

Question 1: Interpreting and Evaluating Experimental Results with Experimental Design

9 points

Crossing over in meiosis I is required for homologous chromosomes to properly align during metaphase and segregate during the first cell division.

Some regions of a chromosome called hotspots display a higher frequency of crossing over than other regions do. Crossing over is suppressed in chromosomal regions near the centromeres. The centromere region of a duplicated chromosome includes a collection of proteins that form a structure called the kinetochore. Scientists hypothesized that one or more of these kinetochore proteins are responsible for suppressing crossing over around the centromere.

To investigate their hypothesis, scientists modified chromosome 8 in yeast such that, in each cell, one chromosome from the pair of homologous chromosome 8s contained the gene encoding red fluorescent protein (RFP), while the other chromosome from the pair contained the gene encoding green fluorescent protein (GFP). Cells expressing RFP emit (give off) red light, and cells expressing GFP emit green light. Models of the modified chromosome 8 both before and after crossing over are shown in Figure 1.

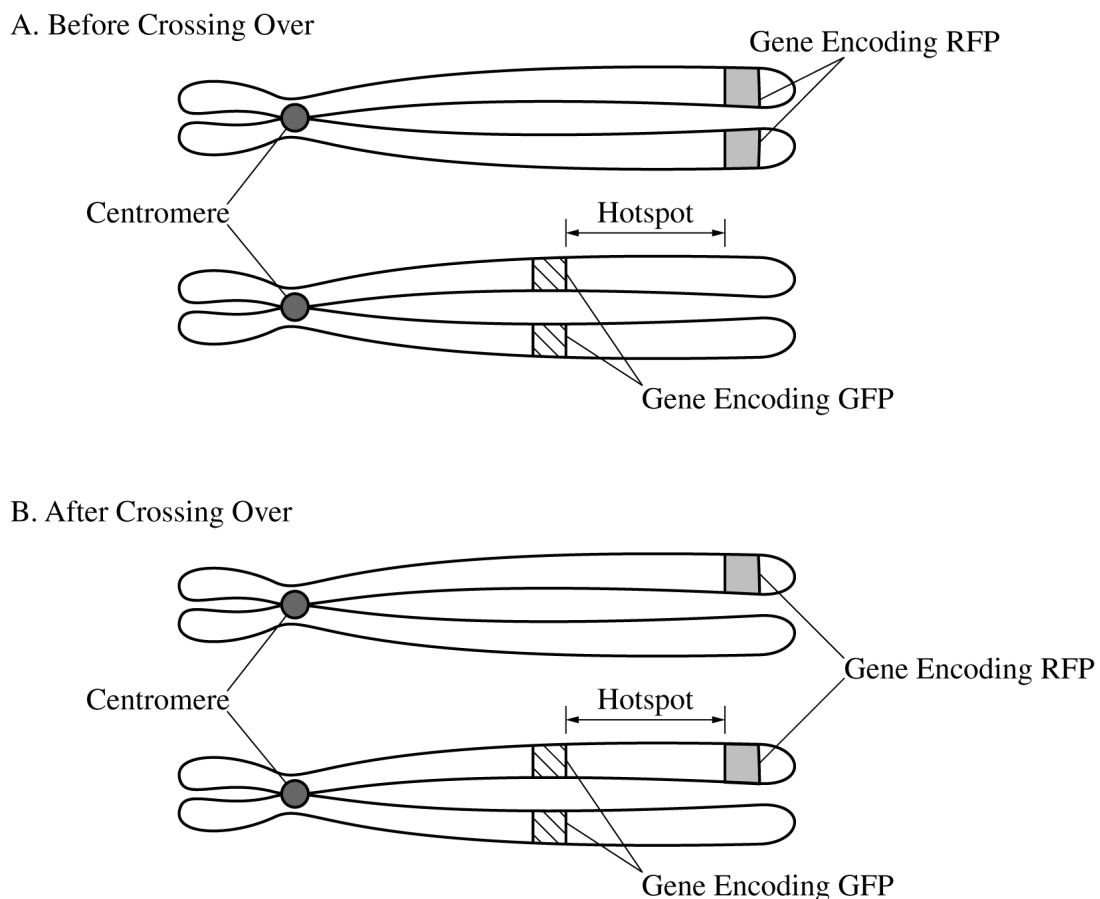


Figure 1. Models of modified chromosome 8 used in the experiment (A) before and (B) after crossing over occurs at the hotspot

The scientists then investigated whether attaching individual kinetochore proteins to a specific DNA sequence present in a known crossing-over hotspot on chromosome 8 affected the frequency of crossing

over at this location. In their first experiment, they examined three groups of yeast cells containing the modified chromosome 8. Group 1 contained no kinetochore proteins attached to the hotspot, group 2 contained the kinetochore protein CTF attached to the hotspot, and group 3 contained the kinetochore protein IML attached to the hotspot. For each group, the scientists determined the frequency of crossing over between the RFP and GFP genes. To determine the frequency, the scientists added the number of cells emitting both red and green light to the number of cells that emitted no light and divided by the total number of cells (Figure 2).

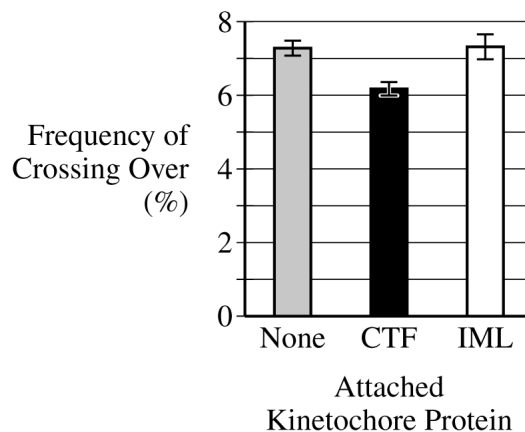


Figure 2. The frequency of crossing over in a hotspot on yeast chromosome 8 for cell groups treated with different kinetochore proteins. Error bars represent $\pm 2SE_{\bar{x}}$.

(a) Describe the function of S phase of interphase. **1 point**

Accept one of the following:

- (The function of S phase is to) replicate/duplicate/synthesize the DNA/chromosomes.
- (The function of S phase is to) double the amount of DNA.

Explain why some haploid cells formed after meiosis in this experiment will have only one fluorescent marker. **1 point**

Accept one of the following:

- Some cells will receive a chromosome/(sister) chromatid that did not undergo crossing over/recombination (in the hotspot).
- Two (or a multiple of two) crossing-over events occurred (in the hotspot).
- Each daughter cell will receive one of the four sister chromatids. Two of the sister chromatids shown in Figure 1 have only one fluorescent protein gene.
- The two chromosomes that were not involved in crossing over will have only the RFP gene or the GFP gene. After meiosis II, a gamete with one of these chromosomes will have only the RFP or the GFP gene.

Total for part (a) 2 points

(b) Identify the control group for the scientists' first experiment, shown in Figure 2. **1 point**

Accept one of the following:

- Group 1
- (The group called) None
- Cells with no (kinetochore) protein (attached to the chromosome)

In a follow-up experiment, the scientists created a modified version of CTF in which the DNA-binding portion had been removed. They compared the frequency of crossing over in yeast cells in the presence and absence of unmodified CTF with that in yeast cells in the presence and absence of the modified CTF protein (data not shown). In the follow-up experiment, **justify** why the scientists used a modified CTF protein that is unable to bind to DNA as a control.

1 point

Accept one of the following:

- (Using a modified CTF enabled the scientists) to determine whether DNA binding of the CTF/kinetochore protein affects/inhibits crossing over/recombination.
- (Using a modified CTF enabled the scientists) to determine whether just the presence of the CTF/kinetochore protein is enough to affect/inhibit the crossing over/recombination frequency.

Identify the independent variable in the follow-up experiment.

1 point

Accept one of the following:

- The type of CTF used
- The presence or absence of (modified/unmodified) CTF

Total for part (b) 3 points

(c) Based on Figure 2, **describe** the effect on the frequency of crossing over when CTF is attached to the chromosome 8 hotspot compared with the effect when IML is attached to the hotspot.

1 point

Accept one of the following:

- CTF attachment results in a decreased/lower frequency of crossing over/recombination, (whereas IML had no effect).
- IML attachment results in an increased/a higher frequency of crossing over/recombination (compared with CTF attachment).

(d) **Predict** the effect on the number of copies of chromosome 8 likely to be present in the resulting daughter cells when CTF is attached to the hotspot.

1 point

Accept one of the following:

- There will be zero/two (copies).
- There will be one less/one extra (copy).

Provide reasoning to **justify** your prediction.

1 point

- Cells (with attached CTF molecules) undergo crossing over/recombination at a lower frequency, so it is more likely that nondisjunction would occur/chromosomes would not separate properly.

Explain how the presence of hotspots (Figure 1) could increase the likelihood that a population will survive in the presence of selective pressures.

1 point

- Hotspots would increase genetic diversity; therefore, it would be more likely that some individuals would survive and reproduce.

Total for part (d) 3 points**Total for question 1 9 points**

Question 5: Analyze Model or Visual Representation of a Biological Concept or Process

4 points

Researchers study mechanisms that enable or prevent speciation.

New genes can evolve from noncoding regions of DNA. It is not until certain regulatory elements are present in the DNA that a noncoding region becomes a new, functional gene that encodes a protein. These regulatory elements include a promoter, a 5' untranslated region (UTR) followed by a start codon, and a 3' UTR following a stop codon (Figure 1).

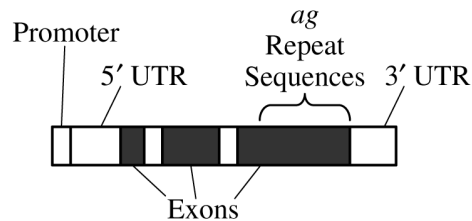


Figure 1. Basic structure of a functional *ag* gene

Researchers studied the evolution of the family of antifreeze-glycoprotein (AG) encoding genes in Gadidae, a family of marine fish known as cods. When present in the fish, these glycoproteins reduce the freezing temperature of the fish. The researchers compared genomic sequences in nine cod species and one non-cod fish species, *B. brosme*. They recorded the presence or absence of the elements of functional *ag* genes as well as *ag*-like sequences that are similar to a functional gene but have undergone mutation and do not contain all the elements required to enable protein production (Figure 2).

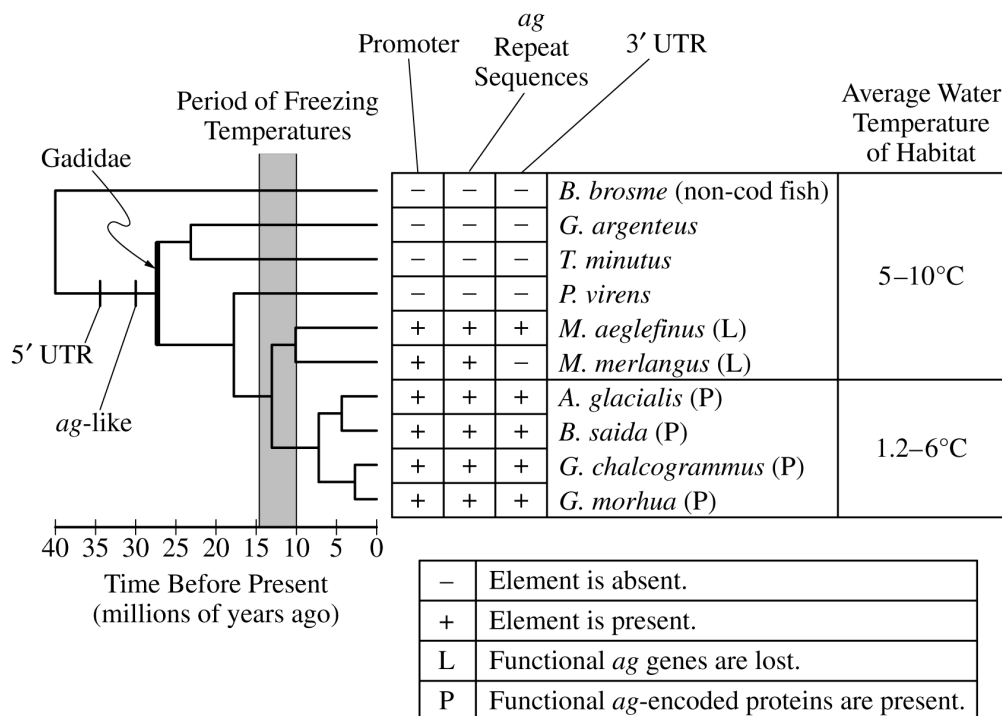
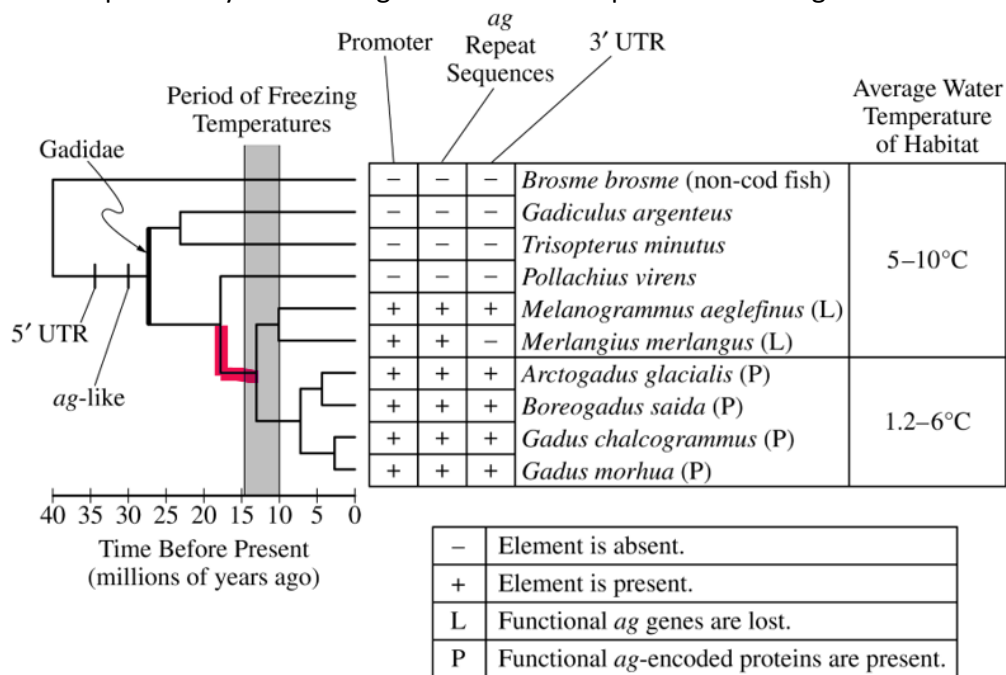


Figure 2. Phylogenetic tree showing the evolution of *ag* genes

- (a) **Describe** a post-zygotic mechanism that prevents gene flow and thus enables speciation. **1 point**
- The offspring do not survive (long enough to reproduce)/cannot (successfully) reproduce.
- (b) Based on the data in Figure 2, **explain** how changes to the genome enabled cods to survive and reproduce after a period of freezing temperatures between 10 and 15 million years ago. **1 point**
- (Over time) the addition of the promoter/ag repeat sequences/3' UTR/regulatory elements led to emergence of new genes/ag genes/functional gene products (that prevent freezing).
- (c) Using the template in the space provided for your response, place an "X" on the phylogenetic tree to **represent** the origin of the functional *ag* gene. **1 point**
- An X is placed anywhere along the colored L-shaped line in the figure.



- (d) Based on Figure 2, **explain** how genetic differences among the species in the Gadidae family determine the habitats in which they can survive. **1 point**
- Species with the functional *ag* gene/antifreeze glycoprotein are able to live in colder water/lower temperatures (than are species without the functional gene).

Total for question 5 4 points

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

Question 4: Conceptual Analysis**4 points**

In 1981 a single immature male *Geospiza conirostris* finch flew more than 100 kilometers from the Galápagos island of Española to the Galápagos island of Daphne Major, where no *G. conirostris* finches were living. The immigrant finch bred with a female *G. fortis*, a species of finch common on Daphne Major. The F_1 finches and later generations interbred only within their lineage. By 2012 scientists counted 23 individuals, including eight breeding pairs, within this hybrid lineage on Daphne Major. The hybrid lineage became known as Big Bird.

Birds with different beak shapes and sizes eat different types of food. The dimensions of the Big Bird beaks relative to the beaks of the major competitor finch species on Daphne Major are shown in Figure 1.

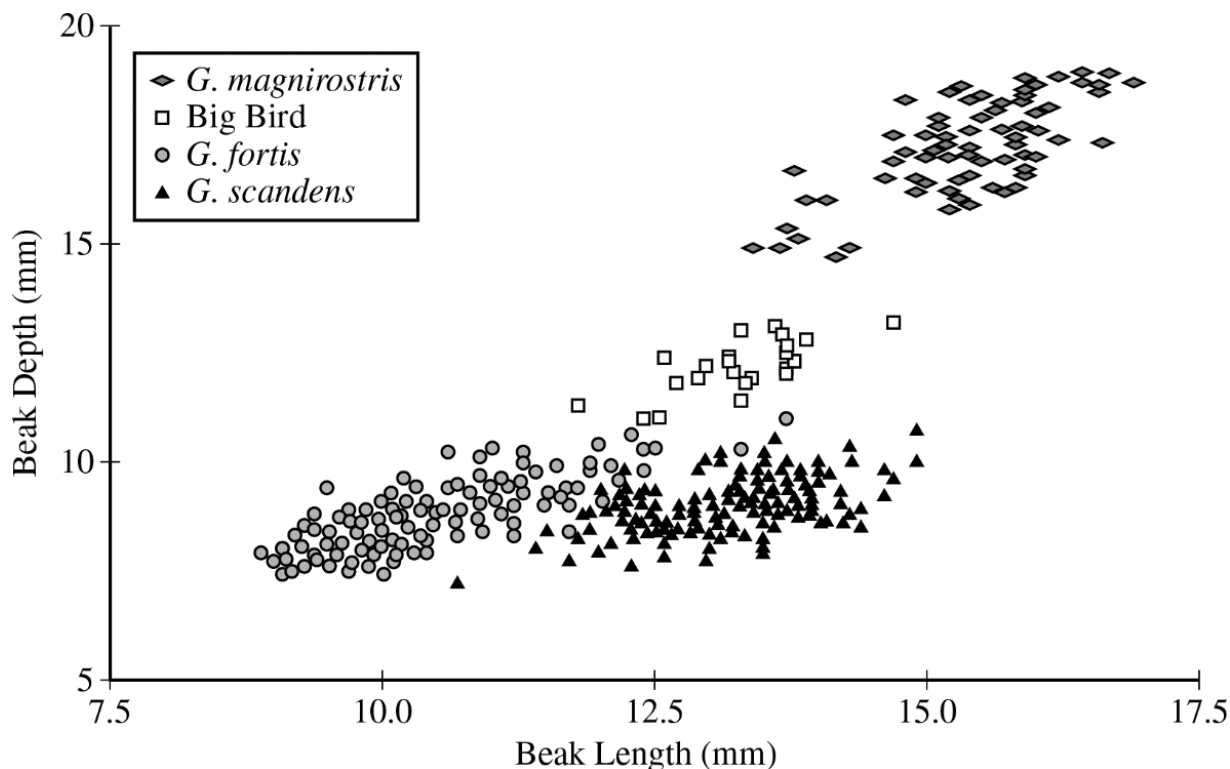


Figure 1. The dimensions of the beaks of the Big Bird lineage and of its major competitor species in 2012 on Daphne Major. Each symbol represents the beak dimensions of a single bird.

- (a) The Big Bird lineage became reproductively isolated from *G. fortis*. **Describe** one prezygotic mechanism that likely contributed to the reproductive isolation of the Big Bird lineage from *G. fortis*. **1 point**

Accept one of the following:

- Beak shape/size or song or behavior or mechanical/chemical differences or time of mating or location on the island or primary food source differs between the Big Bird lineage and *G. fortis*.
- Description of another mechanism that prevents males and females from different populations from encountering each other/recognizing each other as potential mates.

- (b) Based on the data in Figure 1, **explain** why the Big Bird population has been able to survive and reproduce on Daphne Major. **1 point**

- The birds have a beak size/shape that differs from the beaks of the competitor finches on the island. Thus, they probably do not compete with the other finch species for food but instead, eat food that the other finches do not consume.

-
- (c) A virus infects and kills all *G. magnirostris* on Daphne Major but does not affect the other finch species. Assuming food type and availability stay the same, **predict** the most likely change in the beak phenotype of the Big Bird population after six more generations. **1 point**

Accept one of the following predictions:

- Option 1: The (mean) beak size will increase (in the population).
- Option 2: The (average) beak (in the population) will be longer and deeper.
- Option 3: The frequency of large beaks will increase (in the population).
- Option 4: The (mean) beak size will stay the same (in the population).

-
- (d) Provide reasoning to **justify** your prediction in part (c). **1 point**

Accept one of the following:

- Justification for options 1, 2, and 3: There will be directional selection for larger beaks because larger seeds are more accessible.
- Justification for option 4: There is little genetic diversity because all birds are descended from a single pair, and the birds are only six generations from the founder.

Total for question 4 4 points

2019

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Question 1

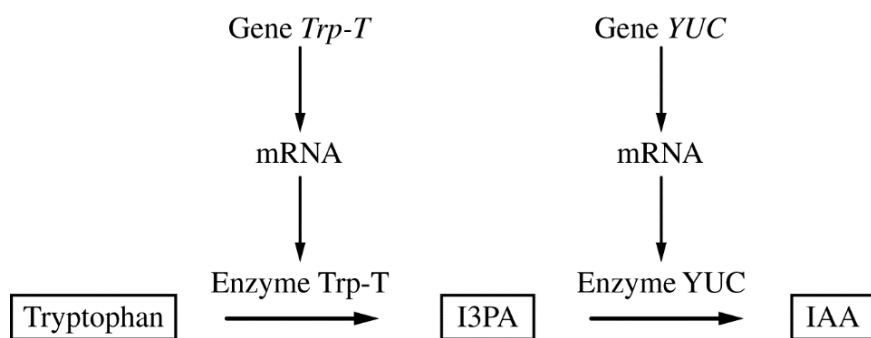


Figure 1. Model of two-step enzymatic plant pathway for synthesis of IAA from tryptophan

Auxins are plant hormones that coordinate several aspects of root growth and development. Indole-3-acetic acid (IAA) is an auxin that is usually synthesized from the amino acid tryptophan (Figure 1). Gene *Trp-T* encodes an enzyme that converts tryptophan to indole-3-pyruvic acid (I3PA), which is then converted to IAA by an enzyme encoded by the gene *YUC*.

- (a) **Circle ONE** arrow that represents transcription on the template pathway. **Identify** the molecule that would be absent if enzyme YUC is nonfunctional.

Circle (1 point)

- Circle around either arrow pointing from a gene (*Trp-T* or *YUC*) to mRNA

Identification (1 point)

- IAA

- (b) **Predict** how the deletion of one base pair in the fourth codon of the coding region of gene *Trp-T* would most likely affect the production of IAA. **Justify** your prediction.

Prediction (1 point)

- Reduction in IAA production OR No production of IAA

Justification (1 point)

- The mutation will result in the translation of an inactive/nonfunctional Trp-T enzyme.
- The mutation will result in no translation of the Trp-T enzyme.
- The mutation will result in no/reduced production of I3PA.

- (c) **Explain** one feedback mechanism by which a cell could prevent production of too much IAA without limiting I3PA production.

Explanation (2 points)

- Negative feedback/feedback inhibition/increasing amounts of IAA inhibits the pathway.
- Production of YUC enzyme is inhibited OR YUC enzyme activity is inhibited.

2019 SCORING GUIDELINES**Question 1 (continued)**

- (d) Rhizobacteria are a group of bacteria that live in nodules on plant roots. Rhizobacteria can produce IAA and convert atmospheric nitrogen into forms that can be used by plants. Plants release carbon-containing molecules into the nodules. Based on this information, **identify** the most likely ecological relationship between plants and rhizobacteria. **Describe** ONE advantage to the bacteria of producing IAA.

Identification (1 point)

- Mutualism

Description (1 point)

- Increases habitat/number of nodules for the rhizobacteria.
- The bacteria receive carbon/carbon-containing molecules (as a result of increased plant growth).

- (e) A researcher removed a plant nodule and identified several “cheater” rhizobacteria that do not produce IAA or fix nitrogen. **Describe** the evolutionary advantage of being a bacterial cheater in a population composed predominantly of noncheater bacteria. Plants can adjust the amount of carbon-containing molecules released into nodules in response to the amount of nitrogen fixed in the nodule. **Predict** the change in the bacterial population that would cause the plant to reduce the amount of carbon-containing molecules provided to the nodule.

Description (1 point)

- Cheaters/bacteria that benefit without producing IAA/fixing nitrogen have more energy for reproduction.

Prediction (1 point)

- Decrease in the nitrogen-fixing/noncheater bacteria
- Decrease in the amount of nitrogen fixed (by bacteria)

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Question 2

A student studying two different aquatic, plant-eating, unicellular protist species (species A and B) designed an experiment to investigate the ecological relationship between the two species (Table 1).

TABLE 1. EXPERIMENTAL TREATMENT GROUPS

Group I.	Species A and B are each grown in separate containers.
Group II.	Species A and B are grown together in the same container.

In treatment group I, the student placed 10 individuals of species A into a container with liquid growth medium and 10 individuals of species B into a separate container with an equal amount of the same liquid growth medium. In treatment group II, the student placed 5 individuals of each species into a single container with the liquid growth medium. The student then maintained the containers under the same environmental conditions and recorded the number of individuals in each population at various time points. The results are shown in Table 2.

TABLE 2. NUMBER OF INDIVIDUALS IN EACH PROTIST POPULATION IN BOTH TREATMENT GROUPS

Time (h)	Group I. Grown Separately		Group II. Grown Together	
	Species A	Species B	Species A	Species B
0	10	10	5	5
10	100	50	45	20
20	400	200	100	50
30	1100	500	250	25
40	1400	650	525	20
50	1500	700	900	10
60	1500	700	1250	0
70	1500	700	1400	0

(a) The growth curves for species B in group I and for species A in group II (shaded columns) have been plotted on the template. Use the template to **complete** an appropriately labeled line graph to illustrate the growth of species A in treatment group I and species B in treatment group II (unshaded columns).

Completion (3 points)

- Correctly plotted lines for remaining two treatments
- Correctly labeled axes including units
- Correctly labeled data lines

2019 SCORING GUIDELINES**Question 2 (continued)**

(b) As shown in the table, the researcher established treatment group II with 5 individuals of each species. **Provide reasoning** for the reduced initial population sizes.

Reasoning (1 point)

- Reduced initial population sizes keep the total number of organisms the same in all containers.
- Reduced initial population sizes serve as a control for population density.

(c) The student claims that species A and B compete for the same food source. **Provide TWO pieces of evidence** from the data that support the student's claim.

Evidence (1 point per row; 2 points max.)

Comparison of Groups	Evidence
I-A to II-A	• Growth rate is faster in I/slower in II
I-A to II-A	• Grows to a higher population density in I/lower population density in II
I-B to II-B	• Growth rate is faster in I/slower in II
I-B to II-B	• Grows to a higher population density in I/lower population density in II/ II dies out/II goes to zero

(d) **Predict** TWO factors that most likely limit the population growth of species A in treatment group I.

Prediction (2 points)

Acceptable factors include:

- Food
- Space
- Metabolic waste
- Dissolved oxygen

(e) Many protists contain an organelle called a contractile vacuole that pumps water out of the cell. The student repeated the experiment using a growth medium with a lower solute concentration. **Predict** how the activity of the contractile vacuole will change under the new experimental conditions. **Justify** your prediction.

Prediction (1 point)

- The contractile vacuole will be more active.

Justification (1 point)

- The environment is hypotonic with respect to the cell.
- The cell is hypertonic with respect to environment.
- Water has entered the cell (which could cause lysis).
- The cell has lower water potential than the environment/the environment has higher water potential than the cell.

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Question 3

The pyruvate dehydrogenase complex (PDC) catalyzes the conversion of pyruvate to acetyl-CoA, a substrate for the Krebs (citric acid) cycle. The rate of pyruvate conversion is greatly reduced in individuals with PDC deficiency, a rare disorder.

(a) **Identify** the cellular location where PDC is most active.

Identification (1 point)

- Mitochondria
- Mitochondrial matrix

(b) **Make a claim** about how PDC deficiency affects the amount of NADH produced by glycolysis AND the amount of NADH produced by the Krebs (citric acid) cycle in a cell. **Provide reasoning** to support your claims based on the position of the PDC-catalyzed reaction in the sequence of the cellular respiration pathway.

(1 point per row; 2 points max.)

	Claim	Reasoning
Glycolysis	No change	• Glycolysis continues; PDC is not needed. • Glycolysis occurs before conversion of pyruvate to acetyl-CoA.
Krebs cycle	Decrease	• The Krebs cycle is greatly reduced/slowed down if there is no/less acetyl-CoA. • The Krebs cycle occurs after conversion of pyruvate to acetyl-CoA.

(c) PDC deficiency is caused by mutations in the *PDHA1* gene, which is located on the X chromosome. A male with PDC deficiency and a homozygous female with no family history of PDC deficiency have a male offspring. **Calculate** the probability that the male offspring will have PDC deficiency.

Calculation (1 point)

- The probability of inheritance is 0.
- The offspring cannot/will not have PDC deficiency.

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Question 4

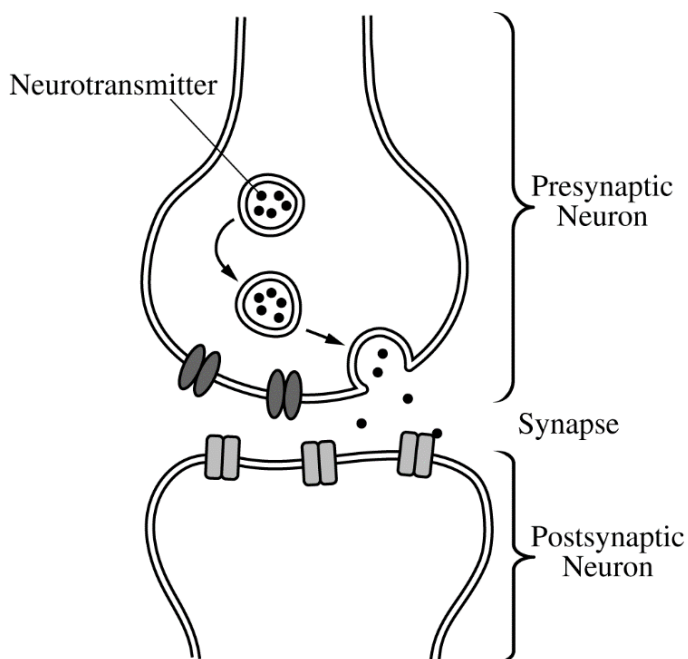


Figure 1. Release of neurotransmitters into the synapse in response to an action potential

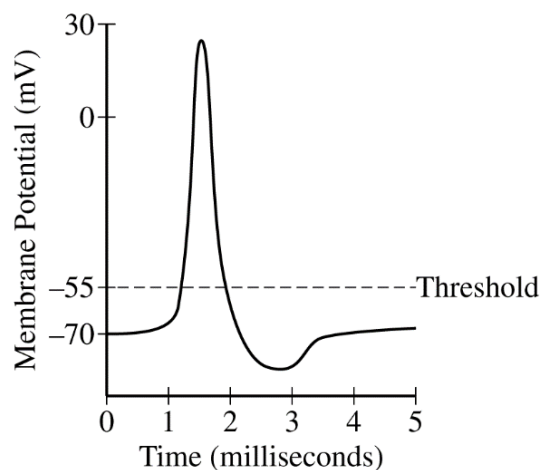


Figure 2. Model of a typical action potential in a neuron

Acetylcholine is a neurotransmitter that can activate an action potential in a postsynaptic neuron (Figures 1 and 2). A researcher is investigating the effect of a particular neurotoxin that causes the amount of acetylcholine released from presynaptic neurons to increase.

(a) **Describe** the immediate effect of the neurotoxin on the number of action potentials in a postsynaptic neuron. **Predict** whether the maximum membrane potential of the postsynaptic neuron will increase, decrease, or stay the same.

Description (1 point)

- It will increase the number of action potentials.

Prediction (1 point)

- It will stay the same.

(b) The researcher proposes two models, A and B, for using acetylcholinesterase (AChE), an enzyme that degrades acetylcholine, to prevent the effect of the neurotoxin. In model A, AChE is added to the synapse. In model B, AChE is added to the cytoplasm of the postsynaptic cell. **Predict** the effectiveness of EACH proposed model. **Provide reasoning** to support your predictions.

(1 point per row; 2 points max.)

	Prediction	Reasoning
Model A	Effective	Acetylcholine is in the synapse.
Model B	Not effective	Acetylcholine is not in the cytoplasm of the postsynaptic cell.

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Question 5

TABLE 1. DIVERGENCE (IN PERCENT) OF MITOCHONDRIAL DNA SEQUENCES AMONG FIVE PRIMATE SPECIES

	Human	Gorilla	Orangutan	Gibbon	Chimpanzee
Human	-	10.3	16.1	18.1	8.8
Gorilla		-	16.7	18.9	10.6
Orangutan			-	18.9	17.2
Gibbon				-	18.9
Chimpanzee					-

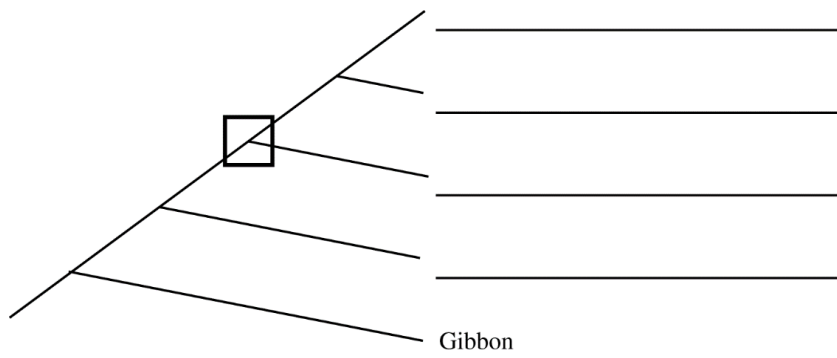
A researcher studying the evolutionary relationship among five primate species obtained data from a sequence of mitochondrial DNA (mtDNA) from a representative individual of each species. The researcher then calculated the percent divergence in the sequences between each pair of primate species (Table 1).

(a) Based on fossil data, the researcher estimates that humans and their most closely related species in the data set diverged approximately seven million years ago. Using these data, **calculate** the rate of mtDNA percent divergence per million years between humans and their most closely related species in the data set. Round your answer to two decimal places.

Calculation (1 point)

- 1.25 OR 1.26

(b) Using the data in the table, **construct** a cladogram on the template provided. **Provide reasoning** for the placement of gibbons as the outgroup on the cladogram.

**Construction (1 point)**

- From top to bottom: Human/Chimpanzee (interchangeable), Gorilla, Orangutan

Reasoning (1 point)

- Gibbon mtDNA is the least similar (to all of the other species)/most different (from all of the other species).
- Gibbon mtDNA is the most divergent (from all of the other species).

2019 SCORING GUIDELINES**Question 5 (continued)**

(c) On the cladogram, **draw** a circle around all of the species that are descended from the species indicated by the node within the square.

Circle (1 point)

- Circle species 1, 2, and 3, as numbered from the top.

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Question 6

	MEDIUM	STRAINS		
		Wild Type	Mutant 1	Mutant 2
Treatment I	All amino acids present	+	+	+
Treatment II	No amino acids present	+	–	–
Treatment III	All amino acids present EXCEPT methionine	+	–	+
Treatment IV	All amino acids present EXCEPT leucine	+	+	–

Table 1. The data show the growth of haploid *Saccharomyces cerevisiae* yeast strains on media that differ in amino acid content. A plus sign (+) indicates that the yeast strains grow, and a minus sign (–) indicates that the strains do not grow.

The yeast *Saccharomyces cerevisiae* is a single-celled organism. Amino acid synthesis in yeast cells occurs through metabolic pathways, and enzymes in the synthesis pathways are encoded by different genes. The synthesis of a particular amino acid can be prevented by mutation of a gene encoding an enzyme in the required pathway.

A researcher conducted an experiment to determine the ability of yeast to grow on media that differ in amino acid content. Yeast can grow as both haploid and diploid cells. The researcher tested two different haploid yeast strains (Mutant 1 and Mutant 2), each of which has a single recessive mutation, and a haploid wild-type strain. The resulting data are shown in Table 1.

(a) **Identify** the role of treatment I in the experiment.

Identification (1 point)

- (Positive) control (for yeast growth).
- To test the viability of all yeast strains.
- Treatment I allows the researcher to be confident that changes in experimental outcome are due to differences in treatments.

(b) **Provide reasoning** to explain how Mutant 1 can grow on treatment I medium but cannot grow on treatment III medium.

Reasoning (1 point)

- Mutant 1 can use methionine when it is present in the medium, but Mutant 1 cannot synthesize methionine.

(c) Yeast mate by fusing two haploid cells to make a diploid cell. In a second experiment, the researcher mates the Mutant 1 and Mutant 2 haploid strains to produce diploid cells. Using the table provided, **predict** whether the diploid cells will grow on each of the four media. Use a plus sign (+) to indicate growth and a minus sign (–) to indicate no growth.

Prediction (1 Point)

- There will be growth (+) in all four cells of the fourth column.

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Question 7

A researcher is studying patterns of gene expression in mice. The researcher collected samples from six different tissues in a healthy mouse and measured the amount of mRNA from six genes. The data are shown in Figure 1.

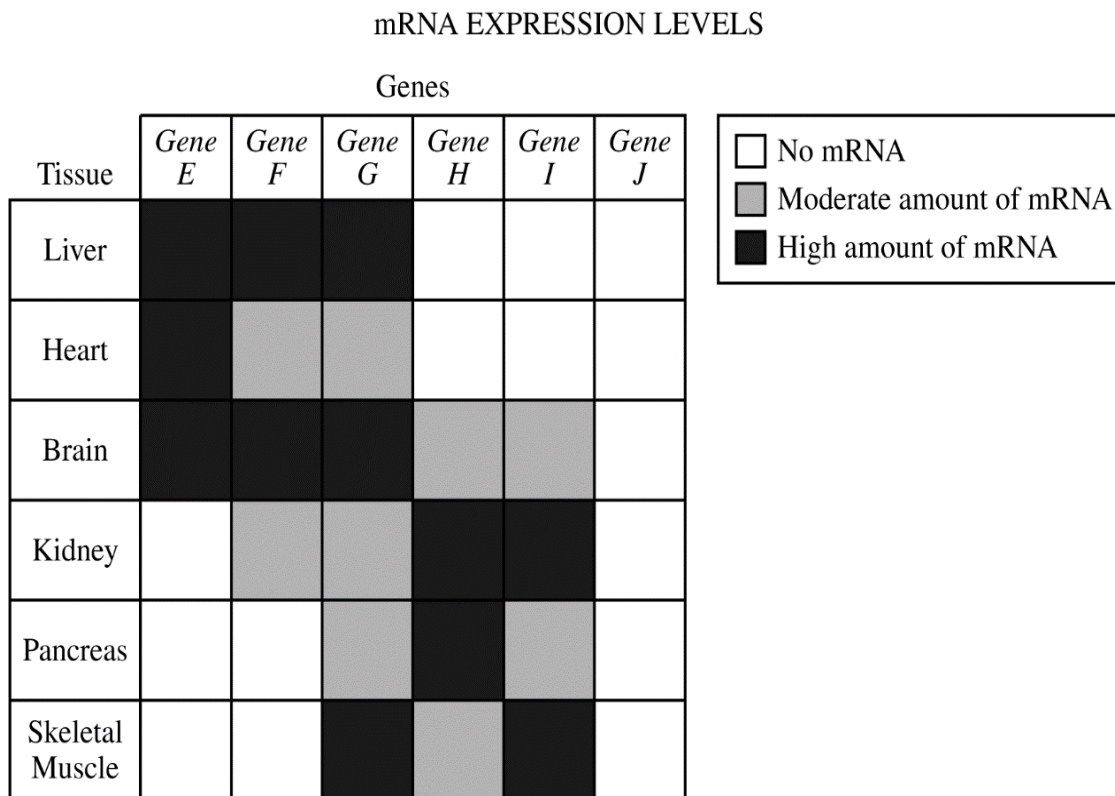


Figure 1. mRNA expression levels of six genes

(a) Based on the data provided, **identify** the gene that is most likely to encode a protein that is an essential component of glycolysis. **Provide reasoning** to support your identification.

Identification (1 point)

- *Gene G*

Reasoning (1 point)

- (*Gene G*) is the only gene expressed in all (six) tissues, AND glycolysis occurs in all (six) tissues.
- (*Gene G*) mRNA is the only mRNA present in all (six) tissues, AND glycolysis occurs in all (six) tissues.

(b) The researcher observed that tissues with a high level of *gene H* mRNA did not always have *gene H* protein. **Provide reasoning** to explain how tissues with high *gene H* mRNA levels can have no *gene H* protein.

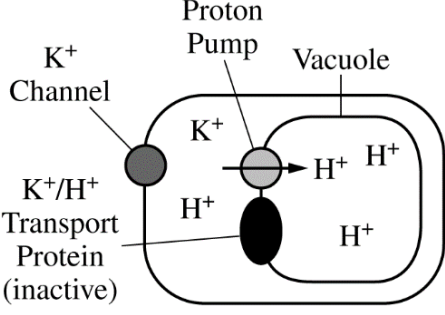
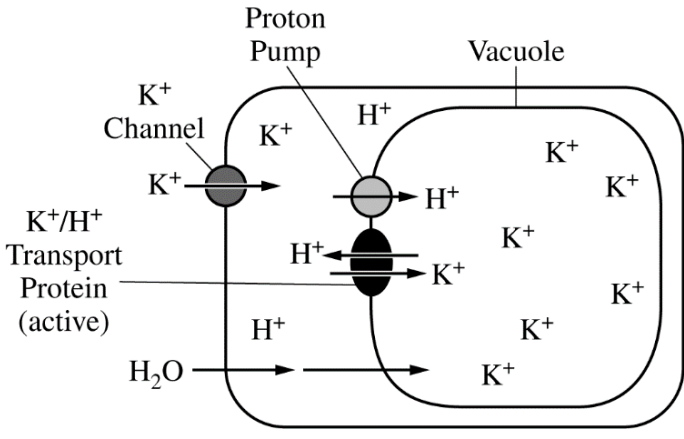
Reasoning (1 point)

- The mRNA is not exported from the nucleus.
- *Gene H* mRNA is not translated/RNA interference prevent(s) translation.
- Post-transcriptional modifications.

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Question 8

TABLE 1. CHANGES IN MORNING GLORY PETAL CELLS DURING FLOWER OPENING

	BUD	OPEN FLOWER
		
Vacuole pH	6.6	7.7
Flower Color	Red	Blue
Cell Volume	Small	Large

The petal color of the Mexican morning glory (*Ipomoea tricolor*) changes from red to blue, and the petal cells swell during flower opening. The pigment heavenly blue anthocyanin is found in the vacuole of petal cells. Petal color is determined by the pH of the vacuole. A model of a morning glory petal cell before and after flower opening is shown in Table 1.

(a) **Identify** the cellular component in the model that is responsible for the increase in the pH of the vacuole during flower opening AND **describe** the component's role in changing the pH of the vacuole.

Identification (1 point)

- (K^+ / H^+) transport protein

Description (1 point)

- It moves H^+ out of the vacuole.

(b) A researcher claims that the activation of the K^+ / H^+ transport protein causes the vacuole to swell with water. **Provide reasoning** to support the researcher's claim.

Reasoning (1 point)

- The concentration of solute (K^+) is increasing inside the vacuole.
- The solute (K^+) is moving into the vacuole, making it hypertonic/hyperosmotic/lowering water potential.

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2018 SCORING GUIDELINES

Question 1

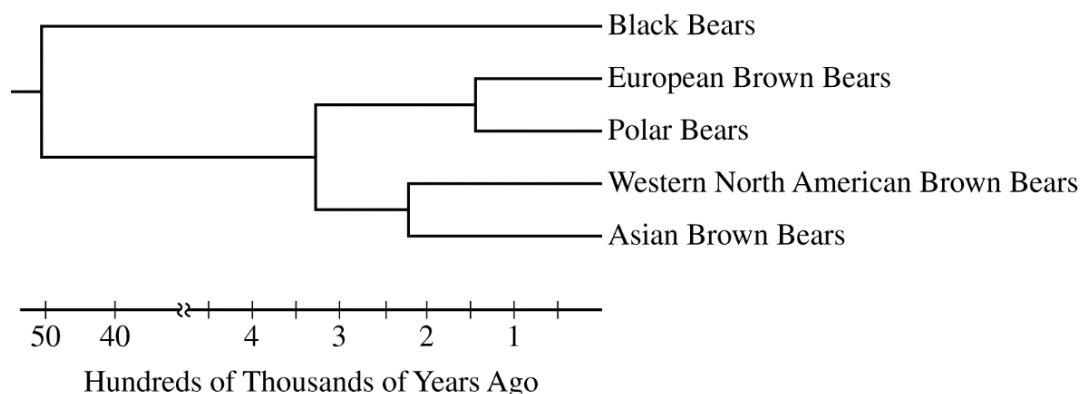


Figure 1. Phylogenetic tree representing the evolutionary relatedness among bear populations based on mitochondrial DNA sequence comparisons

Polar bears are highly adapted for life in cold climates around the North Pole. Brown bears, black bears, and pandas are found in warmer environments. Researchers collected complete mitochondrial DNA sequences from several populations of bears and constructed a phylogenetic tree to represent their evolutionary relatedness (Figure 1).

A researcher studying adaptation in bears sequenced the nuclear gene encoding a lysosomal trafficking protein (LYST) in polar bears, brown bears, black bears, and panda bears. There are seven inferred amino acid substitutions that are found only in polar bears. Mutations that cause similar substitutions in the human LYST protein are associated with Chediak-Higashi syndrome, an autosomal recessive condition in which pigment is absent from the hair and eyes. The researcher used the inferred amino acid sequences to build the distance matrix shown in Table 1.

TABLE 1. AMINO ACID DIFFERENCES IN THE LYST PROTEIN AMONG BEAR SPECIES

	Panda	Black	Brown	Polar
Panda	–			
Black	33	–		
Brown	34	1	–	
Polar	40	7	8	–

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Question 1 (continued)

- (a) Use the phylogenetic tree in Figure 1 to **estimate** the age in hundreds of thousands of years of the most recent common ancestor of all brown bears. **Identify** the population of brown bears to which polar bears are most closely related based on the mitochondrial DNA sequence comparison. **Identify** two populations whose positions could be switched without affecting the relationships illustrated in the phylogenetic tree.

Estimate (1 point)

- First two digits of the answer must be between 30 and 35.

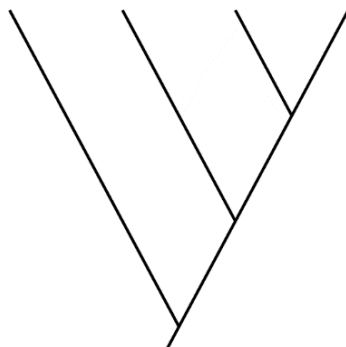
Identification (1 point)

- European

Identification (1 point)

- European/Polar OR Asian/Western (North American)

- (b) **Construct** a cladogram on the template to represent a model of the evolutionary relatedness among the bear species based on the differences in LYST protein sequences (Table 1). **Circle** the position on the cladogram that represents the out-group.

**Construction (1 point)**

- Correctly illustrated evolutionary relationship among the four species

Circling (1 point)

- Correctly circled out-group based on orientation of cladogram

- (c) A student claims that mitochondrial DNA sequence comparisons provide a more accurate phylogeny of bear species than do LYST protein sequence comparisons. **Provide ONE piece of reasoning** to support the student's claim.

Reasoning (1 point)

- Genes show more variability (in nucleotide sequence) than proteins do (in amino acid sequences).
- mtDNA genome contains multiple genes vs. one *lyst* gene.
- The phenotype associated with the *lyst* gene is under strong selection.

2018 SCORING GUIDELINES**Question 1 (continued)**

- (d) A researcher genetically engineers a mouse strain by deleting the mouse *lyst* gene and replacing it with the polar bear *lyst* gene. **Predict** the most likely difference in phenotype of the transgenic mouse strain compared to the wild-type mouse strain. **Justify** your prediction.

Prediction (1 point)

- Mouse fur and/or eyes will not have pigment/will have reduced pigment.
- Mouse (fur) will be white/lighter.

Justification (1 point)

- Polar bear *lyst* gene/LYST protein is associated with a lack of pigment/white hair.
- Mutated human *lyst* gene/ LYST protein is associated with a lack of pigment in hair and eyes.

- (e) **Describe** how the mutation in the *lyst* gene became common in the polar bear population. If the *lyst* gene were the only determinant of fur color, **predict** the percent of white offspring produced by a mating between a polar bear and a brown bear.

Description (1 point)

- Natural selection for the white fur phenotype

Prediction (1 point)

- 0%

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Question 2

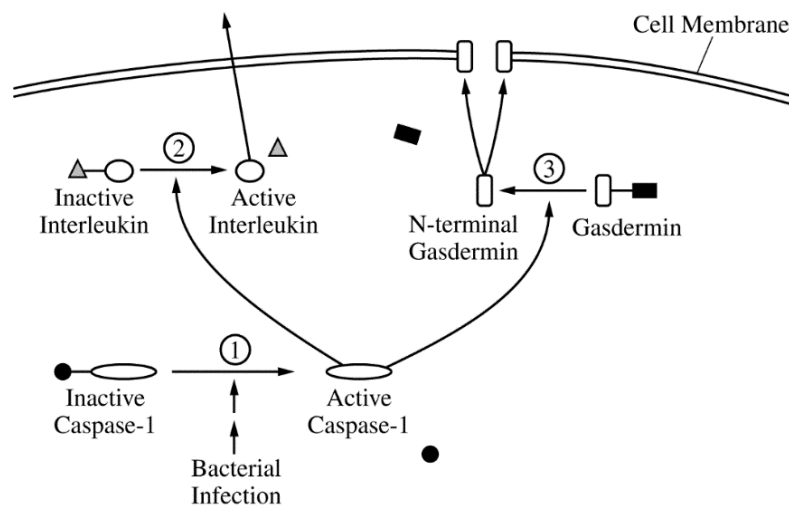


Figure 1. Cellular response to infection by pathogenic bacteria

Some pathogenic bacteria enter cells, replicate, and spread to other cells, causing illness in the host organism. Host cells respond to these infections in a number of ways, one of which involves activating particular enzymatic pathways (Figure 1). Cells normally produce a steady supply of inactive caspase-1 protein. In response to intracellular pathogens, the inactive caspase-1 is cleaved and forms an active caspase-1 (step 1). Active caspase-1 can cleave two other proteins. When caspase-1 cleaves an inactive interleukin (step 2), the active portion of the interleukin is released from the cell. An interleukin is a signaling molecule that can activate the immune response. When caspase-1 cleaves gasdermin (step 3), the N-terminal portions of several gasdermin proteins associate in the cell membrane to form large, nonspecific pores.

Researchers created the model in Figure 1 using data from cell fractionation studies. In the experiments, various parts of the cell were separated into fractions by mechanical and chemical methods. Specific proteins known to be located in different parts of the cell were used as markers to determine the location of other proteins. The table below shows the presence of known proteins in specific cellular fractions.

CELL FRACTIONS CONTAINING DIFFERENT CELLULAR PROTEINS

	Aconitase (Krebs cycle protein)	DNA polymerase	GAPDH (glycolytic protein)	Sodium- potassium pump	NF- κ B (Immune response protein)
Whole cell sample	+	+	+	+	+
Fraction 1	+				
Fraction 2		+			+
Fraction 3			+		+
Fraction 4				+	
+ = presence of protein					

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Question 2 (continued)

(a) **Describe** the effect of inhibiting step 3 on the formation of pores AND on the release of interleukin from the cell.

Description (2 points)

- Pores will not form.
- Interleukin release will not be affected/interleukin release continues.

(b) **Make a claim** about how cleaving inactive caspase-1 results in activation of caspase-1. A student claims that preinfection production of inactive precursors shortens the response time of a cell to a bacterial infection. **Provide ONE reason** to support the student's claim.

Claim (1 point)

- Removes inhibitor/repressor/inhibitory domain of protein
- Changes the shape/protein structure

Reasoning (1 point)

- Cleaving a precursor/protein/molecule is faster than making one upon infection.
- Cells do not have to wait for transcription and translation/protein synthesis.

(c) A student claims that the NF- κ B protein is located in the cytoplasm until the protein is needed for transcription. **Justify** the student's claim with evidence. **Identify TWO** fractions where N-terminal gasdermin would be found in cells infected with pathogenic bacteria.

Justification (1 point)

- NF- κ B and glycolytic enzymes/GAPDH are found together (in the cytoplasm).

Identification (2 points)

- Fraction 3
- Fraction 4

(d) **Describe** the most likely effect of gasdermin pore formation on water balance in the cell in a hypotonic environment.

Description (1 point)

- Water enters the cell.

(e) **Explain** how gasdermin pore formation AND interleukin release contribute to an organism's defense against a bacterial pathogen.

Explanation (2 points)

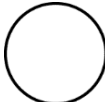
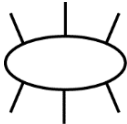
- Cell lysis destroys infected cells OR cell lysis prevents bacteria from replicating.
- Interleukin signaling will stimulate immune cells/components of the immune system (to destroy the infected cells or bacteria).

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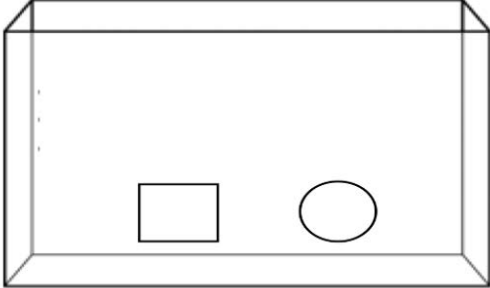
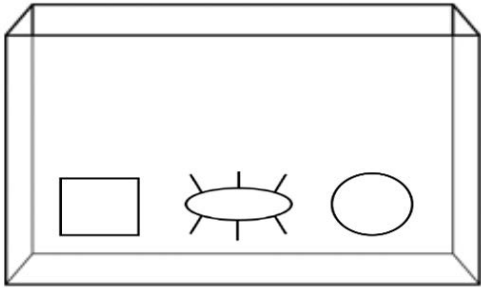
Question 3

Seagrasses are aquatic plants that reproduce sexually. Male seagrass flowers produce sticky pollen that is carried by circulating water to female flowers, resulting in fertilization. A researcher claims that mobile aquatic invertebrates can also transfer pollen from male to female flowers in the absence of circulating water. To investigate this claim, the researcher set up aquariums to model the possible interactions between the invertebrates and seagrasses.

- (a) Use the symbols below and the template aquariums to demonstrate the experimental design for testing the researcher's claim that mobile aquatic invertebrates can pollinate seagrass in the absence of circulating water. **Draw** the appropriate symbols in the negative control aquarium AND the experimental aquarium. Do not use any symbol more than once in the same aquarium.

Male Flower	Female Flower	Invertebrates
		

Drawing (2 points)

Negative Control Aquarium (1 point)	Experimental Aquarium (1 point)
	

- (b) **Identify** the dependent variable in the experiment. **Predict** the experimental results that would support the researcher's claim that mobile aquatic invertebrates can also transfer pollen from male to female flowers in the absence of circulating water.

Identification (1 point maximum)	Prediction (1 point maximum)
Number/presence of pollen grains on female flowers OR pollination	More pollen grains transferred/pollination seen in experimental aquarium
Number/presence of fertilized plants/flowers OR fertilization	More fertilized plants/flowers/fertilization seen in experimental aquarium
Number/presence of seed/fruit/offspring produced OR reproduction	More seeds/fruits/offspring produced/reproduction in experimental aquarium

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Question 4

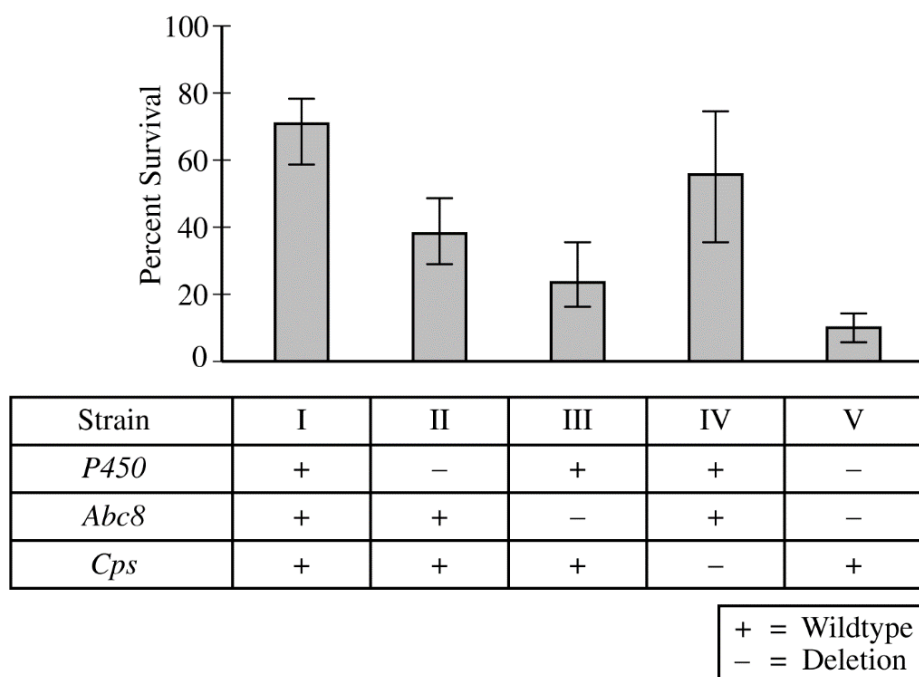


Figure 1. Percent survival of five strains of bedbugs treated with beta-cyfluthrin. A (+) indicates the gene is present; a (-) indicates the gene is deleted. Error bars represent the 95% confidence interval.

The common bedbug (*Cimex lectularius*) is a species of insect that is becoming increasingly resistant to insecticides. Bedbugs possess several genes suspected of contributing to the resistance, including *P450*, *Abc8*, and *Cps*. To investigate the role of these genes in insecticide resistance, researchers deleted one or more of these genes in different strains of bedbugs, as indicated in Figure 1, and treated the strains with the insecticide beta-cyfluthrin. Each strain was genetically identical except for the deleted gene(s) and was equally fit in the absence of beta-cyfluthrin. The percent survival of each strain following beta-cyfluthrin treatment is shown in Figure 1.

- (a) **Identify** the control strain in the experiment. Use the means and confidence intervals in Figure 1 to **justify** the claim that *Abc8* is effective at providing resistance to beta-cyfluthrin.

Identification (1 point)

- Strain I

Justification (1 point)

- Error bars/CIs from strain I/control/WT do not overlap with strain III/*Abc8* deleted strain.
- Mean % survival of strain III/*Abc8* deletion falls outside the 95% confidence interval of strain I/control/WT.
- Strain III/*Abc8* deletion shows a statistically significant difference from strain I/control.

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Question 4 (continued)

- (b) *P450* encodes an enzyme that detoxifies insecticides. *Abc8* encodes a transporter protein that pumps insecticides out of cells. *Cps* encodes an external structural protein located in the exoskeleton that greatly reduces the absorption of insecticides. Based on this information and the data in Figure 1, **explain** how a deletion of both *P450* and *Abc8* results in lower survival in bedbugs compared with a deletion of *Cps* only.

Explanation (1 point per row; 2 points maximum)

Strain	<i>P450</i> and <i>Abc8</i>	<i>Cps</i> only	Explanation
V	Deleted	Present	Bedbugs can neither detoxify nor pump out insecticide, which results in a lower chance of bedbug survival.
IV	Present	Deleted	Bedbugs can detoxify and pump out insecticide, which results in a higher chance of bedbug survival.

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Question 5

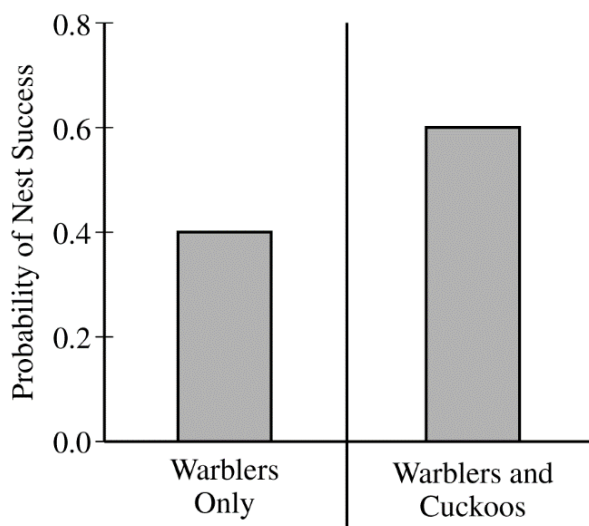


Figure 1. Probability of nest success in an environment with predators

Some birds, including great spotted cuckoos, lay their eggs in the nests of other birds, such as reed warblers. The warbler parents raise the unrelated chicks and provide them with food that would otherwise be given to their biological offspring. A researcher conducted an investigation to determine the type of relationship between warblers and cuckoos in an environment without predators. The researcher found that nests containing only warblers were more likely to be successful than nests containing warblers and cuckoos (data not shown). A successful nest is defined as a nest where at least one chick becomes an adult warbler.

In some geographic areas, several species of nest predators are present. Researchers have found that cuckoo chicks, while in the nest, produce a smelly substance that deters nest predators. The substance does not remain in the nest if cuckoo chicks are removed. Figure 1 shows the probability that nests containing only warblers or containing both warblers and cuckoos will be successful in an environment with predators. In a follow-up experiment, the researchers added cuckoos to a nest that contained only warblers (group 1) and removed cuckoos from a nest containing warblers and cuckoos (group 2).

- (a) **Describe** the symbiotic relationship that exists between the cuckoo and warbler in an environment without predators.

Description (1 point)

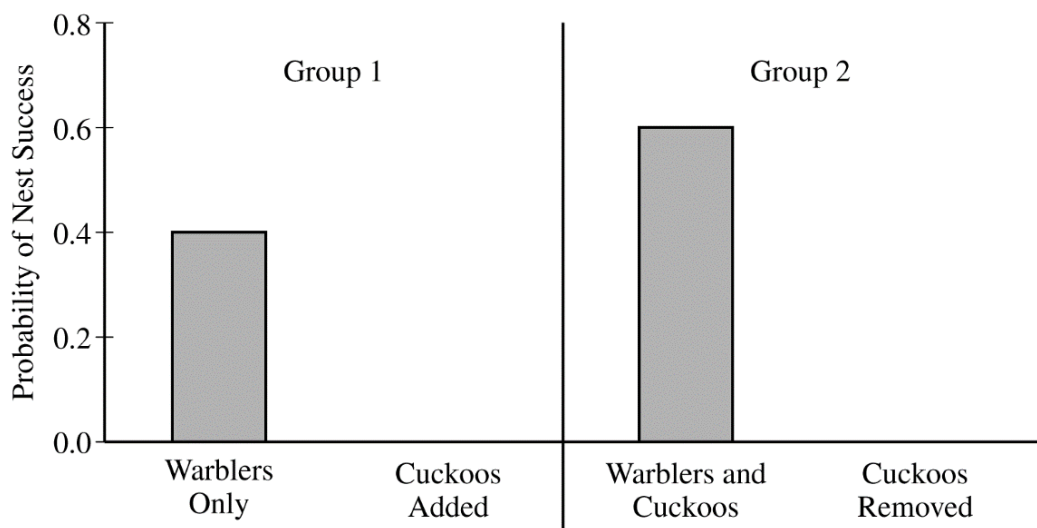
- Cuckoos are parasites (of the warbler).
- The cuckoo benefits from the relationship, and the warbler is harmed by the relationship.

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Question 5 (continued)

(b) On the template provided, **draw** bars in the appropriate locations to predict the relative probability of success for the nest in the presence of predators where:

- the cuckoos were added to the nest containing only warblers (group 1)
- the cuckoos were removed from the nest containing warblers and cuckoos (group 2)



Graph (2 points)

- Cuckoo added (group 1): Bar must be **HIGHER** than the “Warblers Only” bar.
- Cuckoo removed (group 2): Bar must be **LOWER** than the “Warblers and Cuckoos” bar.

(c) **Identify** the symbiotic relationship that exists between the cuckoo and the warbler in the presence of predators.

Identification (1 point)

- Mutualism
- Both organisms benefit

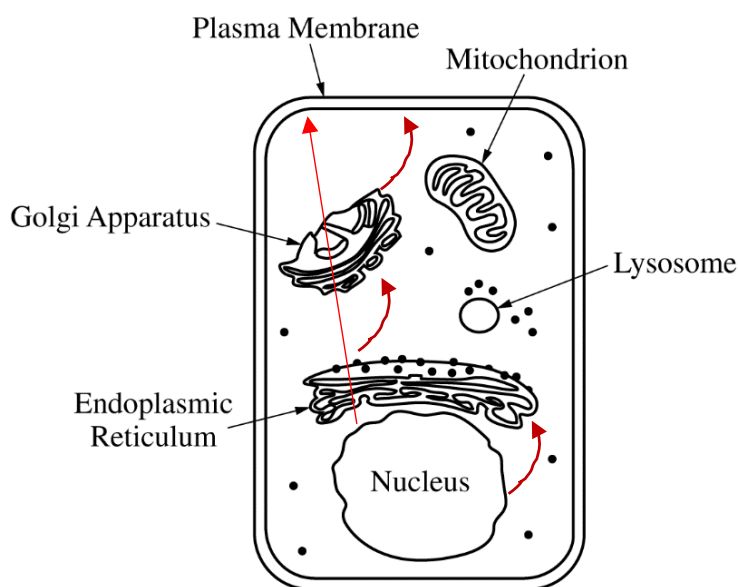
2018 SCORING GUIDELINES

Question 6

Cystic fibrosis is a genetic condition that is associated with defects in the CFTR protein. The CFTR protein is a gated ion channel that requires ATP binding in order to allow chloride ions (Cl^-) to diffuse across the membrane.

- (a) In the provided model of a cell, **draw** arrows to describe the pathway for production of a normal CFTR protein from gene expression to final cellular location.

Drawing (1 point)



The response must follow this pathway: nucleus/nuclear envelope → endoplasmic reticulum → Golgi apparatus → plasma membrane.

The response may be in the form of a continuous arrow or multiple discontinuous arrows.

- (b) **Identify** the most likely cellular location of the ribosomes that synthesize CFTR protein.

Identification (1 point)

- (Rough) Endoplasmic Reticulum/ER

- (c) **Identify** the most likely cellular location of a mutant CFTR protein that has an amino acid substitution in the ATP-binding site.

Identification (1 point)

- In the (cellular/plasma) membrane

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Question 7

In the tongue sole fish (*Cynoglossus semilaevis*), sex is determined by a combination of genetics and environmental temperature. Genetically male fish have two Z chromosomes (ZZ), and genetically female fish have one Z chromosome and one W chromosome (ZW). When fish are raised at 22°C, ZZ fish develop into phenotypic males and ZW fish develop into phenotypic females. However, when fish are raised at 28°C, the Z chromosome is modified (denoted as Z*). Z*W individuals develop as phenotypic males that are fertile and can pass on the Z* chromosome to their offspring even when the offspring are raised at 22°C. A cross between a ZW female and a Z*Z male is shown in the Punnett square below.

	Z	W
Z*	Z* Z	Z* W
Z	Z Z	Z W

- (a) **Predict** the percent of phenotypic males among the F₁ offspring of the cross shown in the Punnett square if the offspring are raised at 22°C.

Prediction (1 point)

75%

- (b) At least one Z or Z* chromosome is necessary for survival of the fish. A researcher crossed two fish and observed a 2:1 ratio of males to females among the offspring. Based on the information, **identify** the genotype of the male parent in the cross. **Describe** ONE fitness cost to the female of mating with this particular male.

Identification (1 point)

Z* W

Description (1 point)

- Fewer offspring will develop/survive.
- 1/4 of the offspring are predicted to die.
- Some of her offspring will have the Z* chromosome/all of her male offspring will have a Z* chromosome.

2018 SCORING GUIDELINES

Question 8

Acetylcholine receptor (AChR) proteins are found at the synapse between neurons and skeletal muscle cells. Acetylcholine released from neurons binds to a specific site on the receptor proteins, which causes an ion channel in the receptors to open and allow sodium ions (Na^+) to enter muscle cells. The resulting depolarization of muscle cells initiates muscle contractions. Another molecule, nicotine, can also bind to certain types of AChR proteins and activate the receptors.

A researcher is investigating two different types of AChR proteins: type 1 and type 2. To determine which stimuli activate the receptors, the researcher exposes muscle cells expressing the different types of receptor proteins to stimuli and observes the results indicated in Table 1.

TABLE 1. RESPONSE OF AChR PROTEINS TO DIFFERENT STIMULI

AChR Protein Type	Acetylcholine	Nicotine
Type 1	+	+
Type 2	+	–

+ indicates activation
– indicates no activation

(a) **Describe** the difference in the structure AND function between AChR type 1 and AChR type 2.

Description (2 points)

Points may be earned from only one row.

Structure (1 point maximum)	Function (1 point maximum)
Binding sites differ in shape/specificity/number	- Differential binding of molecules to type 1 and type 2 receptors - Activated by one (ACh) molecule or both (ACh and nicotine) molecules - No difference in response (both open channels OR both result in depolarization OR both cause muscle contraction)
Differential binding of molecules to type 1 and type 2 receptors	- Activated by one (ACh) or both (ACh and nicotine) molecules - No difference in response (both open channels OR both result in depolarization OR both cause muscle contraction)
Receptors activated by one (ACh) or both (ACh and nicotine) molecules	No difference in response (both open channels OR both result in depolarization OR both cause muscle contraction)

(b) Acetylcholinesterase is an enzyme that breaks down acetylcholine in the synapse. **Describe** the effect of inhibiting acetylcholinesterase on the muscle cells with AChR type 2.

2018 SCORING GUIDELINES**Question 8 (continued)****Description (1 point)**

- Continued activation
- Repeated opening of sodium channels OR repeated depolarization OR muscle spasms

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2016 SCORING GUIDELINES

Question 1

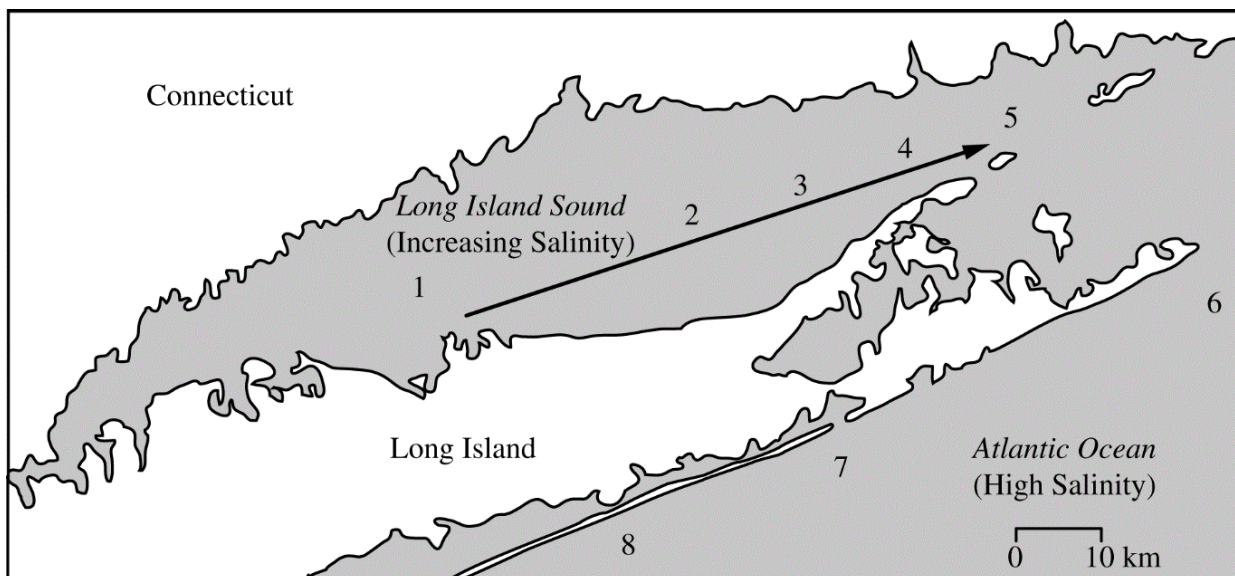


Figure 1. Sampling sites of marine mussels at various locations (1-8) in Long Island Sound and the Atlantic Ocean

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 $\longrightarrow$ 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

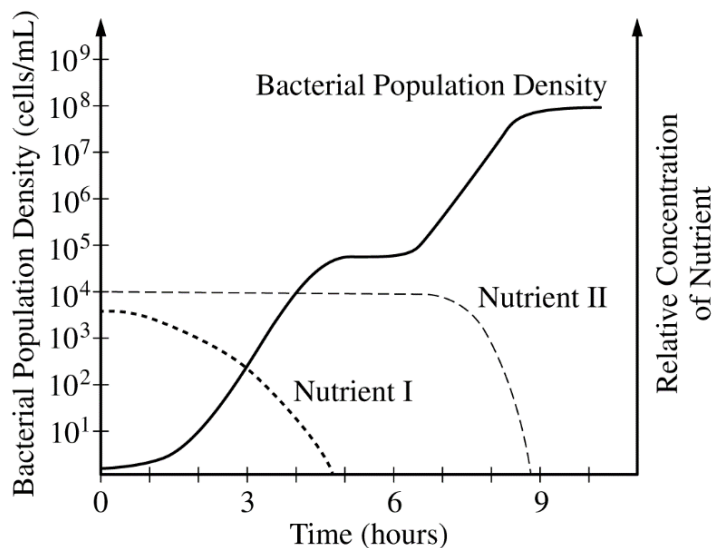


Figure 1. Bacterial population growth in the presence of two nutrients (nutrient I and nutrient II)

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

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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

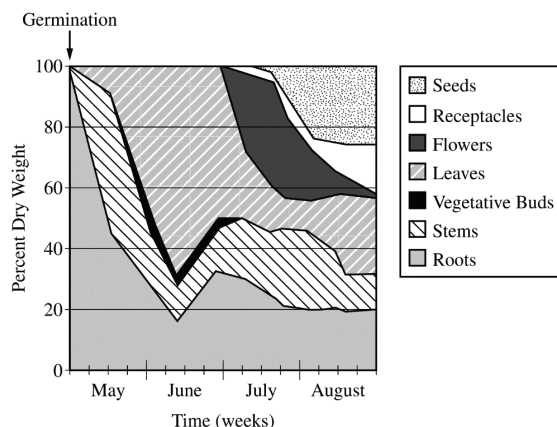


Figure 1. Percent dry weight of different plant structures during the growing season for an annual plant

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

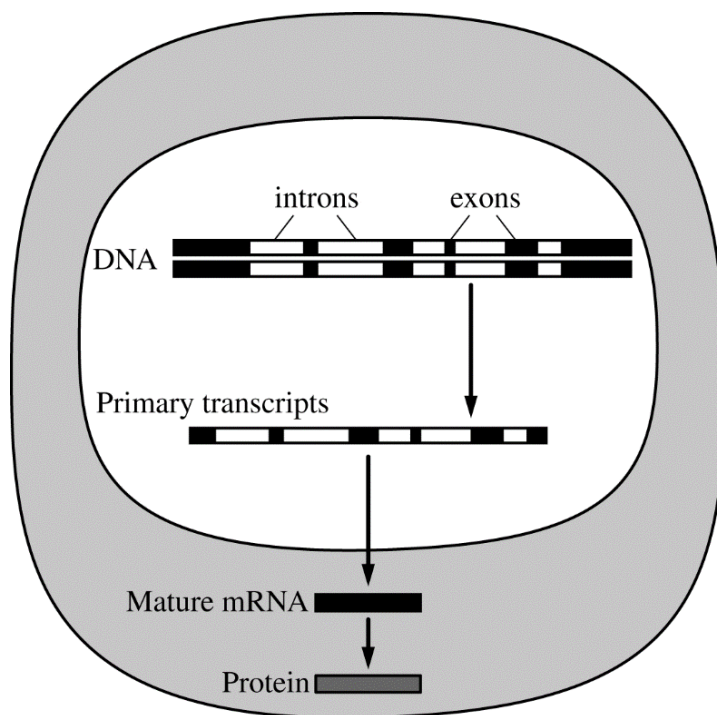
- (c) Compared with perennials (plants that live more than two years), annual plants often allocate a much greater percentage of their total energy to growth of their reproductive parts in any given year. **Propose** ONE evolutionary advantage of the energy allocation strategy in annual plants compared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

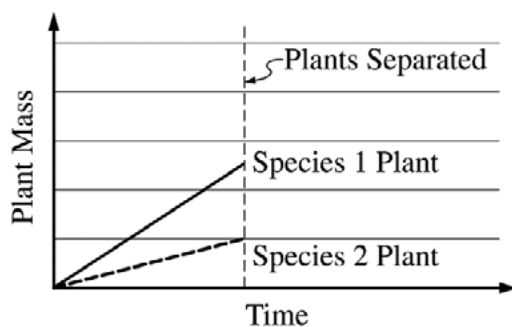
- 15 kb
- Longer than the mature mRNA in the eukaryote

Justification (1 point)

- mRNA processing typically does not occur in prokaryotes

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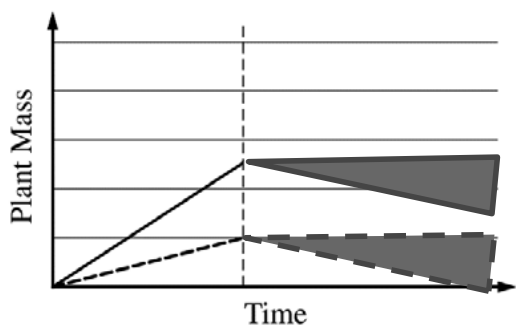
Question 5



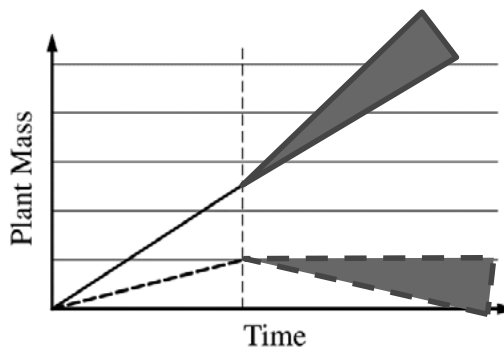
The graph above shows the mass of plants from two different species over time. The plants grew while attached to each other. The plants were separated at the time indicated by the vertical line in the graph.

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

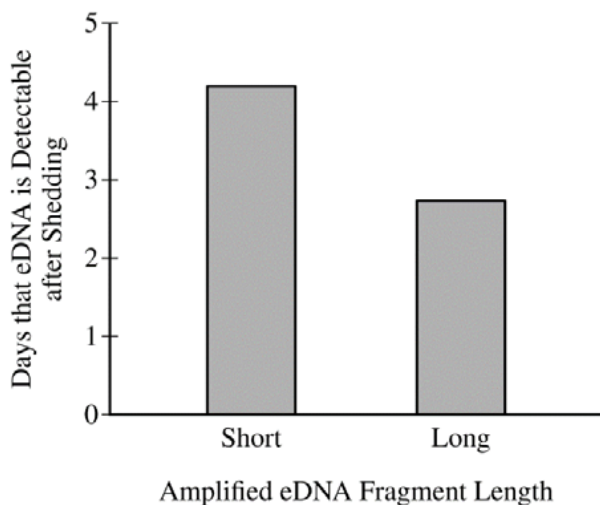


Figure 1. Detectability of eDNA fragments of varying lengths

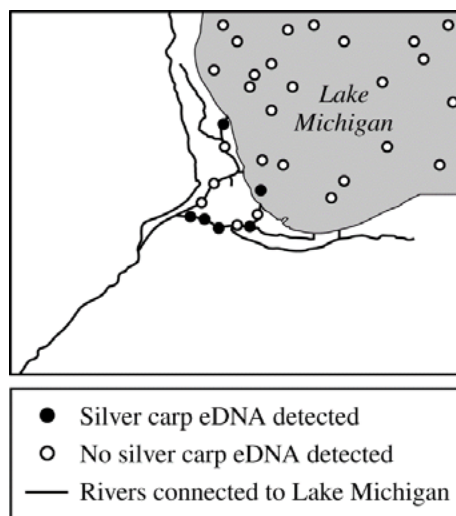


Figure 2. Map of the waterways that connect a nearby river system to Lake Michigan

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.

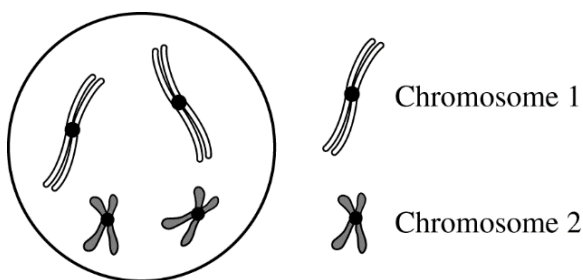
Provide reasoning other than human error to support the researchers' claim. **(1 point)**

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

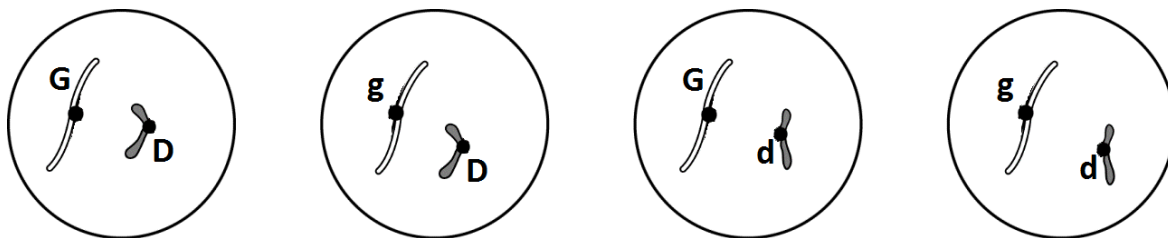


In a certain species of plant, the diploid number of chromosomes is 4 ($2n = 4$). Flower color is controlled by a single gene in which the green allele (G) is dominant to the purple allele (g). Plant height is controlled by a different gene in which the dwarf allele (D) is dominant to the tall allele (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

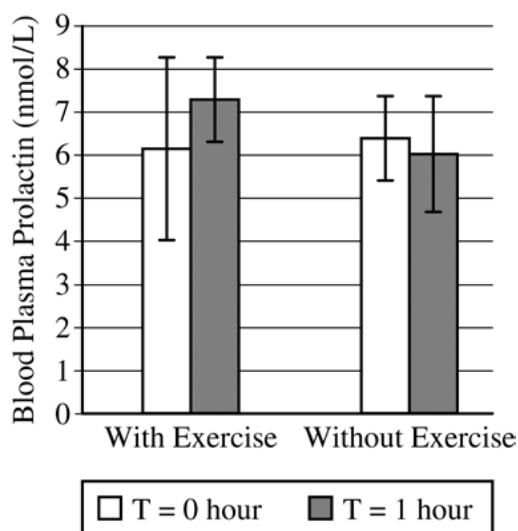


Figure 1. Effect of exercise on blood prolactin levels in adult males. The data represent the mean $\pm 2SE_{\bar{x}}$.

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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2015 SCORING GUIDELINES

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.

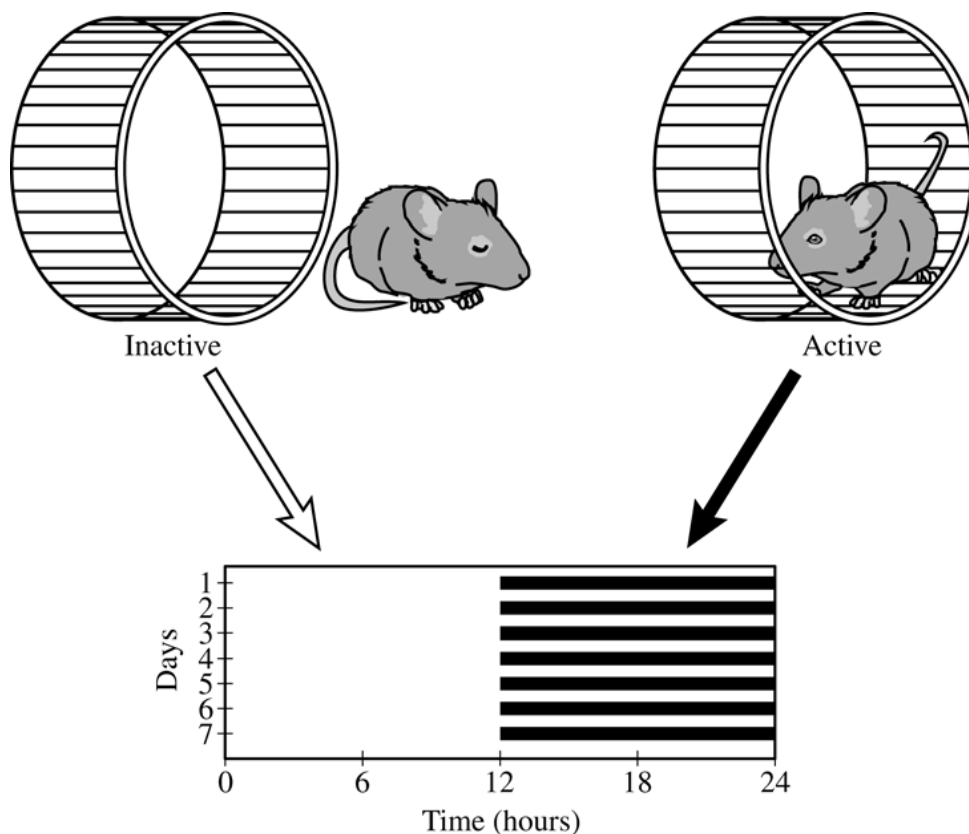


Figure 1. Strategy for recording mouse activity data. When a mouse is active on the running wheel, the activity is recorded as a dark horizontal line on an actogram. When the mouse is inactive, no dark line is recorded.

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)

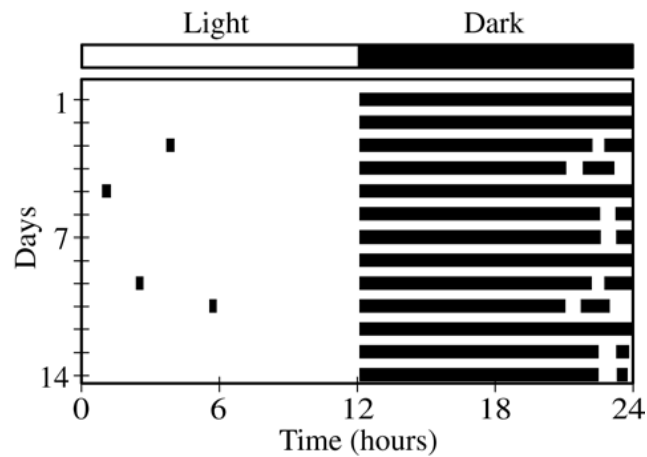


Figure 2. Actogram of mouse activity under L12:D12 conditions. Each row represents a 24-hour period, and the dark horizontal lines represent activity on the running wheel.

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.

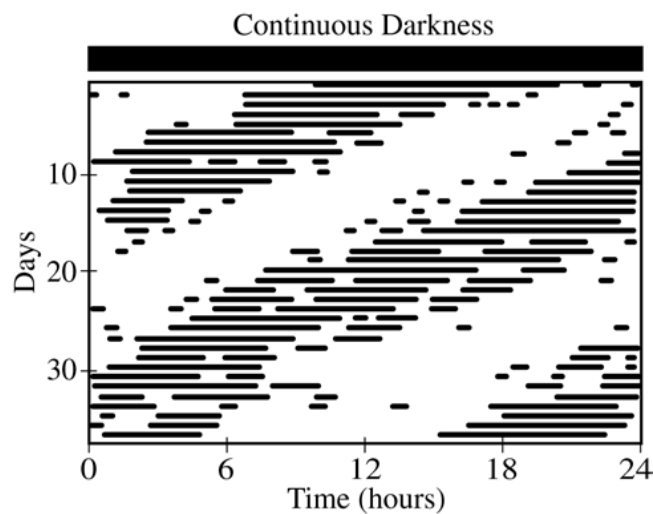


Figure 3. Actogram of mouse activity under DD conditions. Each row represents a 24-hour period, and the dark horizontal lines represent activity on the running wheel.

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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

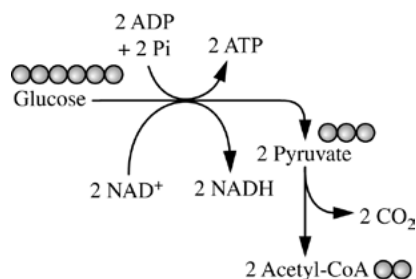


Figure 1. Glycolysis and pyruvate oxidation

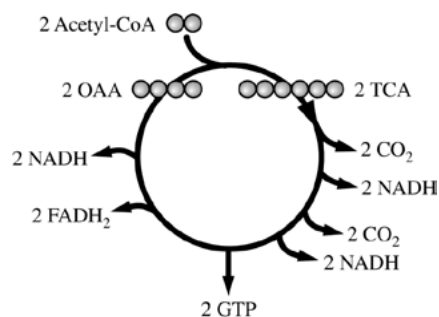


Figure 2. Krebs cycle

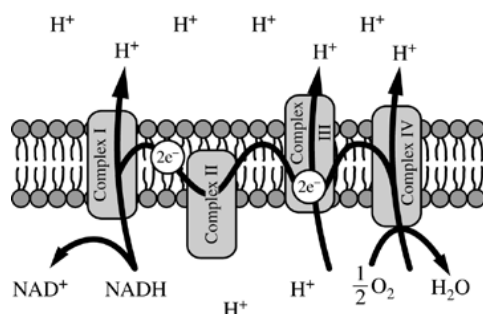


Figure 3. Electron transport chain

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.

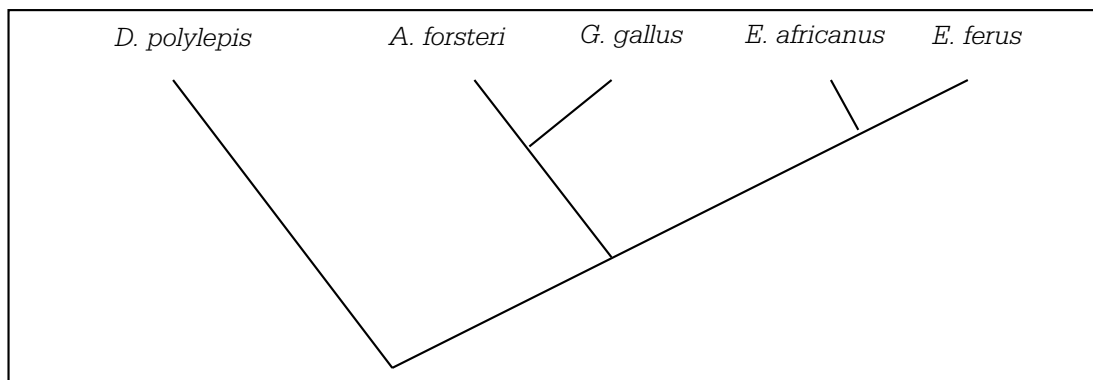
THE NUMBER OF AMINO ACID DIFFERENCES
IN CYTOCHROME *c* AMONG FIVE SPECIES

	<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)

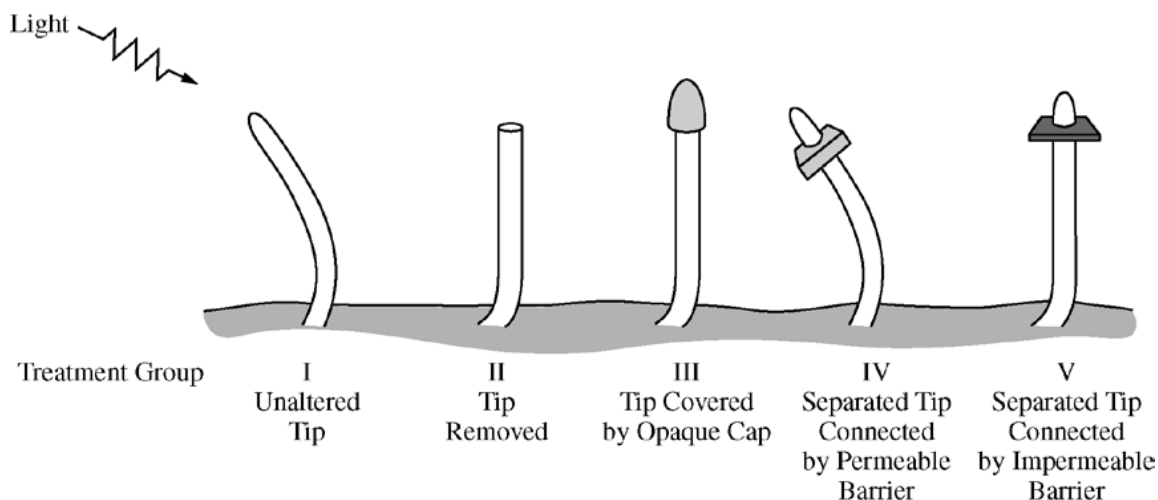
- Spindle elements (microtubules) form/attach to chromosomes
- Chromatin condenses
- Alignment of chromosomes across center of cell prior to chromosome separation
- Separation of chromatids/centromeres to daughter cells
- G2/M checkpoint occurs in both processes
- Replication or synthesis of DNA precedes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

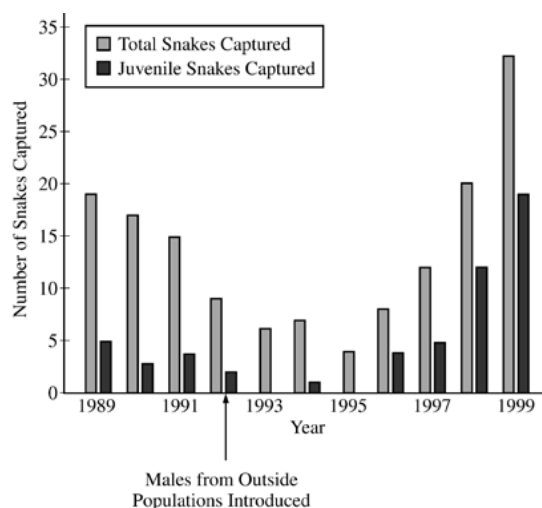
- Tip produces a substance/signal/hormone (auxin) in response to light causing the plants to bend
- Substance must diffuse from the tip causing the plants to bend

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

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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)

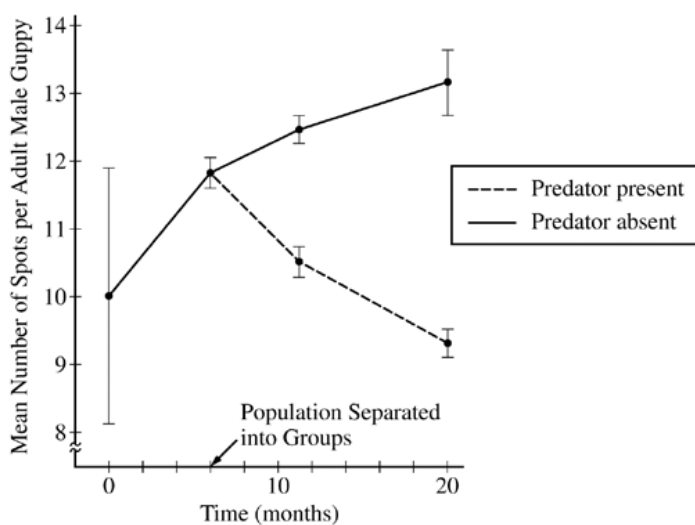
Predicted consequence on animal community (1 point)	Justification of prediction (1 point)
Harm to animals	• Exposure to toxic chemicals • Toxic chemicals accumulate through the food chain Persist in the environment • Contaminated groundwater
Emigration Displacement	• Loss of habitat and/or food • Loss 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)

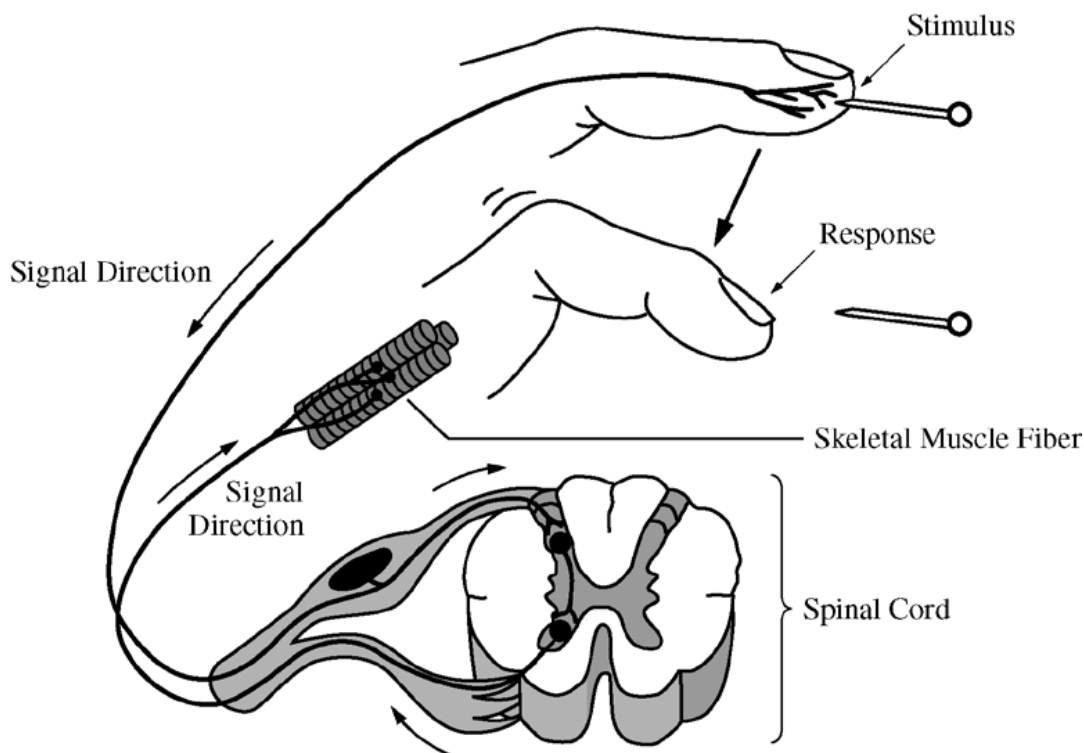
Description of risk (1 point each; 2 points maximum)	Proposed mitigation* + (1 point each box; 2 points maximum)
Unknown human/other animal health risk due to consuming GM proteins	• Testing/labeling product packaging • Isolate animals from crops
Disruption within food chain	• Intersperse GM plants with 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)

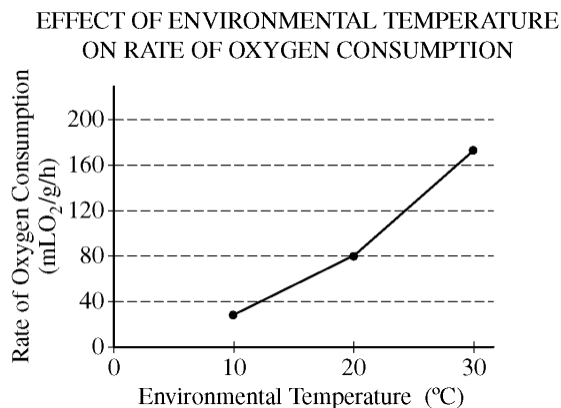
- Quicker response time
- No integration with brain / does not reach brain before response occurs
- Fewer neurons / synapses involved in reflex arc / shorter distance for signal to travel
- Involuntary / no conscious control / no processing by brain

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



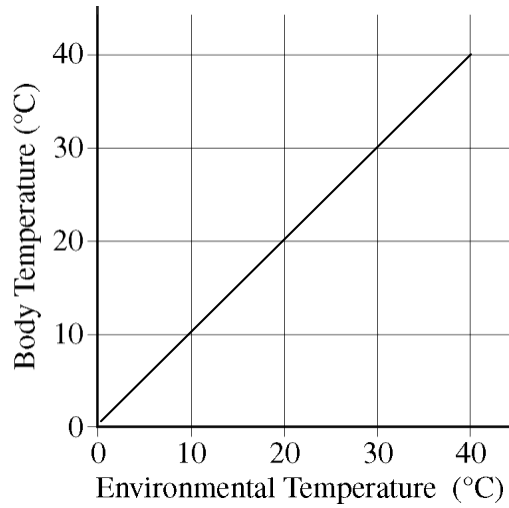
Based on the graph, **describe** a specific method of thermoregulation used by the species of animal. **Provide** support for your answer using the data. (2 points maximum; LO 2.21, 2.24, 2.27)

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