

Question 1: Interpreting and Evaluating Experimental Results**9 points**

Most proteins that are secreted from a cell must be transported to the endoplasmic reticulum (ER) either during translation or after translation.

For proteins transported during translation, this process begins in the cytosol and pauses when a specific sequence of amino acids is translated. The translation complex is then transported to the surface of the ER where translation continues. Proteins that are transported after translation are translated entirely in the cytosol and then transported to the ER. In both instances, the translated proteins enter the ER through a protein channel in the membrane of the ER.

Researchers studying the two types of protein transport identified that the ER membrane protein SR is necessary for transport during translation, while the ER membrane protein Sec62 is necessary for transport after translation. To investigate which transport mechanism is used for different proteins, researchers first created small interfering RNAs (siRNAs) that reduce expression of either SR or Sec 62. They then treated groups of cells with either the SR siRNA or the Sec62 siRNA and determined the relative amount of SR and Sec 62 protein in each group of cells compared with cells treated with a control siRNA. (Figure 1).

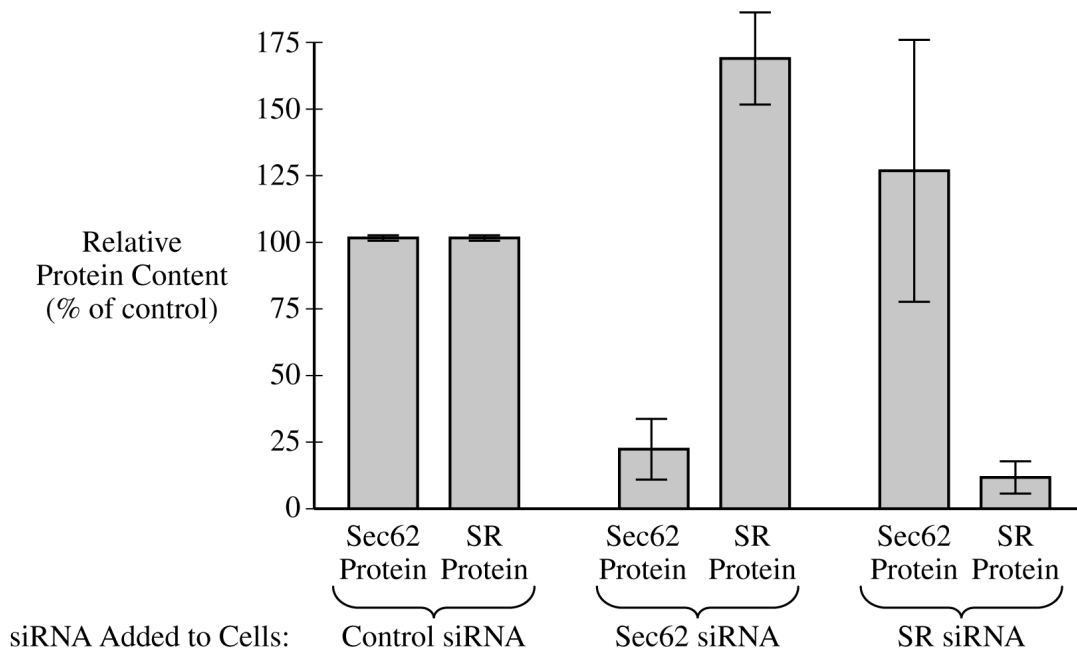


Figure 1. Average relative amounts of Sec62 and SR proteins in cells treated with control siRNA, Sec62 siRNA or SR siRNA. Error bars represent $\pm SE_{\bar{x}}$.

The researchers then measured the amount of each of three different proteins that was transported to the ER in cells treated with Sec62 siRNA or SR siRNA. The researchers calculated the percent transported relative to the cells treated with control siRNA (Figure 2).

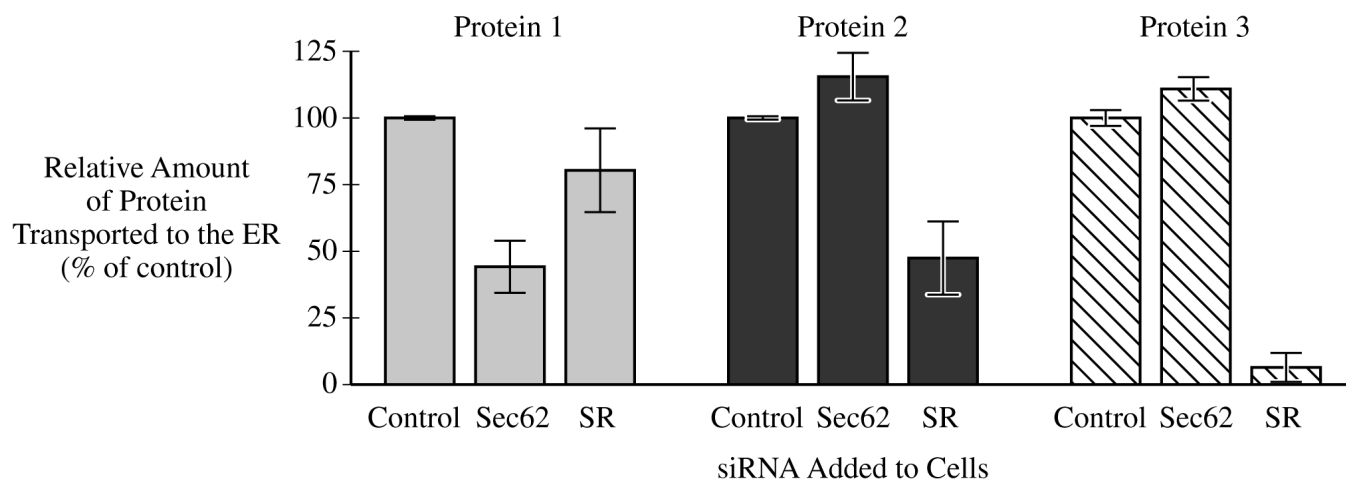


Figure 2. Average relative amounts of three proteins that were transported to the ER when treated with control siRNA, Sec62 siRNA, or SR siRNA. Error bars represent $\pm SE_{\bar{x}}$.

A	Describe the function of ribosomes. Examples of acceptable responses may include the following: - Ribosomes synthesize <u>polypeptides/proteins</u>. - Ribosomes perform translation. - Ribosomes are sites of <u>polypeptide/protein</u> synthesis.	Point A1
B	(i) Identify the dependent variable in the experiments shown in Figure 1. - The (relative) <u>amount of protein/protein content</u> (ii) Justify why the researchers included the control of measuring the relative amounts of both Sec62 and SR proteins in cells that were treated with Sec62 siRNA only (data shown in Figure 1). Examples of acceptable responses may include the following: (The control allowed the researchers) to determine whether the (Sec62) siRNA <u>reduced/affected</u> the content of both proteins (relative to protein content in the presence of the control siRNA). (The control allowed the researchers) to determine whether the (Sec62) siRNA <u>reduced/affected</u> Sec62 (protein content) only. (iii) Based on Figure 1, describe the effect on the production of SR protein when cells are treated with Sec62 siRNA. Examples of acceptable responses may include the following: (SR protein production) increased. (SR protein production) increased by 65% (accept 50–80%).	Point B1 Point B2 Point B3

C	(i) Identify the independent variable in the researchers' second experiment (data shown in Figure 2). Examples of acceptable responses may include the following: • (The type of) siRNA (added to the cells) • The type of protein whose amount was measured	Point C1
	(ii) Based on Figure 2, identify the protein(s) that when treated with Sec62 siRNA showed an increase in percent transport to the ER compared with the control. Examples of acceptable responses may include the following: • Proteins 2 and 3 • Protein 2 • Protein 3	Point C2
	(iii) Protein 1 is encoded by 234 nucleotides, while protein 2 is encoded by 495 nucleotides. Assuming all nucleotides for both proteins encode amino acids, calculate the difference in the number of amino acids between the two proteins. • 87 (amino acids) $[(495/3)-(234/3)]$	Point C3
D	(i) Researchers claim that protein 1 is the only tested protein that is transported to the ER following its complete translation in the cytosol. Using data from Figure 2, support the researchers' claim. • Only protein 1 showed a reduced <u>amount/percentage</u> of transport when cells were treated with Sec62 siRNA.	Point D1
	(ii) For any protein that enters the ER, researchers claim that amino acids close to the protein's amino terminus determine how likely the protein is to pass through the protein channel within the ER membrane. Justify the researchers' claim based on your understanding of factors that affect the transport of proteins across membranes. • Amino acids (at the amino terminus) that have <u>similar polarity to/opposite charge to</u> (the R groups of amino acids lining) the protein channel are more likely to pass through the channel (than are proteins where the amino terminus contains amino acids with dissimilar polarity or similar charge).	Point D2

Question 2: Interpreting and Evaluating Experimental Results with Graphing

9 points

Elevated levels of CO_2 increase the rate of photosynthesis and growth in plants. Scientists studying the mechanisms involved in these increases examined a variety of species and found that when plants are exposed to elevated levels of CO_2 , there is an increase in the number of chloroplasts per cell. To investigate whether the elevated levels of CO_2 have a similar effect on the number of mitochondria in plant cells, the scientists then selected six of these species to quantify the number of mitochondria per cell when the plants were exposed to both normal and elevated levels of CO_2 (Table 1).

TABLE 1. AVERAGE NUMBER OF MITOCHONDRIA IN PLANTS EXPOSED TO NORMAL AND ELEVATED LEVELS OF CO_2

Species	Mitochondria at Normal CO_2 (per 100 μm^2 of cell area) $\pm 2\text{SE}_{\bar{x}}$	Mitochondria at Elevated CO_2 (per 100 μm^2 of cell area) $\pm 2\text{SE}_{\bar{x}}$
1	1.0 ± 0.10	1.6 ± 0.10
2	0.4 ± 0.05	0.9 ± 0.08
3	0.5 ± 0.07	0.9 ± 0.10
4	0.3 ± 0.03	0.6 ± 0.06
5	0.7 ± 0.06	1.5 ± 0.22
6	1.3 ± 0.15	2.4 ± 0.22

(a) **Describe** the role of the inner mitochondrial membrane in cellular respiration.

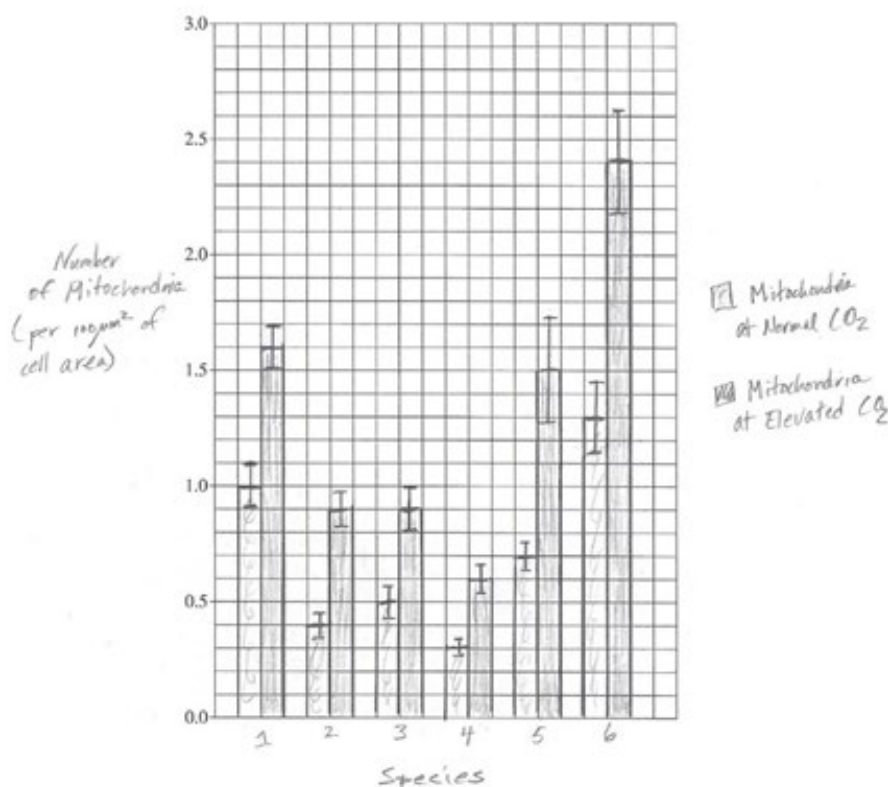
1 point

Accept one of the following:

- It provides the location for the components of the electron transport chain/ATP synthase/oxidative phosphorylation.
- It separates (reactions in) the intermembrane space from (reactions in) the matrix.
- It allows the establishment of a proton gradient.

- (b) Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1. **1 point**

Sample response:



- Appropriate labelling

Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1. **1 point**

- Data are represented in a bar/modified bar graph.

Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1. **1 point**

- Data points and error bars are correctly plotted.

Determine which species show(s) a difference in the number of mitochondria between normal and elevated levels of CO₂. **1 point**

- All of the species

Total for part (b) 4 points

- (c) Based on the data in Table 1, **describe** the relationship between the level of CO₂ and the average number of mitochondria per unit area of a cell. **1 point**

Accept one of the following:

- The number of mitochondria is greater under conditions of elevated CO₂ (than under normal CO₂).
- It is a positive relationship/correlation.

- (d) The leaves of a particular plant species are typically green, but scientists notice a plant in which the leaves have white stripes. They determine that the stripes result from a mutation in mitochondrial DNA that interferes with the development of chloroplasts. The scientists crossed plants using pollen from the plant with white-striped leaves and ovules from a plant with green leaves. **Predict** the phenotype(s) of the leaves of offspring produced from this cross. **1 point**

- The leaves will be (all) green/not have white stripes.

Provide reasoning to **justify** your prediction. **1 point**

- (All offspring will have the same leaf phenotype as the ovule-producing plant because) mitochondria are maternally inherited/transferred by the ovule.

Explain why plants with the same genotype are able to differ in the structure and/or number of certain organelles in response to changes in atmospheric levels of CO_2 . **1 point**

- (Plants have different phenotypes because) changes in CO_2 levels/the environment affect the expression of certain genes.

Total for part (d) 3 points

Total for question 2 9 points

2018

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Scoring Guidelines

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Question 1

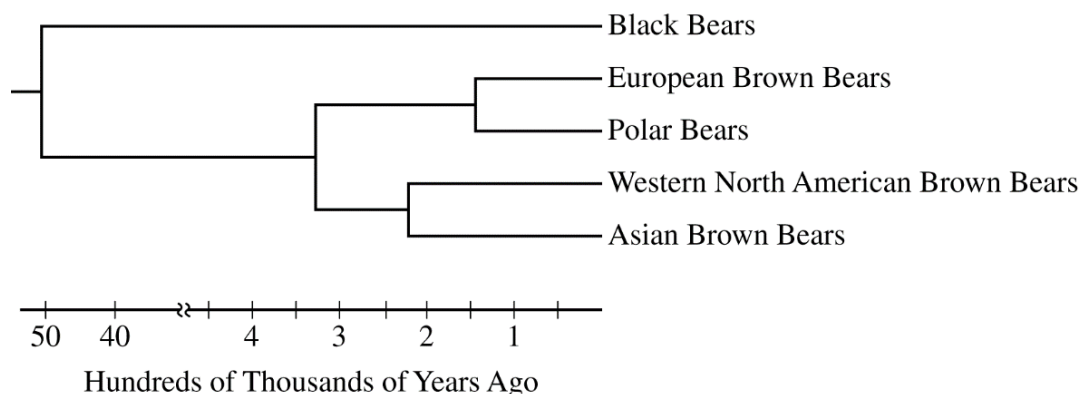


Figure 1. Phylogenetic tree representing the evolutionary relatedness among bear populations based on mitochondrial DNA sequence comparisons

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.

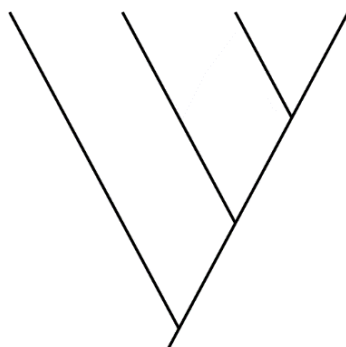
Identification (1 point)

- 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.

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- (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

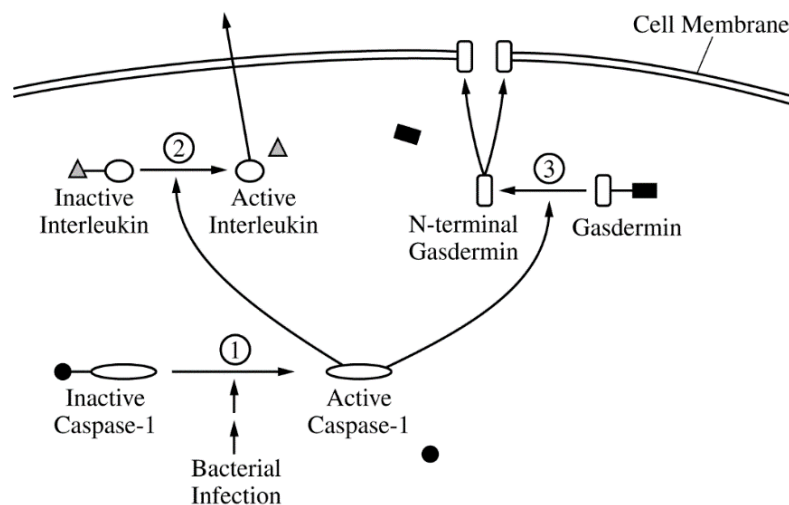


Figure 1. Cellular response to infection by pathogenic bacteria

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)

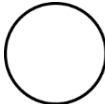
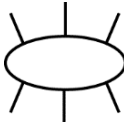
- Cell lysis destroys infected cells OR cell lysis prevents bacteria from replicating.
- Interleukin signaling will stimulate immune cells/components of the immune system (to destroy the infected cells or bacteria).

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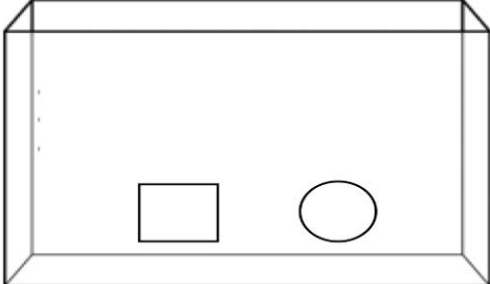
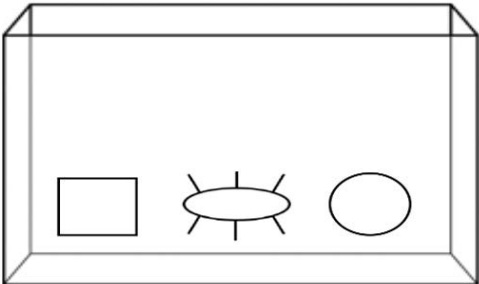
Question 3

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

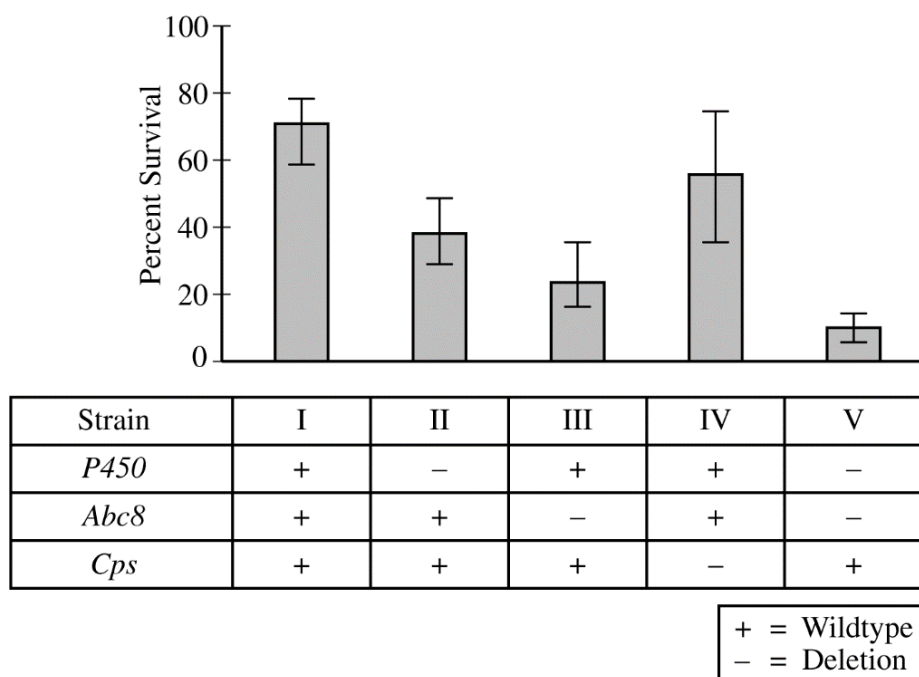


Figure 1. Percent survival of five strains of bedbugs treated with beta-cyfluthrin. A (+) indicates the gene is present; a (–) indicates the gene is deleted. Error bars represent the 95% confidence interval.

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

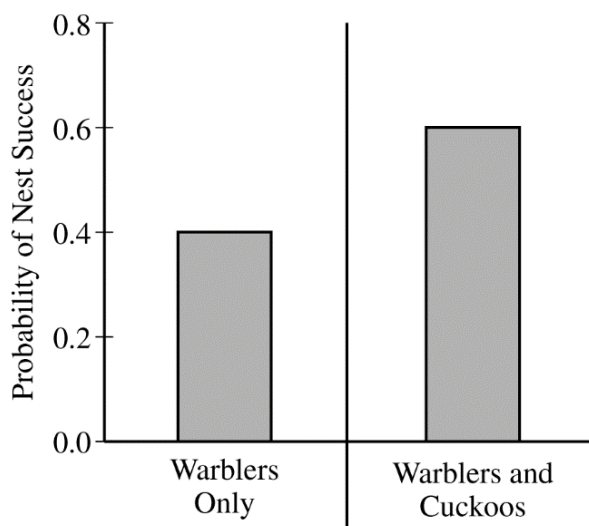


Figure 1. Probability of nest success in an environment with predators

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)

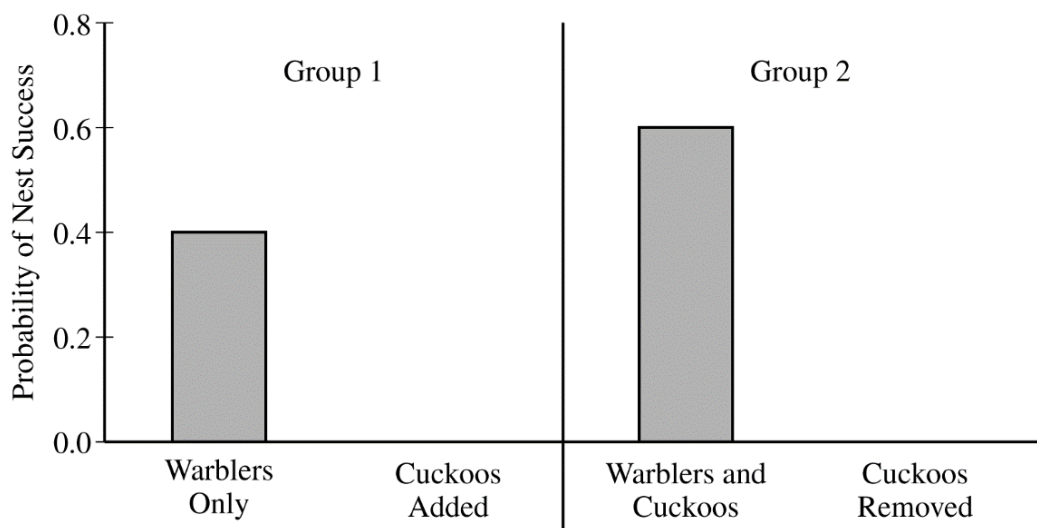
- Cuckoos are parasites (of the warbler).
- The cuckoo benefits from the relationship, and the warbler is harmed by the relationship.

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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

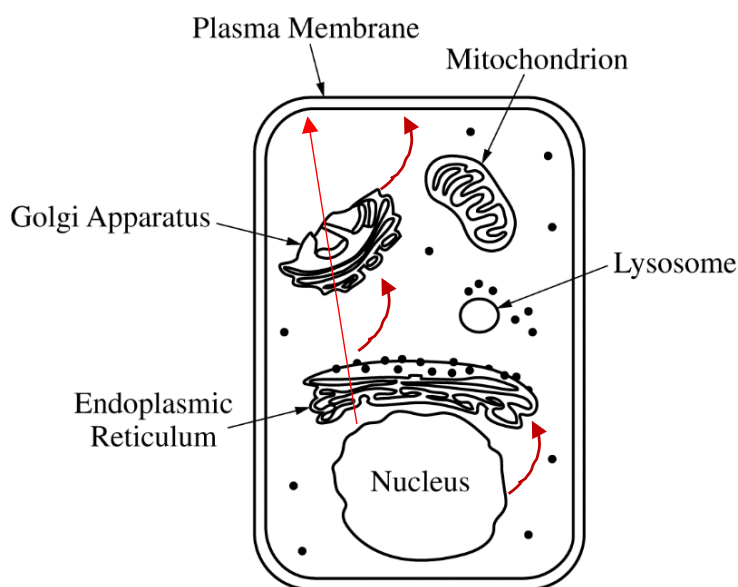
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Question 6

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.

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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