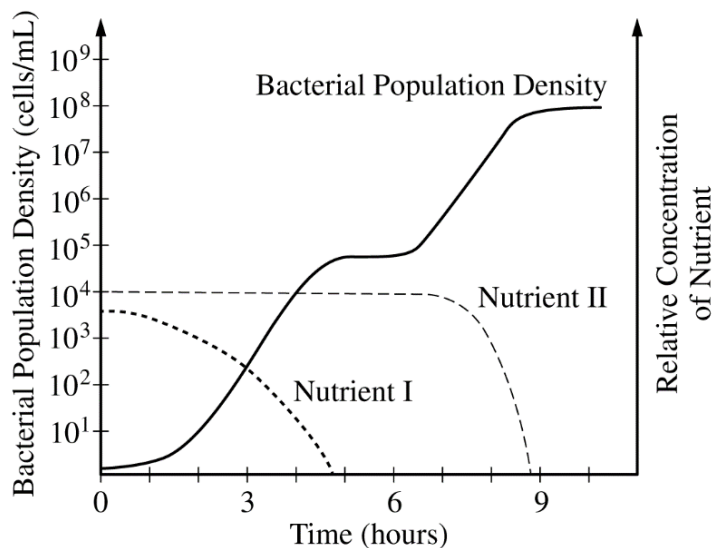


Figure 1. Bacterial population growth in the presence of two nutrients (nutrient I and nutrient II)

Bacteria can be cultured in media with carefully controlled nutrient composition. The graph above shows the growth of a bacterial population in a medium with limiting amounts of two nutrients, I and II.

- (a) **Estimate** the maximum population density in $\frac{\text{cells}}{\text{mL}}$ for the culture. Using the data, **describe** what prevents further growth of the bacterial population in the culture. **(2 points)**

Estimate (1 point)

- 10^8

Description (1 point)

- When both nutrients are depleted

- (b) Using the data, **calculate** the growth rate in $\frac{\text{cells}}{\text{mL} \times \text{hour}}$ of the bacterial population between hours 2 and 4. **(1 point)**.

Calculation (1 point)

- 4,995

2016 SCORING GUIDELINES**Question 2 (continued)**

- (c) **Identify** the preferred nutrient source of the bacteria in the culture over the course of the experiment. Use the graph to **justify** your response. **Propose** ONE advantage of the nutrient preference for an individual bacterium. **(3 points)**

Identification (1 point)

- Nutrient I is the preferred nutrient.

Justification (1 point)

- When both nutrients are present in the growth medium, only nutrient I is used.
- Nutrient II is only used after nutrient I is depleted.

Proposed advantage (1 point)

- Do not spend energy making enzymes/proteins that the cell doesn't need.
- Do not have to express all metabolic genes at once.
- The preferred nutrient provides more energy.

- (d) **Describe** how nutrient I most likely regulates the genes for metabolism of nutrient I and the genes for metabolism of nutrient II. **Provide** TWO reasons that the population does not grow between hours 5 and 6. **(4 points)**

Description (2 points)

- Nutrient I promotes expression of genes required for metabolism of nutrient I.
- Nutrient I represses expression of genes required for metabolism of nutrient II.

Reasoning (2 points)

- Nutrient I is depleted from the growth medium OR neither nutrient is being consumed.
- Takes time to produce proteins/enzymes required to metabolize nutrient II.

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Question 3

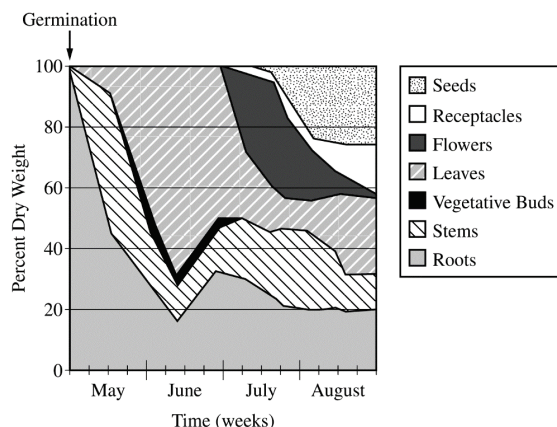


Figure 1. Percent dry weight of different plant structures during the growing season for an annual plant

The graph above illustrates the percent dry weight of different parts of a particular annual plant (plants that live less than one year) from early May to late August. The percent dry weight can be used to estimate the amount of energy a plant uses to produce its leaves, vegetative buds, stems, roots, and reproductive parts (seeds, receptacles, and flowers).

- (a) **Identify** the direct source of the energy used for plant growth during the first week of May, and **identify** the part of the plant that grew the most during the same period. **(2 points)**

Identify direct source of energy (1 point)

- Seed
- Stored organic nutrients/carbohydrates

Identify plant part (1 point)

- Roots

- (b) Based on the data on the graph, **estimate** the percent of the total energy that the plant has allocated to the growth of leaves on the first day of July. **(1 point)**

Identification (1 point)

- Any value between 45-55 percent

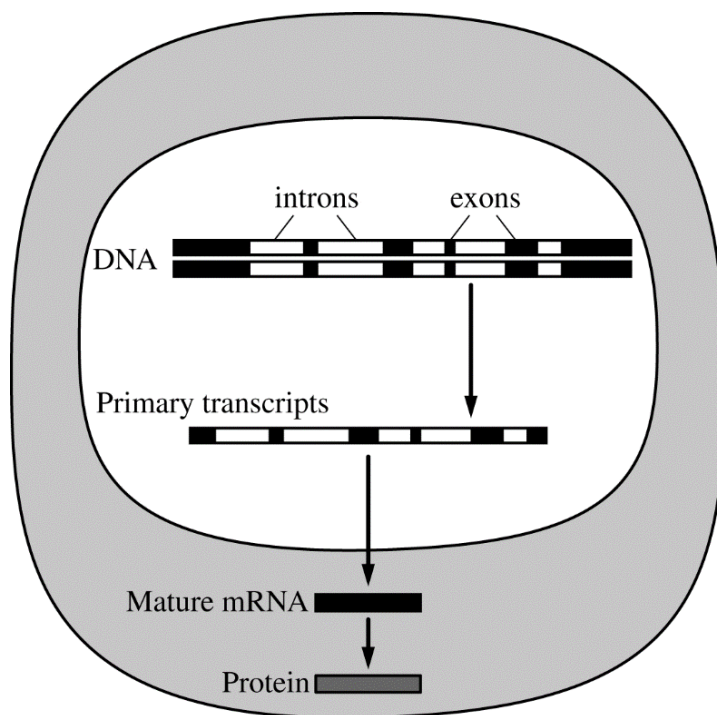
- (c) Compared with perennials (plants that live more than two years), annual plants often allocate a much greater percentage of their total energy to growth of their reproductive parts in any given year. **Propose** ONE evolutionary advantage of the energy allocation strategy in annual plants compared with that in perennial plants. **(1 point)**

Proposed advantage (1 point)

- Increased chance of reproduction before the plants die.
- If the plants do not use the strategy, they decrease the likelihood they will ever reproduce.

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Question 4



The figure represents the process of expression of gene *X* in a eukaryotic cell.

- (a) The primary transcript in the figure is 15 kilobases (kb) long, but the mature mRNA is 7 kb in length.

Describe the modification that most likely resulted in the 8 kb difference in length of the mature mRNA molecule. **Identify** in your response the location in the cell where the change occurs.

(2 points)

Describe process (1 point)

- Removal of introns
- RNA processing

Identification (1 point)

- Nucleus

- (b) **Predict** the length of the mature gene *X* mRNA if the full-length gene is introduced and expressed in prokaryotic cells. **Justify** your prediction. (2 points)

Prediction (1 point)

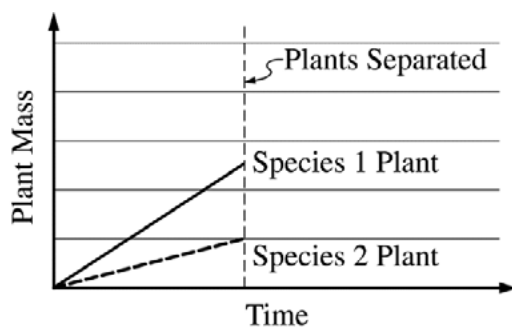
- 15 kb
- Longer than the mature mRNA in the eukaryote

Justification (1 point)

- mRNA processing typically does not occur in prokaryotes

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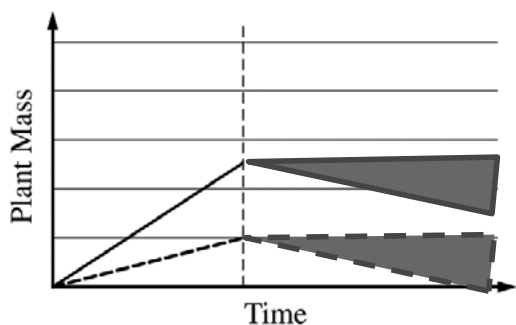
Question 5



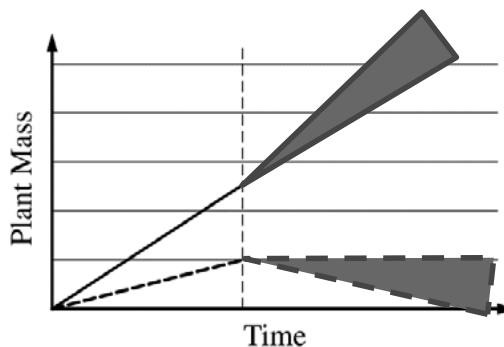
The graph above shows the mass of plants from two different species over time. The plants grew while attached to each other. The plants were separated at the time indicated by the vertical line in the graph.

Using template 1, **graph** the predicted shape of the plant-mass lines after separation of the two plants if the plants were in an obligate mutualistic relationship. On template 2, **graph** the predicted shape of the plant-mass lines if the species 2 plant was a parasite of the species 1 plant. **Justify** each of your predictions. (4 points)

TEMPLATE 1: OBLIGATE MUTUALISM



TEMPLATE 2: PARASITISM



	Graph characteristics (1 point each graph; 2 points maximum)	Justification (1 point each box; 2 points maximum)
Obligate Mutualism	Both of the growth curves level off or decline.	- Each species depends on the other for survival. - Without the relationship, both species are harmed.
Parasitism	Species 1 continues to increase while species 2 levels off or declines.	- The parasite requires an association with the host to survive but harms the host. - Without the relationship, the parasite cannot survive while the host continues to grow.

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Question 6

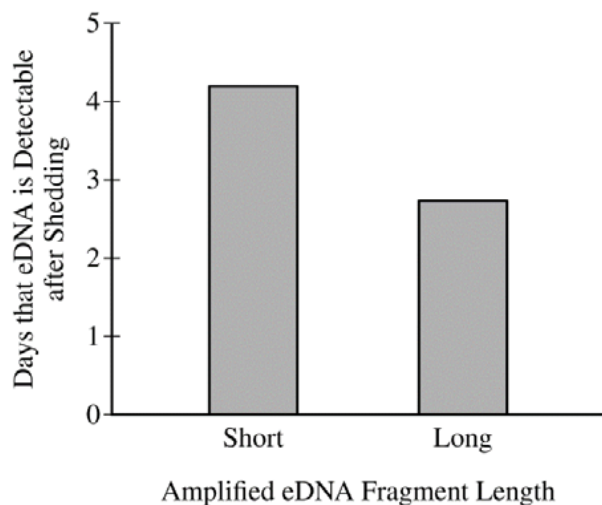


Figure 1. Detectability of eDNA fragments of varying lengths

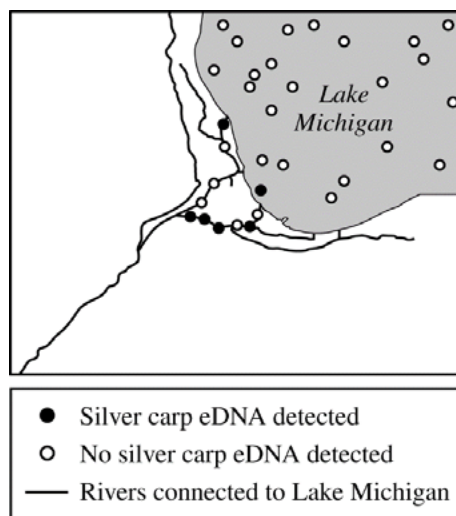


Figure 2. Map of the waterways that connect a nearby river system to Lake Michigan

Living and dead organisms continuously shed DNA fragments, known as eDNA, into the environment. To detect eDNA fragments in the environment, the polymerase chain reaction (PCR) can be used to amplify specific eDNA fragments. eDNA fragments of different lengths persist in the environment for varying amounts of time before becoming undetectable (Figure 1).

To investigate whether silver carp, an invasive fish, have moved from a nearby river system into Lake Michigan, researchers tested water samples for the presence of eDNA specific to silver carp (Figure 2).

- (a) **Justify** the use of eDNA sampling as an appropriate technique for detecting the presence of silver carp in an environment where many different species of fish are found. **Propose** ONE advantage of identifying long eDNA fragments as opposed to short fragments for detecting silver carp. **(2 points)**

Justify (1 point)

- eDNA allows detection of the fish without visual identification/catching the fish.

Proposed advantage (1 point)

- Longer fragments indicate more recent presence of fish.
- Longer fragments are more likely to contain a sequence that is specific to silver carp.
- Longer sequences/more base pairs may increase accuracy/specificity/confidence that the eDNA is from a silver carp and not a related species.

- (b) The researchers tested a large number of water samples from Lake Michigan and found eDNA specific to silver carp in a single sample in the lake, as indicated in Figure 2. The researchers concluded that the single positive sample was a false positive and that no silver carp had entered Lake Michigan.

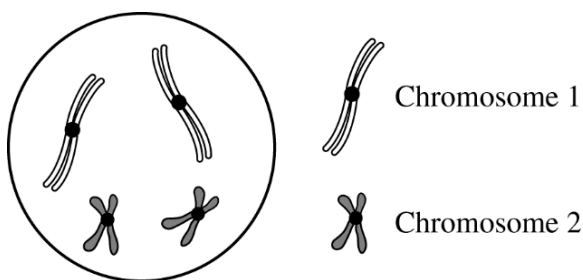
Provide reasoning other than human error to support the researchers' claim. **(1 point)**

Reasoning (1 point)

- eDNA entered the lake by means other than the fish (e.g., river flow, boats, waste from predators).

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Question 7

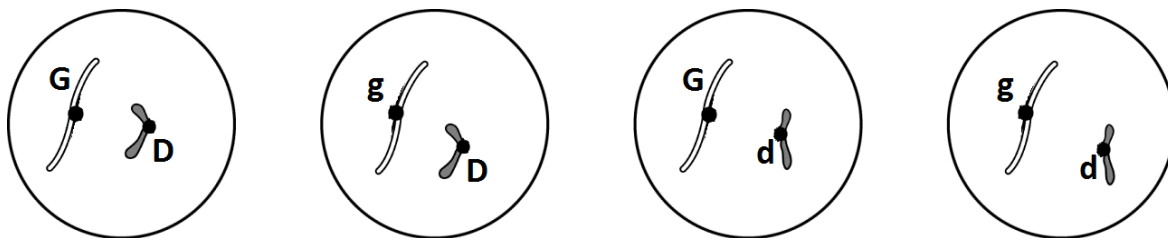


In a certain species of plant, the diploid number of chromosomes is 4 ($2n = 4$). Flower color is controlled by a single gene in which the green allele (G) is dominant to the purple allele (g). Plant height is controlled by a different gene in which the dwarf allele (D) is dominant to the tall allele (d). Individuals of the parental (P) generation with the genotypes $GGDD$ and $ggdd$ were crossed to produce F_1 progeny.

- (a) **Construct** a diagram below to depict the four possible normal products of meiosis that would be produced by the F_1 progeny. Show the chromosomes and the allele(s) they carry. Assume the genes are located on different chromosomes and the gene for flower color is on chromosome 1. **(1 point)**

Construct diagram (1 point)

- Diagram must include all of the following:
 - Each cell has one unduplicated chromosome 1 (with G or g).
 - Each cell has one unduplicated chromosome 2 (with D or d).
 - Genotype combinations should be: GD , Gd , gD , gd .



- (b) **Predict** the possible phenotypes and their ratios in the offspring of a testcross between an F_1 individual and a $ggdd$ individual. **(1 point)**

Prediction (1 point)

- 1 green dwarf: 1 green tall: 1 purple dwarf: 1 purple tall

- (c) If the two genes were genetically linked, **describe** how the proportions of phenotypes of the resulting offspring would most likely differ from those of the testcross between an F_1 individual and a $ggdd$ individual. **(1 point)**

Identify difference (1 point)

- The majority/greater than 50 percent would have the parental plant phenotypes
- Greater than 25 percent would be green dwarf plants and greater than 25 percent would be purple tall plants
- Less than 25 percent would be green tall plants and less than 25 percent would be purple dwarf plants

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Question 8

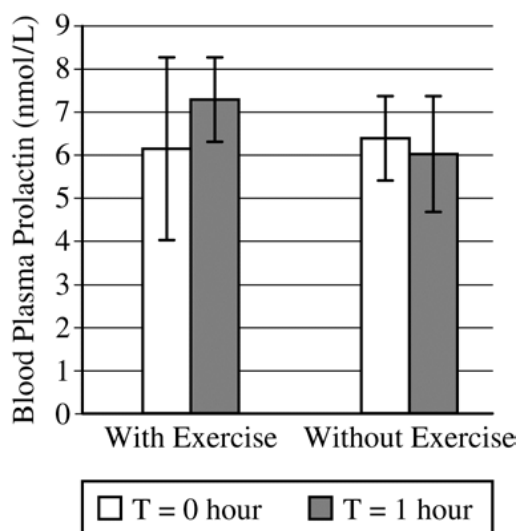


Figure 1. Effect of exercise on blood prolactin levels in adult males. The data represent the mean $\pm 2SE_{\bar{x}}$.

Researchers conducted a study to investigate the effect of exercise on the release of prolactin into the blood. The researchers measured the concentration of prolactin in the blood of eight adult males before (T = 0 hour) and after one hour (T = 1 hour) of vigorous exercise. As a control, the researchers measured the concentration of blood prolactin in the same group of individuals at the same times of day one week later, but without having them exercise. The results are shown in Figure 1.

- (a) **Justify** the use of the without-exercise treatment as the control in the study design. **(1 point)**

Justification (1 point)

- Attribute changes in the concentration of blood prolactin to exercise only
- Rule out normal fluctuations in prolactin release/levels

- (b) Using evidence from the specific treatments, **determine** whether prolactin release changes after exercise. **Justify** your answer. **(2 points)**

Determination (1 point)

- Exercise does not affect prolactin release

Justification (1 point)

- The T=1 hour with-exercise mean and the T=1 hour without-exercise mean are within $\pm 2SE_{\bar{x}}$.
- The $\pm 2SE_{\bar{x}}$ error bars for the T=1 hour with-exercise time point and the T=1 hour time without-exercise point overlap.
- The $\pm 2SE_{\bar{x}}$ error bars for the T=0 and T=1 hour with-exercise time points overlap.
- The T=0 hour with-exercise mean and the T=1 hour with exercise-mean are within $\pm 2SE_{\bar{x}}$.

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Question 1

Many species have circadian rhythms that exhibit an approximately 24-hour cycle. Circadian rhythms are controlled by both genetics and environmental conditions, including light.

Researchers investigated the effect of light on mouse behavior by using a running wheel with a motion sensor to record activity on actograms, as shown in Figure 1.

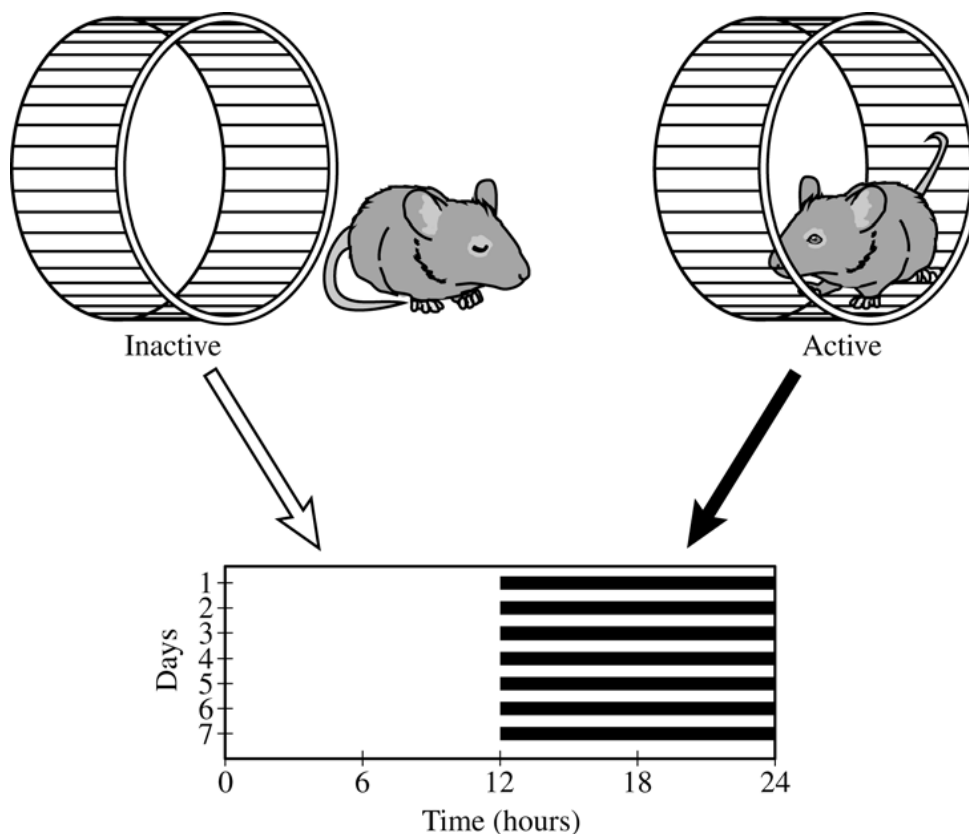


Figure 1. Strategy for recording mouse activity data. When a mouse is active on the running wheel, the activity is recorded as a dark horizontal line on an actogram. When the mouse is inactive, no dark line is recorded.

For the investigation, adult male mice were individually housed in cages in a soundproof room at 25°C. Each mouse was provided with adequate food, water, bedding material, and a running wheel. The mice were exposed to daily periods of 12 hours of light (L) and 12 hours of dark (D) (L12:D12) for 14 days, and their activity was continuously monitored. The activity data are shown in Figure 2.

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Question 1 (continued)

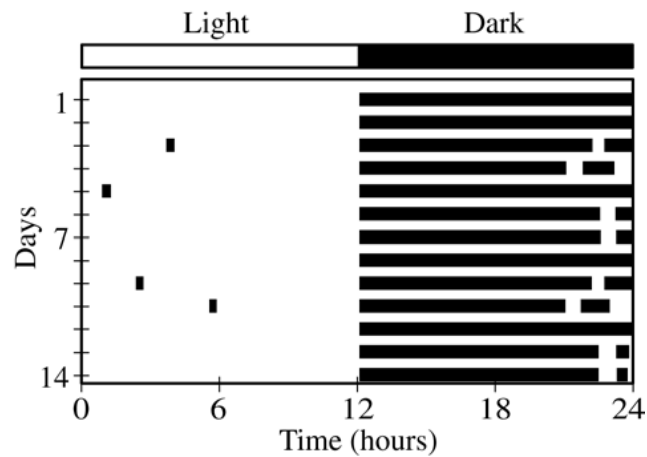


Figure 2. Actogram of mouse activity under L12:D12 conditions. Each row represents a 24-hour period, and the dark horizontal lines represent activity on the running wheel.

After 14 days in L12:D12, the mice were placed in continuous darkness (DD), and their activity on the running wheel was recorded as before. The activity data under DD conditions are shown in Figure 3.

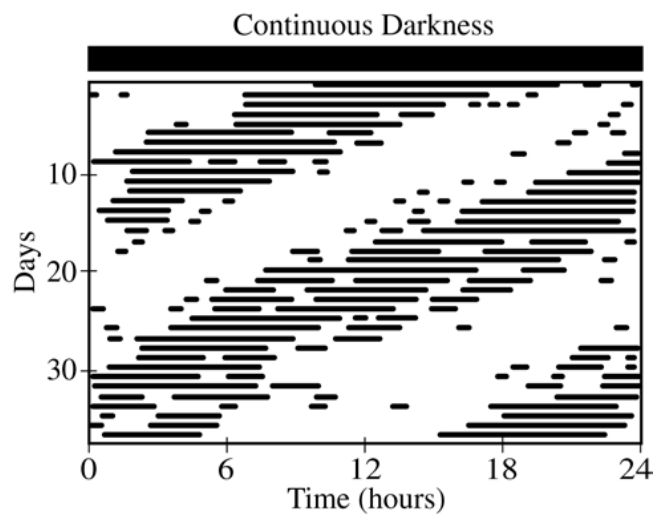


Figure 3. Actogram of mouse activity under DD conditions. Each row represents a 24-hour period, and the dark horizontal lines represent activity on the running wheel.

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Question 1 (continued)

- (a) The nervous system plays a role in coordinating the observed activity pattern of the mice in response to light-dark stimuli. **Describe** ONE role of each of the following anatomical structures in responding to light-dark stimuli.

- A photoreceptor in the retina of the eye
- The brain
- A motor neuron

	Descriptions (1 point per box; 3 points maximum)
Photoreceptor	Detects light/dark stimulus and initiates/transmits signal
Brain	Integrates/processes/coordinates information
Motor neuron	Transmits signal from brain to an effector

- (b) Based on an analysis of the data in Figure 2, **describe** the activity pattern of the mice during the light and dark periods of the L12:D12 cycle.

Description (1 point)

- Active during dark phase AND inactive during light phase
- Active ONLY during the dark period
- Inactive ONLY during the light period

- (c) The researchers claim that the genetically controlled circadian rhythm in the mice does not follow a 24-hour cycle. **Describe** ONE difference between the daily pattern of activity under L12:D12 conditions (Figure 2) and under DD conditions (Figure 3), and use the data to **support** the researchers' claim.

Description (1 point)

- Active period begins a little earlier each day
- Active/inactive period is shorter than 12 hours each day
- Daily circadian rhythm is less than 24 hours
- Pattern of activity shifts each day

Support (1 point)

- Without light, active/inactive periods are determined only by the genetically controlled circadian rhythm.
- If it were a 24-hour circadian rhythm, the pattern of activity in DD would be the same as the pattern of activity in L12:D12.

- (d) To investigate the claim that exposure to light overrides the genetically controlled circadian rhythm, the researchers plan to repeat the experiment with mutant mice lacking a gene that controls the circadian rhythm. **Predict** the observed activity pattern of the mutant mice under L12:D12 conditions and under DD conditions that would support the claim that light overrides the genetically controlled circadian rhythm.

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Question 1 (continued)

Conditions	Predicted Activity Pattern (1 point per box; 2 points maximum)
Mutant under L12:D12	Normal rhythm/rhythm similar to wild-type mouse under L12:D12 (Figure 2)
Mutant under DD	• Random activity throughout the 24 hour period • No pattern/rhythm • Constantly active/constantly inactive

- (e) In nature, mice are potential prey for some predatory birds that hunt during the day. **Describe** TWO features of a model that represents how the predator-prey relationship between the birds and the mice may have resulted in the evolution of the observed activity pattern of the mice.

	Description (1 point per box; 2 points maximum)
Selective Advantage	• Selection for individuals active at night • Selection against individuals active during the day • Day-active variants susceptible to predation • Night-active variants able to avoid predation
Reproductive Success	• Mice selected for produce more offspring • Mice selected against produce fewer offspring

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Question 2

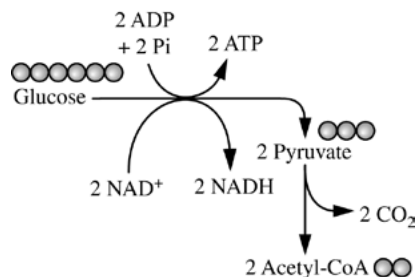


Figure 1. Glycolysis and pyruvate oxidation

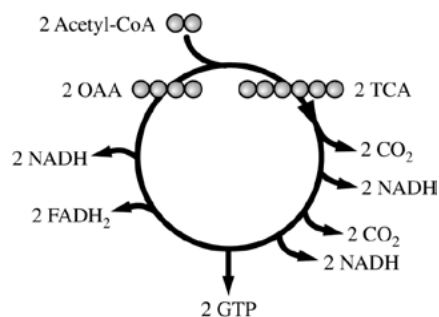


Figure 2. Krebs cycle

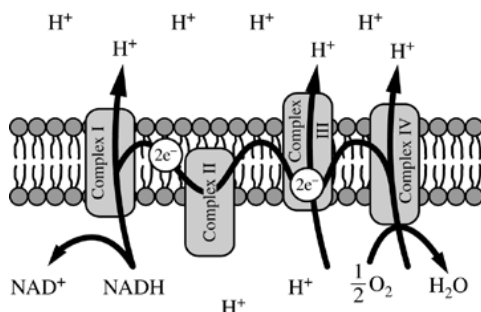


Figure 3. Electron transport chain

Cellular respiration includes the metabolic pathways of glycolysis, the Krebs cycle, and the electron transport chain, as represented in the figures. In cellular respiration, carbohydrates and other metabolites are oxidized, and the resulting energy-transfer reactions support the synthesis of ATP.

(a) Using the information above, **describe** ONE contribution of each of the following in ATP synthesis.

- Catabolism of glucose in glycolysis and pyruvate oxidation
- Oxidation of intermediates in the Krebs cycle
- Formation of a proton gradient by the electron transport chain

Process	Description (1 point each box; 3 points maximum)
Catabolism of glucose in glycolysis and pyruvate oxidation	• Produces NADH for use in ETC • Produces acetyl-CoA for entry into Krebs cycle • Provides energy for (substrate level) phosphorylation of ADP
Oxidation of intermediates in the Krebs cycle	• Produces NADH or FADH₂ for use in ETC • Releases high energy electrons for use in ETC • Provides energy to pump protons against their concentration gradient • Produces GTP for (substrate level) phosphorylation of ADP
Formation of a proton gradient by the electron transport chain	• The flow of protons through membrane-bound ATP synthase generates ATP • Provides energy for (oxidative) phosphorylation of ADP

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Question 2 (continued)

(b) Use each of the following observations to **justify** the claim that glycolysis first occurred in a common ancestor of all living organisms.

- Nearly all existing organisms perform glycolysis.
- Glycolysis occurs under anaerobic conditions.
- Glycolysis occurs only in the cytosol.

Observation	Justification (1 point each box; 3 points maximum)
Nearly all existing organisms perform glycolysis	• Trait/gene/process originated early and was inherited/passed down/highly conserved • Glycolysis provided a selective advantage that was passed on to descendants
Glycolysis occurs under anaerobic conditions	Origin of glycolysis pre-dates free atmospheric oxygen/photosynthesis
Glycolysis occurs only in the cytosol	Origin of glycolysis pre-dates cell types with membrane-bound organelles/eukaryotes/endosymbiosis

(c) A researcher estimates that, in a certain organism, the complete metabolism of glucose produces 30 molecules of ATP for each molecule of glucose. The energy released from the total oxidation of glucose under standard conditions is 686 kcal/mol. The energy released from the hydrolysis of ATP to ADP and inorganic phosphate under standard conditions is 7.3 kcal/mol. **Calculate** the amount of energy available from the hydrolysis of 30 moles of ATP. **Calculate** the efficiency of total ATP production from 1 mole of glucose in the organism. **Describe** what happens to the excess energy that is released from the metabolism of glucose.

	Calculation/description (1 point each box; 3 points maximum)
Calculate available energy in ATP	219 kcal
Calculate efficiency	0.31 - 0.32 or 31 - 32%
Describe fate of excess energy	Released as heat/increases entropy

(d) The enzymes of the Krebs cycle function in the cytosol of bacteria, but among eukaryotes the enzymes function mostly in the mitochondria. **Pose** a scientific question that connects the subcellular location of the enzymes in the Krebs cycle to the evolution of eukaryotes.

Question (1 point)

- A valid scientific question related to evolution of eukaryotes (e.g., Since the Krebs cycle occurs in the “cytoplasm” of the mitochondria (matrix), does it suggest that mitochondria were once prokaryotes?)

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Question 3

The amino-acid sequence of cytochrome *c* was determined for five different species of vertebrates. The table below shows the number of differences in the sequences between each pair of species.

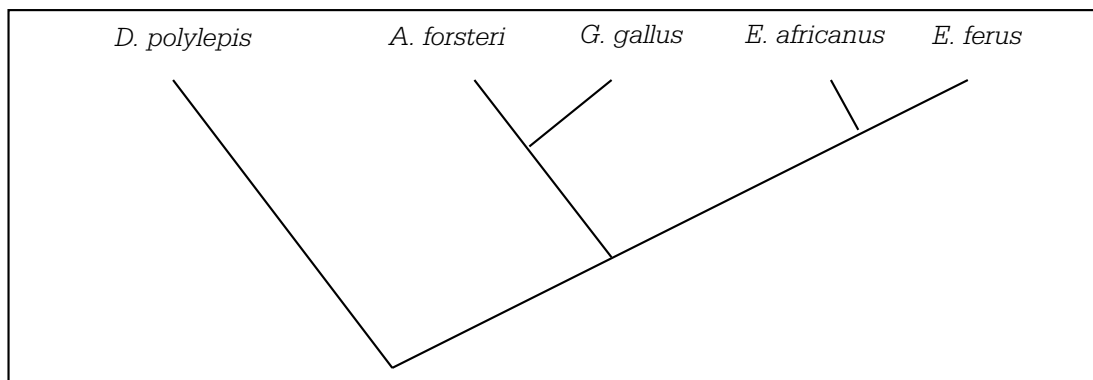
THE NUMBER OF AMINO ACID DIFFERENCES
IN CYTOCHROME *c* AMONG FIVE SPECIES

	<i>E. ferus</i>	<i>D. polylepis</i>	<i>G. gallus</i>	<i>A. forsteri</i>	<i>E. africanus</i>
<i>E. ferus</i>	0	21	11	13	1
<i>D. polylepis</i>		0	18	17	20
<i>G. gallus</i>			0	3	10
<i>A. forsteri</i>				0	12
<i>E. africanus</i>					0

- (a) Using the data in the table, **create** a phylogenetic tree on the template provided to reflect the evolutionary relationships of the organisms. **Provide reasoning** for the placement on the tree of the species that is least related to the others.

Phylogenetic tree (1 point)

NOTE: There can be free rotation around the nodes in the tree.



Reasoning (1 point)

- *D. polylepis* has the most differences in amino acids (or changes in DNA or proteins as they relate to amino acids).
- (b) **Identify** whether morphological data or amino acid sequence data are more likely to accurately represent the true evolutionary relationships among the species, and **provide reasoning** for your answer.

2015 SCORING GUIDELINES**Question 3 (continued)****Identification (1 point)**

- Amino acid/molecular data

Reasoning (1 point)

- Morphology may be similar (due to convergent evolution/analogous structures) even if there are differences in amino acid/DNA sequences.
- Molecular data (e.g. amino acid changes, DNA changes) directly show genetic make-up/ reveal evolution.

OR

Identification (1 point)

- Morphological data

Reasoning (1 point)

- Similar molecular sequences may result in different morphologies.
- An example of species with similar proteins but different morphology (e.g., chimps and humans).

2015 SCORING GUIDELINES

Question 4

Both mitosis and meiosis are forms of cell division that produce daughter cells containing genetic information from the parent cell.

- (a) **Describe** TWO events that are common to both mitosis and meiosis that ensure the resulting daughter cells inherit the appropriate number of chromosomes.

Description (1 point each; 2 points maximum)

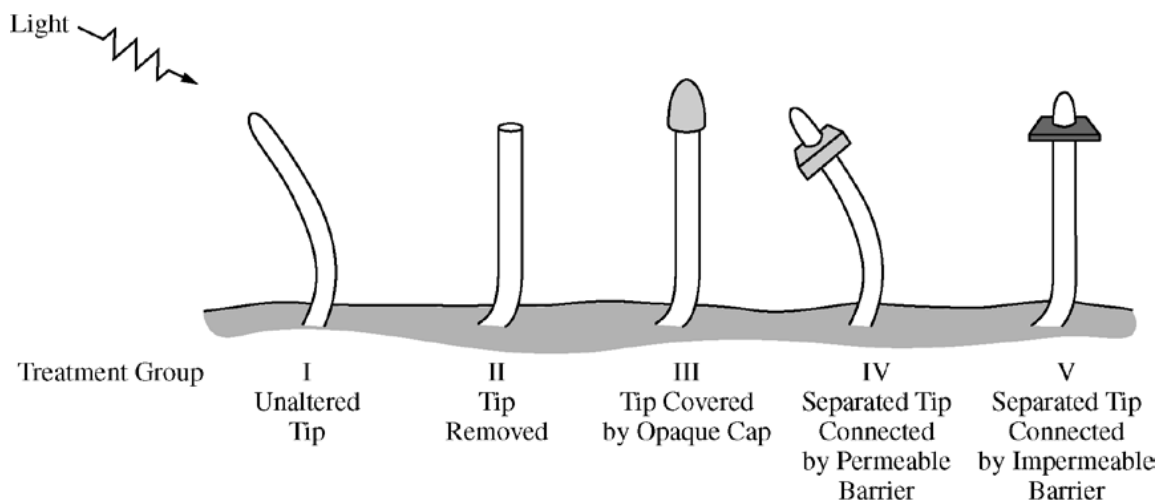
- Spindle elements (microtubules) form/attach to chromosomes
- Chromatin condenses
- Alignment of chromosomes across center of cell prior to chromosome separation
- Separation of chromatids/centromeres to daughter cells
- G2/M checkpoint occurs in both processes
- Replication or synthesis of DNA precedes mitosis/meiosis
- Cytokinesis separates daughter cells after mitosis/meiosis

- (b) The genetic composition of daughter cells produced by mitosis differs from that of the daughter cells produced by meiosis. **Describe** TWO features of the cell division processes that lead to these differences.

Feature	Description (1 point each row; 2 points maximum)	
	Mitosis	Meiosis
Number of divisions/ number of resulting cells	1 division/ 2 cells result	2 divisions/ 4 cells result
Ploidy of daughter cells	• Same as parent cell • Diploid • ($2n \rightarrow 2n$ or $n \rightarrow n$)	• Half of parent cell • Haploid • ($4n \rightarrow 2n$; $2n \rightarrow n$)
Chromatids separate	Occurs	Not in meiosis I/only in meiosis II
Crossing over	Does not occur	Occurs
Homologous chromosomes separate/independently assort	Does not occur	Occurs

2015 SCORING GUIDELINES

Question 5



Phototropism in plants is a response in which a plant shoot grows toward a light source. The results of five different experimental treatments from classic investigations of phototropism are shown above.

- (a) **Give support** for the claim that the cells located in the tip of the plant shoot detect the light by comparing the results from treatment group I with the results from treatment group II and treatment group III.

Support (2 points maximum)

- In treatment II the tip is removed and the plant no longer bends toward light.
- In treatment III the cap blocks the light to the tip and the plant no longer bends toward light.

- (b) In treatment groups IV and V, the tips of the plants are removed and placed back onto the shoot on either a permeable or impermeable barrier. Using the results from treatment groups IV and V, **describe** TWO additional characteristics of the phototropism response.

Description (2 points maximum)

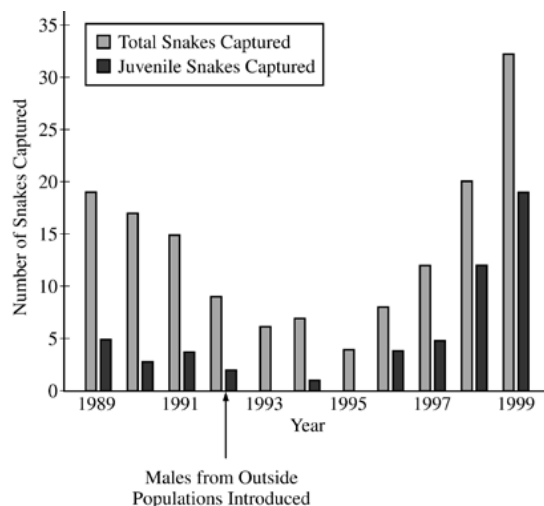
- Tip produces a substance/signal/hormone (auxin) in response to light causing the plants to bend
- Substance must diffuse from the tip causing the plants to bend

2015 SCORING GUIDELINES

Question 6

In an attempt to rescue a small isolated population of snakes from decline, a few male snakes from several larger populations of the same species were introduced into the population in 1992. The snakes reproduce sexually, and there are abundant resources in the environment.

The figure below shows the results of a study of the snake population, both before and after the introduction of the outside males. In the study, the numbers of captured snakes is an indication of the overall population size.



- (a) **Describe** ONE characteristic of the original population that may have led to the population's decline in size between 1989 and 1993.

Description (1 point)

- Lacked genetic diversity/variation
- Was an aged/post-reproductive population/not enough young snakes
- Had unfavorable sex ratio/too few males
- Possessed a harmful mutation/disease

- (b) **Propose** ONE reason that the introduction of the outside males rescued the snake population from decline.

Proposal (1 point)

- Increased genetic diversity in the population
- Increased reproductive success
- Established beneficial sex ratio/sufficient proportion of males for reproduction
- Introduced resistance to disease that was affecting the original population

- (c) **Describe** how the data support the statement that there are abundant resources in the environment.

Description (1 point)

- Population can/does grow
- If resources are limited population would not grow

2015 SCORING GUIDELINES

Question 7

Smell perception in mammals involves the interactions of airborne odorant molecules from the environment with receptor proteins on the olfactory neurons in the nasal cavity. The binding of odorant molecules to the receptor proteins triggers action potentials in the olfactory neurons and results in transmission of information to the brain. Mammalian genomes typically have approximately 1,000 functional odorant-receptor genes, each encoding a unique odorant receptor.

- (a) **Describe** how the signal is transmitted across the synapse from an olfactory sensory neuron to the interneuron that transmits the information to the brain.

Description (1 point)

- Neurotransmitters are released from the olfactory neuron and bind to receptors in the postsynaptic neuron.

- (b) **Explain** how the expression of a limited number of odorant receptor genes can lead to the perception of thousands of odors. Use the evidence about the number of odorant receptor genes to **support** your explanation.

Explanation and support (2 points maximum: points may be earned from only one row)

	Explanation (1 point)	Support (1 point)
Molecular	• One odorant molecule can be recognized by more than one odorant receptor • One odorant receptor can bind to more than one odorant molecule	Mathematical combinations expand possible odors detected
CNS Control	Signals integrated in the brain	Multiple interactions among neurons in the brain
Genetic	Alternate processing/splicing (of pre-mRNA/primary transcript)	Multiple receptors can be produced from a gene

2015 SCORING GUIDELINES**Question 8**

An individual has lost the ability to activate B-cells and mount a humoral immune response.

- (a) **Propose** ONE direct consequence of the loss of B-cell activity on the individual's humoral immune response to an initial exposure to a bacterial pathogen.

Proposal (1 point)

- Does not produce antibodies
- Does not produce memory B cells

- (b) **Propose** ONE direct consequence of the loss of B-cell activity on the speed of the individual's humoral immune response to a second exposure to the bacterial pathogen.

Proposal (1 point)

- Does not mount a faster response than the first response
- Mounts a second response at the same speed as the first response
- Mounts a second response more slowly than would a normal individual

- (c) **Describe** ONE characteristic of the individual's immune response to the bacterial pathogen that is not affected by the loss of B cells.

Description (1 point)

- Cell-mediated immunity still active
- Components of cell mediated immunity (e.g., Natural Killer/ Cytotoxic T cells) still active
- Nonspecific immune response remains active
- Components of non-specific immunity (e.g., macrophage/ phagocyte, epidermis) still active

AP[®] Biology

2014 Scoring Guidelines

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2014 SCORING GUIDELINES

Question 1

Trichomes are hairlike outgrowths of the epidermis of plants that are thought to provide protection against being eaten by herbivores (herbivory). In a certain plant species, stem trichome density is genetically determined.

To investigate variation in stem trichome density within the plant species, a student counted the number of trichomes on the stems of six plants in each of three different populations. The student used the data to calculate the mean trichome density (numbers of hairs per square centimeter) for each population. The results are provided in the table below.

TRICHOME DENSITY IN THREE PLANT POPULATIONS (number of trichomes/cm²)

Population	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Sample Mean	Standard Error of the Mean (SEM)
I	8	11	9	10	8	6	9	1
II	12	6	15	9	13	8	11	1
III	13	17	9	14	12	16	14	1

- (a) On the axes provided, **create** an appropriately labeled graph to illustrate the sample means of the three populations to within 95 percent confidence (i.e., sample mean $\pm$ 2 SEM). (**3 points maximum**; LO 1.1)
- Correctly labeled, scaled, with proper units
 - Bar graph or modified bar graph with appropriately plotted means
 - 2x standard error (SEM) above and below means
- (b) Based on the sample means and standard errors of the means, **identify** the two populations that are most likely to have statistically significant differences in the mean stem trichome densities. **Justify** your response. (**2 points maximum**; LO 4.11, 4.19)

Identification (**1 point**)

- Populations I and III

Justification (**1 point**)

- The error bars/95 percent confidence intervals for populations I and III do not overlap
- (Sample mean + 2 SEM of population I) < (Sample mean – 2 SEM of population III)

2014 SCORING GUIDELINES

Question 1 (continued)

- (c) **Describe** the independent and dependent variables and a control treatment for an experiment to test the hypothesis that higher trichome density in plants is selected for in the presence of herbivores. Also **identify** an appropriate duration of the experiment to ensure that natural selection is measured and **predict** the experimental results that would support the hypothesis. (**5 points maximum**; LO 1.5, 1.11)

NOTE: Points are earned in a single row only.

Independent Variable (1 point)	Dependent Variable (1 point)	Control (1 point)	Duration (1 point)	Prediction (1 point)
Presence of herbivores	Trichome density	Absence of herbivores	More than one generation	Increased trichome density relative to control
Trichome density in the presence of herbivores	Reproductive success OR # of plants	Plants with lower trichome density	More than one generation	Size of the population with higher trichome density will be larger than control population

SCORING GUIDELINES

Question 2

Mammalian milk contains antibodies that are produced by the mother's immune system and passed to offspring during feeding. Mammalian milk also contains a sugar (lactose) and may contain proteins (protein A, protein B, and casein), as indicated in the table.

MILK COMPONENTS IN DIFFERENT MAMMALS

Character	Cat	Cow	Horse	Human	Pig
Lactose	+	+	+	+	+
Protein A	+	+	+	+	+
Protein B	–	+	+	–	+
Casein	–	+	+	–	+
+ indicates the presence of the character, and – indicates the absence of a character					

Using the data in the table, **construct** a cladogram on the template provided to indicate the most likely evolutionary relationships among the different mammals. **Indicate** on the cladogram where each of the characters most likely arose in the evolutionary process, and **justify** the placement of the characters on the cladogram. (3 points maximum; LO 1.18, 1.19)

NOTE: Points are earned in one column only.

1 point Casein Protein B Cow Pig Horse Lactose Protein A Cat Human 1 point	Lactose Casein Protein A Protein B Cow Pig Horse Cat Human Loss of both Casein & Protein B 1 point 1 point
Justification (1 point) Lactose and Protein A arose in a common ancestor to all 5 animals. Protein B and Casein arose only in the common ancestor to the pig/cow/horse clade/branch.	Justification (1 point) Lactose, Casein, Protein A, and Protein B arose in a common ancestor to all 5 animals. Protein B and Casein were lost in the common ancestor to the cat/human clade/branch.

SCORING GUIDELINES

Question 2 (continued)

Describe FOUR steps in the activation of the mother's specific immune response following exposure to a bacterial pathogen. Predict how the mother's immune response would differ upon a second exposure to the same bacterial pathogen a year later. (5 points maximum; LO 2.29).

Description (1 point each; 4 points maximum)

- Endocytosis of antigen by dendritic cell/macrophage/B-cell
- Degradation of antigen
- Antigen complexed with MHC molecule
- Presentation of antigen on surface of cell
- Recognition of antigen on surface of antigen presenting cell by (helper) T-cell
- Activation of signal transduction mechanism in T-cell
- Activation of (helper) T-cell
- (Helper) T-cells release chemicals that recruit/activate B-cells
- Antigen recognition by B-cell
- Activation of signal transduction mechanism in B-cell
- Activated B-cell or T-cell will clone itself
- Plasma cells/B-cells produce antibodies
- Antibodies recognize antigen
- Antibody binding to antigen is specific
- Memory B cells/memory helper T cells are produced

Prediction (1 point)

- Results in more rapid immune response
- Presence of memory cells
- Greater production of antibodies
- Antibodies circulate longer
- Antibodies have a greater affinity for the antigen

Predict the most likely consequence for a nursing infant who is exposed to an intestinal bacterial pathogen (e.g., *Salmonella*) to which the mother was exposed three months earlier. **Justify** your prediction. (2 points maximum; LO 4.9, 2.40, 2.36)

NOTE: Points are earned in a single row only.

Prediction (1 point)	Justification (1 point)
Infant will be protected/not get sick	Antibodies are passed to infant <i>in utero</i> /via breast milk/infant receives B-cells in breast milk
Infant will become sick/die	Insufficient antibodies were transferred to the offspring/infant exposed to high infecting dose of the pathogen

SCORING GUIDELINES

Question

As part of a new suburban development, a sports complex consisting of athletic fields and buildings is constructed in a formerly wooded area.

Predict ONE ecological consequence on the local plant community that is likely to result during the site preparation and construction of the sports complex. **Justify** your prediction. (**2 points maximum**; LO 4.16, 2.21, 4.21)

Predicted consequences on plant community (1 point)	Justification of prediction (1 point)
Plant death / Loss of plant biomass	• Removing trees/shrubs • Pollution from construction equipment • Fewer individuals for reproduction • Altered habitat, e.g. change in amount of sunlight, obstruction by buildings, isolation of populations
Reduced number of plant species / Loss of biodiversity	• Removal of trees/shrubs • Reduced habitat • Pollution from construction kills local species
Decreased genetic diversity	Reduction in population size / bottleneck
Habitat loss	• Removal of trees/shrubs • Soil loss due to lack of ground cover
Increased success of sun-tolerant plants	Removal of shading trees
Introduction / Immigration of new plant species	Creation of new habitat and landscaped environments

SCORING GUIDELINES

Question 3 (continued)

To maintain the playing fields, large quantities of water and chemicals are applied regularly to the grass-covered areas. **Predict** ONE effect on the local animal community that might result from regular use and maintenance of the playing fields. **Justify** your prediction. (2 points maximum; 6, 2.21, 4.21)

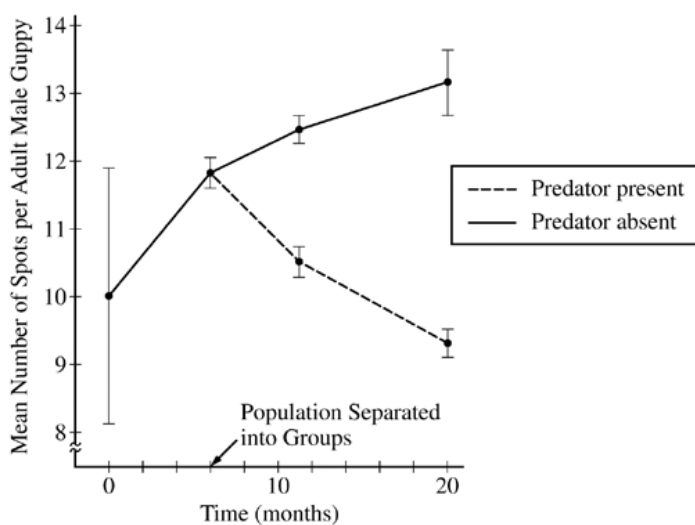
Predicted consequence on animal community (1 point)	Justification of prediction (1 point)
Harm to animals	- Exposure to toxic chemicals - Toxic chemicals accumulate through the food chain Persist in the environment - Contaminated groundwater
Emigration Displacement	- Loss of habitat and/or food - Loss of access - Exposure to toxic chemicals
Loss of native animal biodiversity	- Loss of plants on which the animals depend - Loss of habitat
Mutations	Chemicals effect on DNA
Improved conditions for animals	Increased food sources
Immigration of new animal species	Formation of new habitat
Less potable/drinking water for animals	- Increased salinity in water reservoir - Removal of water from reservoir / wells - Contamination of water with chemicals

2014 SCORING GUIDELINES

Question 4

Adult male guppies (*Poecilia reticulata*) exhibit genetically determined spots, while juvenile and adult female guppies lack spots. In a study of selection, male and female guppies from genetically diverse populations were collected from different mountain streams and placed together in an isolated environment containing no predators.

The study population was maintained for several generations in the isolated area before being separated into two groups. One group was moved to an artificial pond containing a fish predator, while a second group was moved to an artificial pond containing no predators. The two groups went through several generations in their new environments. At different times during the experiment, the mean number of spots per adult male guppy was determined as shown in the figure below. Vertical bars in the figure represent two standard errors of the mean (SEM).



- (a) **Describe** the change in genetic variation in the population between 0 and 6 months and **provide** reasoning for your description based on the means and SEM. (2 points maximum; LO 1.2, 2.24, 4.12, 4.26)

Describe change (1 point)	Provide reasoning (1 point)
Genetic variation is decreasing	SEM gets smaller

- (b) **Propose** ONE type of mating behavior that could have resulted in the observed change in the number of spots per adult male guppy between 6 and 20 months in the absence of the predator. (1 point; LO 1.2, 1.5, 2.40, 3.26, 3.40)

- Sexual selection for individuals with more spots
- Random mating behavior resulted in increased number of spots by chance

2014 SCORING GUIDELINES**Question 4 (continued)**

- (c) **Propose** an evolutionary mechanism that explains the change in average number of spots between 6 and 20 months in the presence of the predator.

(1 point; LO 1.2, 3.26, 4.19)

- Directional selection against individuals with large numbers of spots
- Directional selection for individuals with fewer spots
- Natural selection used in context
- Genetic drift resulted in several generations of decreased numbers of spots

SCORING GUIDELINES

Question

Genetically modified crops have been developed that produce a protein that makes the plants resistant to insect pests. Other genetic modifications make the crops more resistant to chemicals that kill plants (herbicides).

Describe TWO potential biological risks of large-scale cultivation and use of such genetically modified plants. (**2 points maximum**)

For each of the risks you described in part (a), **propose** a practical approach for reducing the risk. (**2 points maximum**; LO 4.21, 2.23)

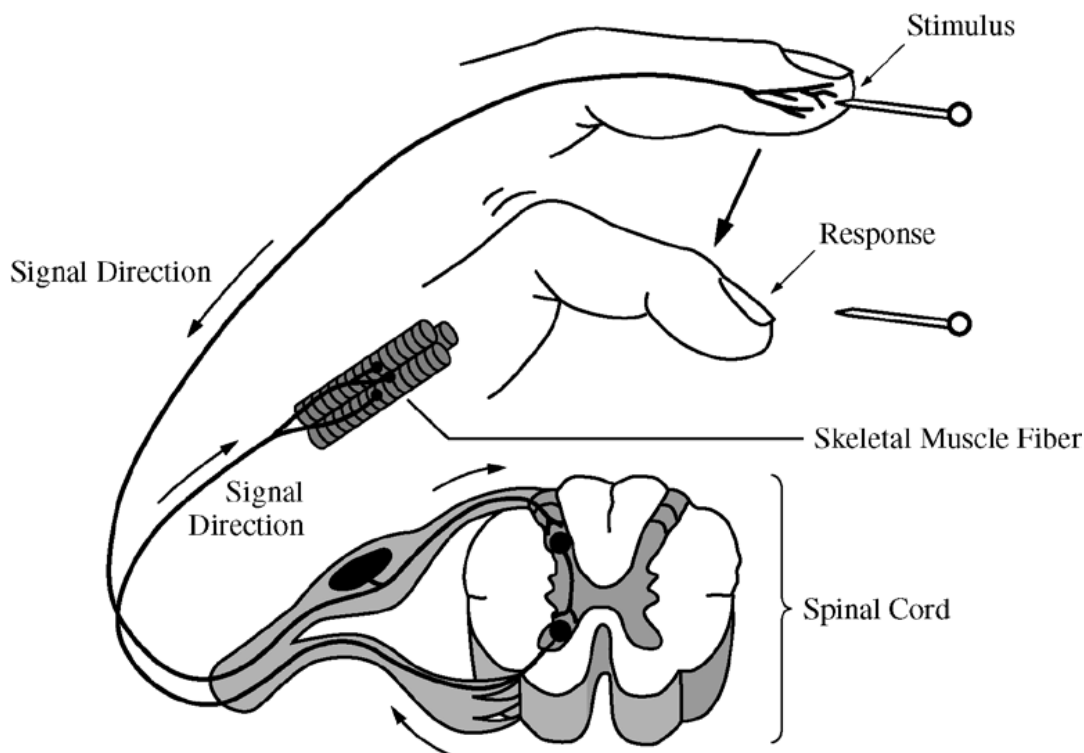
Description of risk (1 point each; 2 points maximum)	Proposed mitigation* + (1 point each box; 2 points maximum)
Unknown human/other animal health risk due to consuming GM proteins	• Testing/labeling product packaging • Isolate animals from crops
Disruption within food chain	• Intersperse GM plants with non-GM plants in culture • Provide alternative food source
Developed resistance in pest species	• Increased use of effective pesticides • Introduce pest predators • Further engineer the GMO to produce more resistance protein • Rotate GM and non-GM crops
Spread of genetic modifications to non-GM plants	• Contain pollen of GM plants • Disable the ability of GM plants to produce viable seeds
GM plants out-compete native species	• Contain/isolate GM plants • Disable GM plants' ability to produce viable seeds
Reduced numbers of pollinators	Contain/isolate GM plants
Loss of biodiversity	Intersperse GM plants with non-GM plants in culture
Use of herbicides harms non-target species	• Rotate GM and non-GM crops • Use organic/alternative herbicides
Invasive disease wiping out the monoculture	Intersperse GM plants with non-GM plants in culture

* Proposed mitigation of non-use of GM plants is acceptable for any described risk above.

† Mitigation must be practical for the risk given.

2014 SCORING GUIDELINES

Question 6



Cross Section of Spinal Cord and Skeletal Muscle Fiber

Information processing involves complex neural pathways that require a certain amount of time between recognition of a stimulus and the resulting response. For some types of stimuli, a reflex arc replaces the typical stimulus-response pathway. A representation of a reflex arc is shown in the figure above.

Based on the figure, **describe** TWO ways that the reflex arc differs from typical stimulus-response transmission pathways. **Provide** reasoning to support the claim that reflex arcs help organisms avoid serious injury. (3 points maximum; LO 2.38, 3.44, 3.45, 4.10)

Description of difference (1 point each; 2 points maximum)

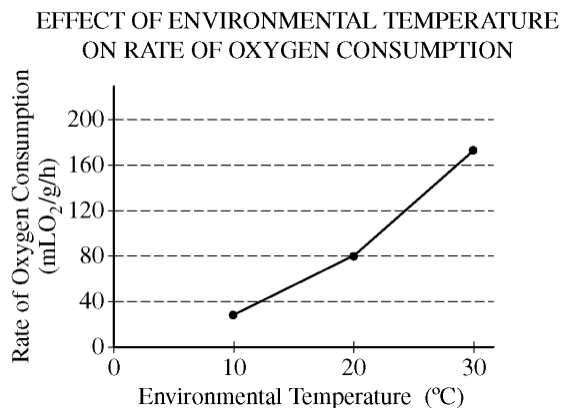
- Quicker response time
- No integration with brain / does not reach brain before response occurs
- Fewer neurons / synapses involved in reflex arc / shorter distance for signal to travel
- Involuntary / no conscious control / no processing by brain

Reasoning to support claim (1 point maximum)

- Quicker response to a threat
- Response is innate (automatic response) rather than learned / predetermined neuron pathway / hardwired

SCORING GUIDELINES

Question



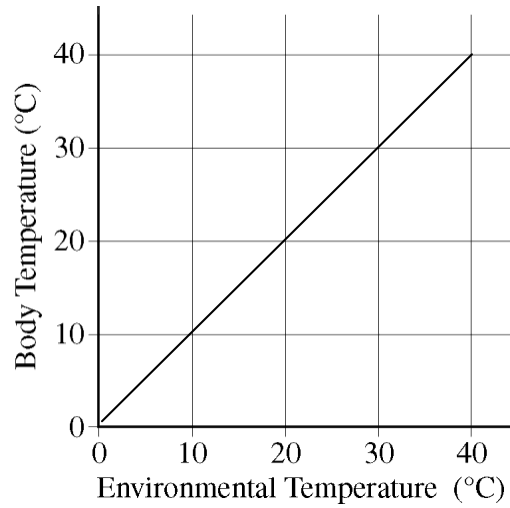
Based on the graph, **describe** a specific method of thermoregulation used by the species of animal. **Provide** support for your answer using the data. (2 points maximum; LO 2.21, 2.24, 2.27)

NOTE: students may only earn points within one row.

Describe method (1 point)	Support (1 point)
This species is an ectotherm/incapable of endoregulation	- Increased metabolic rate/O₂ consumption rate/respiration rate with increased temperature - Decreased metabolic rate/O₂ consumption rate/respiration rate with decreased temperature - If the animal were endothermic, O₂ consumption rate/respiration rate/metabolic rate would increase with decreasing temperature
Behavior to adjust body temperature, i.e., seeking shade, basking in the sun, burrowing in mud, evaporative cooling	- Increased metabolic rate/O₂ consumption rate/respiration rate with increased temperature - Decreased metabolic rate/O₂ consumption rate/respiration rate with decreased temperature - This species is ectothermic/incapable of endoregulation

SCORING GUIDELINES**Question 7 (continued)**

On the labeled axis provided below, **draw** a line to indicate the most likely relationship between body temperature and environmental temperature in the species. (**1 point**; LO 2.22)



- Line/curve with positive slope

2014 SCORING GUIDELINES

Question 8

A research team has genetically engineered a strain of fruit flies to eliminate errors during DNA replication. The team claims that this will eliminate genetic variation in the engineered flies. A second research team claims that eliminating errors during DNA replication will not entirely eliminate genetic variation in the engineered flies. **(3 points maximum)**

- (a) **Provide** ONE piece of evidence that would indicate new genetic variation has occurred in the engineered flies. **(1 point; LO 1.10)**

Piece of evidence

- New phenotypes
- Different DNA sequence
- New genotypes
- Chromosomal differences
- Different mRNA sequence
- Protein with different amino acid sequence

- (b) **Describe** ONE mechanism that could lead to genetic variation in the engineered strain of flies. **(1 point; LO 3.28)**

Describe mechanism

- Sexual reproduction produces offspring with new combinations of alleles/traits
- Meiosis produces new combinations of alleles/traits
- Crossing over produces new combinations of alleles/traits
- Independent assortment produces new combinations of alleles/traits
- Random fertilization produces new combinations of alleles/traits
- Immigration/gene flow introduces new alleles/gene sequences
- Viral infection inserts DNA into genome
- Nondisjunction causes anomaly in chromosome number
- Chromosomal rearrangements (e.g., large deletions, duplications, translocations, inversions, transposons, etc.) inactivate genes or result in multiple copies of genes
- Radiation or chemicals or mutagens induce mutations/changes in DNA

- (c) **Describe** how genetic variation in a population contributes to the process of evolution in the population. **(1 point; LO 1.25)**

Description

- Genetic variation is the basis of phenotypic variation that can be acted upon by natural selection
- Without genetic variation, there is no phenotypic variation on which natural selection can act