Exam Date & Time:
Friday, May 14 th 2021 @ 8:00 AM

The following materials have been constructed using the 2020 CED, the 2013 Practice Exam, the 2015 CED, released FRQ questions, and self-created questions.

It is organized with the standards from the CED (Course and Exam Description) followed by questions designed to allow you to refresh your memory on the topics. There might be some repeating as topics overlap and I am isolating each standard individually. This has no association with AP/CollegeBoard and was designed as a resource for review of the content for the AP Biology exam.

After each CED unit, there are multiple choice and/or free response questions with an answer key. Some items were topic assigned using the AP Classroom resource and others were assigned by the author of this document using their best judgement.

AP Biology Exam Review

Before we get started, let's look at the science practices that will be used to assess your knowledge on the AP Biology exam. Notice the action verb in each of the skills and note any of these science practices can be used in any question.

Science Practice	Skills
1 – Concept Explanation Explain biological concepts, processes, and models presented in written format	1.A – **Describe** biological concepts and/or processes.
	1.B – **Explain** biological concepts and/or processes.
	1.C – **Explain** biological concepts, processes, and/or models in applied contexts.
2 – Visual Representation Analyze visual representations of biological concepts and processes.	2.A – **Describe** characteristics of a biological concept, process, or model represented visually.
	2.B – **Explain** relationships between different characteristics of biological concepts, processes, or models represented visually a. In theoretical contexts. b. In applied contexts.
	2.C – **Explain** how biological concepts or processes represented visually relate to larger biological principles, concepts, processes, or theories.
	2.D – **Represent** relationships within biological models, including a. Mathematical models. b. Diagrams. c. Flow charts.
3 – Questions and Methods Determine scientific questions and methods	3.A – **Identify** or **pose a testable question** based on an observation, data, or a model.
	3.B – **State** the null or alternative hypotheses, or predict the results of an experiment.
	3.C – **Identify** experimental procedures that are aligned to the question, including a. Identifying dependent and independent variables. b. Identifying appropriate controls. c. Justifying appropriate controls.
	3.D – Make observations, or collect data from representations of laboratory setups or results. (Lab only; not assessed)
	3.E – Propose a new/next investigation based on a. An evaluation of the evidence from an experiment. b. An evaluation of the design/methods.
4 – Representing and Describing Data Represent and describe data	4.A – **Construct** a graph, plot, or chart (X,Y; Log Y; Bar; Histogram; Line, Dual Y; Box and Whisker; Pie). a. Orientation b. Labeling c. Units d. Scaling e. Plotting f. Type g. Trend line
	4.B – **Describe** data from a table or graph, including a. Identifying specific data points. b. Describing trends and/or patterns in the data. c. Describing relationships between variables.
5 – Statistical Tests and Data Analysis Perform statistical tests and mathematical calculations to analyze and interpret data.	5.A – Perform mathematical **calculations**, including a. Mathematical equations in the curriculum. b. Means. c. Rates. d. Ratios. e. Percentages.
	5.B – Use confidence intervals and/or error bars (both determined using standard errors) to **determine** whether sample means are statistically different.
	5.C – Perform chi-square hypothesis testing.
	5.D – Use data to **evaluate** a hypothesis (or prediction), including a. Rejecting or failing to reject the null hypothesis. b. Supporting or refuting the alternative hypothesis.

6 – Argumentation Develop and justify scientific arguments using evidence	6.A – **Make a** scientific **claim**.
	6.B – **Support a claim** with evidence from biological principles, concepts, processes, and/or data.
	6.C – Provide reasoning to **justify** a claim by connecting evidence to biological theories.
	6.D – **Explain** the relationship between experimental results and larger biological concepts, processes, or theories.
	6.E – **Predict** the causes or effects of a change in, or disruption to, one or more components in a biological system based on a. Biological concepts or processes. b. A visual representation of a biological concept, process, or model. c. Data.

The following **task verbs** are commonly used in the free-response questions:

Calculate: Perform mathematical steps to arrive at a final answer, including algebraic expressions, properly substituted numbers, and correct labeling of units and significant figures.

Construct/Draw: Create a diagram, graph, representation, or model that illustrates or explains relationships or phenomena. Labels may or may not be required.

Describe: Provide relevant characteristics of a specified topic.

Determine: Decide or conclude after reasoning, observation, or applying mathematical routines (calculations).

Evaluate: Judge or determine the significance or importance of information, or the quality or accuracy of a claim.

Explain: Provide information about how or why a relationship, process, pattern, position, situation, or outcome occurs, using evidence and/or reasoning to support or qualfiy a claim. Explain "how" typically requires analyzing the relationship, process, pattern, position, situation, or outcome; whereas explain "why" typically requires analysis of motivations or reasons for the relationship, process, pattern, position, situation, or outcome.

Identify: Indicate or provide information about a specified topic, without elaboration or explanation.

Justify: Provide evidence to support, qualify, or defend a claim, and/or provide reasoning to explain how that evidence supports or qualifies the claim.

Make a claim: Make an assertion that is based on evidence or knowledge.

Predict/Make a prediction: Predict the causes or effects of a change in, or disruption to, one or more components in a relationship, pattern, process, or system.

Represent: Use appropriate graphs, symbols, words, illustrations, and/or tables of numerical values to describe biological concepts, characteristics, and/or relationships.

State (the null/alternative hypothesis): Indicate or provide a hypothesis to support or defend a claim about a scientifically testable question.

Support a claim: Provide reasoning to explain how evidence supports or qualifies a claim.

Pacing Guide

Done?	Date	Section	Done?	Date	Section	Done?	Date	Section	Done?	Date	Section
	2/1	1.1		3/1	3.6		4/1	6.4		5/1	8.1
	2/2	1.2		3/2	3.6		4/2	6.5		5/2	8.1
	2/3	1.3		3/3	3.7		4/3	6.5		5/3	8.2
	2/4	1.4		3/4	MC Practice		4/4	6.6		5/4	8.2
	2/5	1.5		3/5	FRQ Practice		4/5	6.7		5/5	8.3
	2/6	1.6		3/6	FRQ Practice		4/6	6.7		5/6	8.4
	2/7	MC Practice		3/7	4.1		4/7	6.7		5/7	8.5
	2/8	2.1		3/8	4.2		4/8	6.8		5/8	8.6
	2/9	2.2		2/9	4.2		4/9	MC Practice		5/9	8.7
	2/10	2.3		3/10	4.3		4/10	FRQ Practice		5/10	MC Practice
	2/11	2.4		3/11	4.4		4/11	FRQ Practice		5/11	FRQ Practice
	2/12	2.5		3/12	4.5		4/12	7.1		5/12	FRQ Practice
	2/13	2.6		3/13	4.6		4/13	7.2		5/13	Remember you are an AP Biology Penguin – RELAX TODAY!
	2/14	2.7		3/14	4.6		4/14	7.3			
	2/15	2.8		3/15	4.7		4/15	7.4			
	2/16	2.8		3/16	MC Practice		4/16	7.5		5/14	AP Bio Exam
	2/17	2.9		3/17	FRQ Practice		4/17	7.6			
	2/18	2.10		3/18	FRQ Practice		4/18	7.6			
	2/19	2.11		3/19	5.1		4/19	7.7			
	2/20	MC Practice		3/20	5.2		4/20	7.8			
	2/21	FRQ Practice		3/21	5.3		4/21	7.9			
	2/22	3.1		3/22	5.3		4/22	7.9			
	2/23	3.2		3/23	5.4		4/23	7.10			
	2/24	3.3		3/24	5.5		4/24	7.10			
	2/25	3.3		3/25	5.6		4/25	7.11			
	2/26	3.4		3/26	MC Practice		4/26	7.12			
	2/27	3.5		3/27	FRQ Practice		4/27	7.13			
	2/28	3.5		3/28	6.1		4/28	MC Practice			
				3/29	6.1		4/29	FRQ Practice			
				3/30	6.2		4/30	FRQ Practice			
				3/31	6.3						

Unit 1: Chemistry of Life

Topic	Learning Objective (s)
1.1 Structure of Water	**SYI-1.A** Explain how the properties of water that result from its polarity and hydrogen bonding affect its biological function.
1.2 Elements of Life	**ENE-1.A** Describe the composition of macromolecules required by living organisms.
1.3 Introduction of Biological Macromolecules	**SYI-1.B** Describe the properties of the monomers and the type of bonds that connect the monomers in biological macromolecules.
1.4 Properties of Biological Macromolecules	**SYI-1.B** Describe the properties of the monomers and the type of bonds that connect the monomers in biological macromolecules.
1.5 Structure and Function of Biological Macromolecules	**SYI-1.C** Explain how a change in the subunits of a polymer may lead to changes in structure or function of the macromolecule.
1.6 Nucleic Acids	**IST-1.A** Describe the structural similarities and differences between DNA and RNA.

Topic 1.1: Structure of Water and Hydrogen Bonding

Learning Objective	SY1-1.A Explain how the properties of water that result from its polarity and hydrogen bonding affect its biological function.
I can…	☐ I can describe a hydrogen bond. ☐ I can explain how two strands of DNA bind to create the double helix. ☐ I can explain ways that R groups affect the structure of a protein. ☐ I can identify the properties of water caused by hydrogen bonds. ☐ I can explain what makes water polar. ☐ I can explain what moves water against gravity up a capillary tube. ☐ I can explain what allows a water strider to walk on water.

1. What is a hydrogen bond?
2. Where are hydrogen bonds found in water?
3. Where are hydrogen bonds found in DNA?
    a. How many hydrogen bonds are found between each complementary base pairing?
4. What is the structure of an amino acid?
    a. What are the three options for the R group?
    b. For each R group option, describe the polarity and justify your response.
5. What are three properties of water?
    a. How did hydrogen bonding allow for each property?
6. Describe why water is considered a polar molecule?
7. Using the properties of water, describe how water can move up a capillary tube to move from the roots to the leaves in a plant.
8. Using the properties of water, describe how a water strider can walk on water.

Topic 1.2: Elements of Life

Learning Objective	ENE-1.A Describe the composition of macromolecules required by living organisms.
I can…	☐ I can identify the macromolecules required by living organisms. ☐ I can describe the function of proteins in living organisms. ☐ I can describe the function of lipids in living organisms. ☐ I can describe the function of carbohydrates in living organisms. ☐ I can describe the function of nucleic acids in living organisms. ☐ I can describe how the R group affects the folding of a protein. ☐ I can identify the elements found in carbohydrates. ☐ I can identify the elements found in proteins. ☐ I can identify the elements found in nucleic acids. ☐ I can identify the elements found in lipids. ☐ I can describe how macromolecules are formed. ☐ I can describe how macromolecules are broken down. ☐ I can identify which macromolecules contain nitrogen. ☐ I can identify which macromolecules contain phosphorus. ☐ I can identify which macromolecules contain sulfur.

1. What are the four macromolecules?
2. What are the elements found in a carbohydrate?
3. What are three functions of carbohydrates in living organisms?
4. What are the elements found in a protein?
    a. What are the functional groups found in all amino acids?
5. What are three functions of proteins in living organisms?
6. What are the elements found in nucleic acids?
    a. What are parts found in all nucleotides?
7. What are three functions of nucleic acids in living organisms?
8. What are the elements found in a lipid?
    a. How are the three different types of lipids different?
9. What are three functions of lipids in living organisms?
10. Which macromolecule(s) contain nitrogen?
11. Which macromolecule(s) contain phosphorus?
12. Which macromolecule(s) contain sulfur?
13. How does the R group affect the folding of the protein? (include polar and nonpolar R groups)
14. What is dehydration?
    a. Provide an example of dehydration.
15. What is hydrolysis?
    a. Provide an example of hydrolysis.

Topic 1.3: Introduction to Biological Macromolecules

Learning Objective	**SY1-1.B** Describe the properties of the monomers and the type of bonds that connect the monomers in biological macromolecules.
I can…	☐ I can describe the process of hydrolysis. ☐ I can describe the process of dehydration. ☐ I can identify the bond between carbohydrate monomers. ☐ I can identify the bond between protein monomers. ☐ I can identify the bond between nucleic acid monomers.

1. What is the hydrolysis?
    a. Identify inputs and outputs using a specific example.
2. What is the dehydration?
    a. Identify inputs and outputs using a specific example.
3. What type of bond is found in carbohydrates?
    a. Specifically, where is this bond located?
4. What type of bond is found between protein monomers?
    a. Specifically, where is this bond located?
5. What type of bond is found between nucleic acid monomers?
    a. Specifically, where is this bond located?

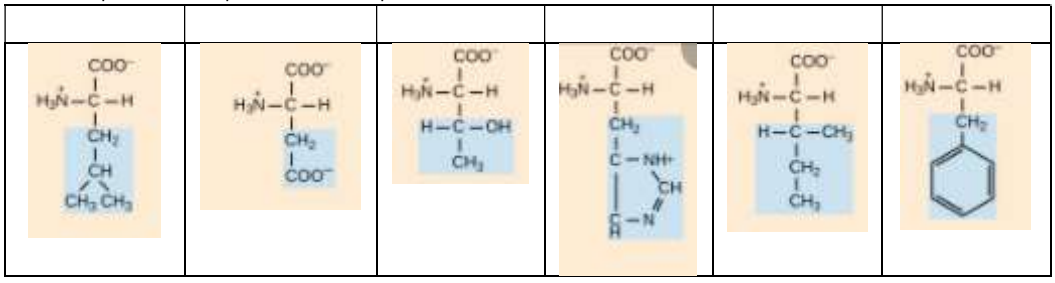
Topic 1.4: Properties of Biological Macromolecules

Learning Objective	SYI-1.B Describe the properties of the monomers and the type of bonds that connect the monomers in biological macromolecules.
I can…	☐ I can describe the structural components of the monomer of a carbohydrate. ☐ I can describe the structural components of the monomer of a protein. ☐ I can describe the structural components of the monomer of a nucleic acid. ☐ I can describe the structural components of a phospholipid. ☐ I can describe the difference between the bonds of starch and cellulose. ☐ I can describe the structural differences between DNA and RNA. ☐ I can identify an R group as hydrophobic, hydrophilic, or ionic. ☐ I can describe the effect of level of saturation on function of lipids.

1. What is the monomer of a carbohydrate?
    a. Identify the components of the monomer.
2. What is the monomer of a protein?
    a. Identify the components of the monomer.
3. What is the monomer of a nucleic acid?
    a. Identify the components of the monomer.
4. Identify the components of a phospholipid.
5. Starch vs. Cellulose
    a. What type of bond is found in starch?
    b. What type of bond is found in cellulose?
    c. Which bond can be broken by animals?
6. Compare and contrast DNA and RNA using the following chart:

	DNA	RNA
Pentose Sugar		
Nitrogenous Bases		
Strandedness (traditionally)		

7. Identify the group as hydrophobic, hydrophilic, or charged?



8. How does a saturated and unsaturated fatty acid differ?
    a. How does the level of saturation affect the function of the lipid?

Topic 1.5: Structure and Function of Biological Macromolecules

Learning Objective	SYI-1.C Explain how a change in the subunits of a polymer may lead to changes in structure or function of the macromolecule.
I can…	☐ I can explain how changes in the subunits of a protein may lead to changes in structure. ☐ I can explain how changes in the subunits of a protein may lead to changes in function. ☐ I can explain how changes in the subunits of a nucleic acid may lead to changes in structure. ☐ I can explain how changes in the subunits of a nucleic acid may lead to changes in function. ☐ I can describe the directionality of a nucleic acid. ☐ I can describe the directionality of a protein. ☐ I can identify the appropriate base pairing based on Chargaff's rules. ☐ I can identify the location of a growing nucleic acid strand. ☐ I can describe the levels of folding found in a protein. ☐ I can describe the structure of carbohydrate polymers. ☐ I can describe the structure of nucleic acid polymers. ☐ I can describe the structure of protein polymers. ☐ I can describe the structure of a fat. ☐ I can describe the structure of a phospholipid. ☐ I can describe the structure of a steroid.

1. Describe how a nonpolar to polar R group substitution changes the structure and function of a protein.
2. Describe how a cytosine to thymine substitution changes the structure and function of DNA.
    - Note this is a pyrimidine-to-pyrimidine substitution
3. Describe how a cytosine to guanine substitution changes the structure and function of DNA.
    - Note this is a pyrimidine-to-purine substitution
4. Describe how a deoxyribose to ribose changes the structure and function of a nucleic acid.
5. Describe the structure of the nucleic acid polymer.
    a. What are the ends called and what is found at each end?
    b. Which end is the location of the growing nucleic acid strand?
6. What are the complementary base pairings found in nucleic acids?
    a. Identify the number of hydrogen bonds found between these two nitrogenous bases.
7. Use the following chart to describe the levels of folding found in proteins.

Level of Folding	Description	Types of Bonds
Primary		
Secondary		
Tertiary		
Quaternary		

8. What are the ends of a protein called and what is found at each end?
    a. Which end is the location of the growing polypeptide strand?
9. Describe the structure of a carbohydrate polymer.
10. What are the components of a fat molecule?
11. What are the components of a phospholipid?
12. Describe the structure of a steroid.

Topic 1.6: Nucleic Acid

Learning Objective	IST-1.A Describe the structural similarities and differences between DNA and RNA.
I can…	☐ I can describe the structure of DNA ☐ I can describe the structure of RNA ☐ I can describe the structural similarities between DNA and RNA ☐ I can describe the sugar differences between DNA and RNA ☐ I can describe the nitrogenous base differences between DNA and RNA ☐ I can describe the structural differences between polymers of DNA and RNA ☐ I can describe the structural differences between directionality of DNA and RNA

1. What are the three components of a DNA or RNA molecule?
2. Identify differences between DNA and RNA using the following chart:

	DNA	RNA
Pentose Sugar		
Nitrogenous Base Difference		
Strandedness (traditionally)		
Directionality		

Multiple Choice Practice

1. Scientists examined the folded structure of a purified protein resuspended in water and found that amino acids with nonpolar R groups were primarily buried in the middle of the protein, whereas amino acids with polar R groups were primarily on the surface of the protein. Which of the following best explains the location of the amino acids in the folded protein?
    a. Polar R groups on the surface of the protein can form ionic bonds with the charged ends of the water molecules.
    b. Polar R groups are too bulky to fit in the middle of the protein and are pushed toward the protein's surface.
    c. Nonpolar R groups that cannot form hydrogen bonds with water are pushed into the middle of the protein.
    d. Nonpolar R groups from different parts of the protein form covalent bonds with each other to maintain the protein's structure.

2. Rosalind Franklin's x-ray diffraction images taken in the 1950s most directly support which of the following claims about DNA?
    a. The ratios of base pairs are constant.
    b. The nucleotide sequence determines genetic information.
    c. The two strands of DNA are antiparallel.
    d. The basic molecular structure is a helix.

3. Which of the following does not result from hydrogen bonding in water molecules?
    a. Cohesion
    b. Adhesion
    c. Surface Tension
    d. Dissolving fats

4. Why is water considered polar?
    a. Nonpolar covalent bonds in structure
    b. Ionic bonds in structure
    c. Polar covalent bonds in structure
    d. Hydrophobic interaction in structure

5. Which macromolecule(s) have nitrogen?
    a. Carbohydrates
    b. Proteins
    c. Nucleic Acids
    d. Nucleic Acids & Proteins

6. Which macromolecule(s) have phosphorus?
    a. Carbohydrates
    b. Proteins
    c. Nucleic Acids
    d. Fats

7. Which macromolecule(s) have sulfur?
    a. Carbohydrates
    b. Proteins
    c. Nucleic Acids
    d. Fats

8. Describes the forming of a bond between monomers with the removal of a water molecule.
    a. Hydrolysis
    b. Dehydration

9. Describes the breaking of a bond within a polymer using water.
    a. Hydrolysis
    b. Dehydration

10. Which of the following is NOT in the monomer of a nucleic acid?
    a. pentose sugar
    b. nitrogenous base
    c. phosphate
    d. amino acid

11. Which of the following is NOT in the monomer of a protein?
    a. Amine Group
    b. R Group
    c. Carboxyl Group
    d. Nitrogenous Base

12. Describe the orientation of the phospholipids in the membrane.
    a. Phospholipids orient in bilayer with hydrophilic heads on exterior
    b. Phospholipids orient in monolayer with hydrophilic head on extracellular
    c. Phospholipids orient in bilayer with hydrophobic tails on exterior
    d. Phospholipids orient in monolayer with hydrophobic tails on extracellular

13. How is DNA/RNA synthesis directionally oriented?
    a. new nucleotides are added to 5' phosphate
    b. new nucleotides are added to 3' phosphate
    c. new nucleotides are added to 5' hydroxyl
    d. new nucleotides are added to 3' hydroxyl

14. Identify the pairing and number of bonds in DNA double helix
    a. A pairs with T (2 bonds) & G pairs with C (3 bonds)
    b. A pairs with G (2 bonds) & T pairs with C (3 bonds)
    c. A pairs with T (3 bonds) & G pairs with C (2 bonds)
    d. A pairs with G (3 bonds) & T pairs with C (2 bonds)

15. What component of the polypeptide is the next amino acid added forming the peptide bond?
    a. amino group
    b. hydrogen
    c. carboxyl group
    d. R group

16. Which protein involves R group bonding to form the final three-dimensional structure?
    a. primary
    b. secondary
    c. tertiary
    d. quaternary

17. Which protein structure involves the peptide bonds between amino acids?
    a. primary
    b. secondary
    c. tertiary
    d. quaternary

18. DNA and RNA differ on many qualities, which of the following is NOT a difference?
    a. Sugar
    b. Nitrogenous Base
    c. Phosphate Group
    d. Strandedness

Multiple Choice Key

Question	Correct Answer	Unit/Topic	Source
1	C. Nonpolar R groups that cannot form hydrogen bonds with water are pushed into the middle of the protein.	1.4	2020 CED #12
2	D. The basic molecular structure is a helix.	1.5	2013 #6
3	D. Dissolving fats	1.1	Self
4	C. Polar covalent bonds in structure	1.1	Self
5	D. Nucleic Acids & Proteins	1.2	Self
6	C. Nucleic Acids	1.2	Self
7	B. Proteins	1.2	Self
8	B. Dehydration	1.3	Self
9	A. Hydrolysis	1.3	Self
10	D. Amino Acid	1.4	Self
11	D. Nitrogenous Base	1.4	Self
12	A. Phospholipids orient in bilayer with hydrophilic heads on exterior	1.4	Self
13	D. new nucleotides are added to 3' hydroxyl	1.5	Self
14	A. A pairs with T (2 bonds) & G pairs with C (3 bonds)	1.5	Self
15	C. carboxyl group	1.5	Self
16	C. tertiary	1.5	Self
17	A. primary	1.5	Self
18	C. Phosphate Group	1.6	Self

Free Response Practice

Free Response Scoring Guidelines

Unit 2: Cell Structure and Function

Topic	Learning Objective(s)
2.1 Cell Structure: Subcellular Components	**SYI-1.D** Describe the structure and/ or function of subcellular components and organelles.
2.2 Cell Structure and Function	**SYI-1.E** Explain how subcellular components and organelles contribute to the function of the cell.
	SYI-1.F Describe the structural features of a cell that allow organisms to capture, store, and use energy
2.3 Cell Size	**ENE-1.B** Explain the effect of surface area-to-volume ratios on the exchange of materials between cells or organisms and the environment.
	ENE-1.C Explain how specialized structures and strategies are used for the efficient exchange of molecules to the environment.
2.4 Plasma Membranes	**ENE-2.A** Describe the roles of each of the components of the cell membrane in maintaining the internal environment of the cell.
	ENE-2.B Describe the Fluid Mosaic Model of cell membranes.
2.5 Membrane Permeability	**ENE-2.C** Explain how the structure of biological membranes influences selective permeability
	ENE-2.D Describe the role of the cell wall in maintaining cell structure and function.
2.6 Membrane Transport	**ENE-2.E** Describe the mechanisms that organisms use to maintain solute and water balance.
	ENE-2.F Describe the mechanisms that organisms use to transport large molecules across the plasma membrane.
2.7 Facilitated Diffusion	**ENE-2.G** Explain how the structure of a molecule affects its ability to pass through the plasma membrane.
2.8 Tonicity and Osmoregulation	**ENE-2.H** Explain how concentration gradients affect the movement of molecules across membranes.
	ENE-2.I Explain how osmoregulatory mechanisms contribute to the health and survival of organisms.
2.9 Mechanisms of Transport	**ENE-2.J** Describe the processes that allow ions and other molecules to move across membranes.
2.10 Cell Compartmentalization	**ENE-2.K** Describe the membrane-bound structures of the eukaryotic cell.
	ENE-2.L Explain how internal membranes and membrane-bound organelles contribute to compartmentalization of eukaryotic cell functions.
2.11 Origins of Cell Compartmentalization	**EVO-1.A** Describe similarities and/or differences in compartmentalization between prokaryotic and eukaryotic cells.
	EVO-1.B Describe the relationship between the functions of endosymbiotic organelles and their free-living ancestral counterparts.

Topic 2.1: Cell Structure: Subcellular Components

Learning Objective	SYI-1.D Describe the structure and/ or function of subcellular components and organelles.
I can…	☐ I can describe the structure of subcellular components and organelles. ☐ I can describe the function of subcellular components and organelles. ☐ I can describe the structure of ribosomes. ☐ I can describe the function of the ribosome. ☐ I can identify the types of RNA involved in the ribosome ☐ I can describe how ribosomes demonstrate common ancestry of all known life. ☐ I can identify the two types of endoplasmic reticulum (ER). ☐ I can describe the structure of rough ER. ☐ I can describe the function of rough ER. ☐ I can describe the structure of smooth ER. ☐ I can describe the function of smooth ER. ☐ I can describe the relationship between ribosomes and rough ER. ☐ I can describe the structure of Golgi bodies/apparatus/complex. ☐ I can describe the function of Golgi bodies/apparatus/complex. ☐ I can describe the structure of mitochondria. ☐ I can describe the function of mitochondria. ☐ I can describe the structure of lysosome. ☐ I can describe the function of lysosome. ☐ I can describe the structure of vacuoles. ☐ I can describe the function of food vacuoles. ☐ I can describe the function of central vacuoles. ☐ I can describe the function of contractile vacuoles. ☐ I can describe the structure of chloroplasts. ☐ I can describe the function of chloroplasts.

1. Ribosome
    a. What is the structure and function of the ribosome?
    b. How does the structure of the ribosome aid in the function?
    c. What are the three types of RNA involved in the structure or function of the ribosome?
2. How does the ribosome demonstrate a common ancestry of all known life?
3. Endoplasmic Reticulum
    a. What is the structure and function of the rough ER?
    b. How does the structure of the rough ER aid in the function?
    c. What is the structure and function of the smooth ER?
    d. How does the structure of the smooth ER aid in the function?
4. What is the relationship between the ribosome and the rough ER?
5. Golgi Bodies/Apparatus/Complex
    - Note: any of the names could appear on the exam so be knowledgeable about the different ways you might see this structure
    a. What is the structure and function of the Golgi?
    b. How does the structure of the Golgi aid in the function?

6. Mitochondria
    a. What is the structure and function of the mitochondria?
    - Note: Mitochondria is the "powerhouse of the cell" is not an appropriate response on the AP exam
    b. How does the structure of the mitochondria aid in the function?
7. Lysosome
    a. What is the structure and function of the lysosome?
    b. How does the structure of the lysosome aid in the function?
8. Vacuoles
    a. What is the structure of the vacuole?
    b. What is the function of the food vacuole?
    c. What is the function of the central vacuole?
    d. What is the function of the contractile vacuole?
9. Chloroplast
    a. What is the structure and function of a chloroplast?
    b. How does the structure of the chloroplast aid in the function?

Topic 2.2: Cell Structure and Function

Learning Objective	SYI-1.E Explain how subcellular components and organelles contribute to the function of the cell.
I can…	☐ I can explain ways subcellular components contribute to the function of the cell. ☐ I can explain ways organelles contribute to the function of the cell. ☐ I can describe the role of the ER on mechanical support. ☐ I can describe the role of the ER on protein synthesis. ☐ I can describe the role of the ER on intracellular transport. ☐ I can describe the role of the lysosome on intracellular digestion. ☐ I can describe the role of the lysosome on recycling cell's organic materials. ☐ I can describe the role of the lysosome on apoptosis (programmed cell death). ☐ I can describe the role of the vacuoles on storage and release of macromolecules. ☐ I can describe the role of vacuoles on turgor pressure.

1. How does the endoplasmic reticulum provide mechanical support?
2. How does the endoplasmic reticulum aid in protein synthesis?
3. How does the endoplasmic reticulum aid in intracellular transport?
4. How does the lysosome aid in intracellular digestion?
5. How does the lysosome aid in recycling the cell's organic materials?
6. How does the lysosome aid in apoptosis (programmed cell death)?
7. How does the vacuole assist in storage of macromolecules?
8. How does the vacuole provide turgor pressure?

Learning Objective	SYI-1.F Describe the structural features of a cell that allow organisms to capture, store, and use energy
I can…	☐ I can describe the structural features of a cell that allow organisms to capture, store, and use energy. ☐ I can describe the structure of the cristae in the mitochondria. ☐ I can describe ways the structure of the cristae aids in energy storing. ☐ I can describe the structure of the chloroplast. ☐ I can describe the structure of the grana in the chloroplast. ☐ I can describe ways the structure of the thylakoid aids in energy capturing. ☐ I can describe ways the structure of the thylakoid aids in energy storing. ☐ I can identify the location of the light-dependent reactions of photosynthesis. ☐ I can identify the location of carbon fixation (Calvin-Benson cycle) of photosynthesis. ☐ I can identify the location of the Krebs cycle (citric acid cycle) reactions of cellular respiration. ☐ I can identify the location of the electron transport chain and ATP synthesis in cellular respiration.

9. What is the structure of the inner membrane (cristae) of the mitochondria?
    a. How des that contribute to the function of the inner membrane (cristae) of the mitochondria?
10. How is the chloroplast organized?
11. What is embedded in the chloroplast and how does it aid in the function of the chloroplast?
12. Where do the light-dependent and light-independent reactions take place?
13. How does the thylakoid aid in energy capturing?

14. How does the thylakoid aid in energy storing?
15. Where does the citric acid cycle (Krebs cycle) in cellular respiration take place?
16. Where does the electron transport chain in cellular respiration take place?
17. Where does the electron transport chain in photosynthesis take place?
18. Where is ATP synthesized in cellular respiration?
    - Don't get tricked…
19. Where is ATP synthesized in photosynthesis?

Topic 2.3: Cell Size

Learning Objective	ENE-1.B Explain the effect of surface area-to-volume ratios on the exchange of materials between cells or organisms and the environment.
I can…	☐ I can explain the effect of surface area to volume ratios on exchange of materials between cells and the environment. ☐ I can explain the effect of surface area to volume ratios on exchange of materials between organisms and the environment. ☐ I can calculate surface area of a sphere. ☐ I can calculate the surface area of a cube. ☐ I can calculate the surface area of a rectangular solid. ☐ I can calculate the surface area of a cylinder. ☐ I can calculate the volume of a sphere. ☐ I can calculate the volume of a cube. ☐ I can calculate the volume of a rectangular solid. ☐ I can calculate the volume of a cylinder. ☐ I can explain which type cell would be most efficient. ☐ I can describe the relationship between an increase in surface area and an increase in volume. ☐ I can describe ways cells increase their surface area without increasing their volume. ☐ I can describe ways that surface area to volume ratio affects heat exchange with the environment.
Formula Sheet	**RELEVANT EQUATIONS** Volume of a Sphere: $V = \frac{4}{3}\pi r^3$ Volume of a Cube: $V = s^3$ Volume of a Rectangular Solid: $V = lwh$ Volume of a Cylinder: $V = \pi r^2 h$ Surface Area of a Sphere: $SA = 4\pi r^2$ Surface Area of a Cube: $SA = 6s^2$ Surface Area of a Rectangular Solid: $SA = 2lh + 2lw + 2wh$ Surface Area of a Cylinder: $SA = 2\pi rh + 2\pi r^2$ r = radius l = length h = height w = width s = length of one side of a cube

1. How does surface area to volume ratio affect the size of the cell?
2. What type of surface area to volume ratio is most favorable for cells?
3. Calculate the surface areas for the following "cells":

Shape of "cell"	Surface Area
Sphere with a radius of 2	
Cube with a side length of 3	
Rectangular solid with dimensions of 2 x 3 x 4	
Cylinder with a radius of 2 and height of 4	

4. Calculate the volumes for the following "cells":

Shape of "cell"	Volume
Sphere with a radius of 2	
Cube with a side length of 3	
Rectangular solid with dimensions of 2 x 3 x 4	
Cylinder with a radius of 2 and height of 4	

5. Calculate the surface area to volume ratio for the following "cells"

Shape of "cell"	Surface Area
Sphere with a radius of 2	
Cube with a side length of 3	
Rectangular solid with dimensions of 2 x 3 x 4	
Cylinder with a radius of 2 and height of 4	

6. Which "cell" from question #5 would be the most efficient? Justify.
7. How does an increase of surface area affect the increase in volume?
8. How can a cell increase surface area without increasing the volume?
9. How can an increase in surface affect heat exchange?

Learning Objective	ENE-1.C Explain how specialized structures and strategies are used for the efficient exchange of molecules to the environment.
I can…	☐ I can explain ways specialized structures are used for efficient exchange of molecules to the environment. ☐ I can explain ways specialized strategies are used for efficient exchange of molecules to the environment. ☐ I can describe the specialized exchange surfaces available to obtain and release molecules from or into the surrounding environment. ☐ I can describe organism's evolved strategies to obtain nutrients and eliminate wastes.

10. Identify and describe two examples of specialized surfaces for exchanging materials with the surrounding environment.
11. Identify and describe two examples of strategies that organisms use to obtain nutrients and eliminate wastes.

Topic 2.4: Plasma Membranes

Learning Objective	ENE-2.A Describe the roles of each of the components of the cell membrane in maintaining the internal environment of the cell.
I can…	☐ I can identify the components of the cell membrane. ☐ I can describe the structure of a phospholipid. ☐ I can describe the orientation of a phospholipids based on internal conditions of a cell. ☐ I can describe the orientation of a phospholipids based on external conditions of a cell. ☐ I can describe the role of phospholipids in maintaining the internal environment of the cell. ☐ I can describe embedded proteins. ☐ I can describe the role of embedded proteins in maintaining the internal environment of the cell.

1. What are the components of the cell membrane?
2. How do each of the above components function in the cell membrane?
3. Describe the orientation of the components for the structure of the phospholipid.
4. Based on the following internal and external conditions of the cell, how would the phospholipid molecules be oriented? (Note: aqueous means that it contains water)

Internal conditions	External condition	Describe or draw the orientation of the phospholipid molecule(s)
Aqueous	Aqueous	
Nonaqueous	Aqueous	
Aqueous	Nonaqueous	
Nonaqueous	Nonaqueous	

5. How does the phospholipid bilayer maintain the internal environment of a cell?
6. What are the different types of membrane proteins?
7. Describe six functions of membrane proteins.
8. How does the polarity of the membrane protein affect its orientation in the membrane?
9. How does the membrane protein maintain the internal environment of a cell?

Learning Objective	ENE-2.B Describe the Fluid Mosaic Model of cell membranes.
I can…	☐ I can describe the fluid mosaic model of cell membranes. ☐ I can identify the components of the cell membrane. ☐ I can describe the function of steroids (like cholesterol) in the membrane. ☐ I can describe the function of glycoproteins. ☐ I can describe the function of glycolipids. ☐ I can describe characteristics of the membrane that allows for an embedded protein.

10. Define the fluid mosaic model.
11. What is the function of steroids in the plasma membrane?
12. What is the function of glycoproteins in the plasma membrane?
13. What is the function of glycolipids in the plasma membrane?

Topic 2.5: Membrane Permeability

Learning Objective	ENE-2.C Explain how the structure of biological membranes influences selective permeability
I can…	☐ I can explain ways the structure of biological membranes influences selective permeability. ☐ I can describe components of the cell membrane that results in selective permeability. ☐ I can identify the location of a cell membrane. ☐ I can identify the function of a cell membrane. ☐ I can explain why the cell membrane is selectively permeable using membrane structure. ☐ I can describe molecules that can freely pass across the membrane. ☐ I can describe molecules that require a transport protein to pass across the membrane. ☐ I can identify the polarity of a molecule to determine its passage across the membrane.

1. What types of materials can easily pass through the membrane?
    a. Identify two examples.
    b. Why does this type of material easily pass through the membrane?
2. What types of materials require a protein to pass through the membrane?
    a. Identify two examples.
    b. Why does this type of material require a protein to pass through the membrane?
3. True or False? Any molecule can use any transport protein.
4. What types of materials require a vesicle for export or a food vacuole for import?
    a. Identify two examples.
    b. Why does this type of material require bulk transport?
5. Where are plasma membranes found in a cell?

Learning Objective	ENE-2.D Describe the role of the cell wall in maintaining cell structure and function.
I can…	☐ I can describe the role of the cell wall in terms of maintaining cell structure. ☐ I can describe the role of the cell wall in terms of cell function. ☐ I can describe ways that materials can pass through a cell wall ☐ I can describe the cell wall of a plant. ☐ I can describe the cell wall of a fungi. ☐ I can describe the cell wall of prokaryote.

6. What types of cells have a cell wall?
7. How does the cell wall maintain cell structure?
8. How does the cell wall protect the cell from hypotonic solutions?
9. How do materials pass through the cell wall?
10. What composes the cell wall of a plant?
11. What composes the cell wall of a fungi?
12. What composes the cell wall of a prokaryote?

Topic 2.6: Membrane Transport

Learning Objective	**ENE-2.E** Describe the mechanisms that organisms use to maintain solute and water balance.
I can…	☐ I can describe the mechanisms that organisms use to maintain solute balance. ☐ I can describe the mechanisms that organisms use to maintain water balance. ☐ I can describe passive transport. ☐ I can describe active transport.

1. What is passive transport?
2. Identify two examples of passive transport.
3. What is active transport?
4. Identify two examples of active transport.
5. What is required for active transport?

Learning Objective	**ENE-2.F** Describe the mechanisms that organisms use to transport large molecules across the plasma membrane.
I can…	☐ I can describe the mechanisms that organisms use to transport large molecules across the plasma membrane. ☐ I can describe a concentration gradient. ☐ I can describe the cause of a concentration gradient. ☐ I can describe the process of endocytosis. ☐ I can describe the process of exocytosis.

6. What is a concentration gradient?
7. How is a concentration gradient maintained?
8. What causes a concentration gradient?
9. What is endocytosis?
10. Describe the three types of endocytosis.
11. Identify an example of a material that would require endocytosis.
12. How are the food materials brought in by endocytosis digested?
13. What is exocytosis?
14. Identify an example of a material that would require exocytosis.

Topic 2.7: Facilitated Diffusion

Learning Objective	ENE-2.G Explain how the structure of a molecule affects its ability to pass through the plasma membrane.
I can…	☐ I can explain ways the structure of a molecule affects its ability to pass through the plasma membrane. ☐ I can describe ways for charged molecules to pass through the membrane. ☐ I can describe ways for large polar molecules to pass through the membrane. ☐ I can describe ways for large quantities of water to pass through the membrane. ☐ I can describe ways for charged ions to pass through the membrane. ☐ I can identify materials needed of active transport. ☐ I can describe ways to establish and maintain a concentration gradient. ☐ I can describe the function of Na^+/K^+ ATPase in the maintenance of the membrane potential.

1. How do charged molecules or ions pass through the membrane?
2. How do large polar molecules pass through the membrane?
3. How do small amounts of water pass through the membrane?
    - Note: Be careful on this answer
4. How do large amounts of water pass through the membrane?
5. How do the passage of ions affect the membrane potential?
6. What is required for active transport?
7. How is a concentration gradient established and maintained?
8. What is the function of an ATPase?
9. How does the Na^+/K^+ ATPase maintain the membrane potential?

Topic 2.8: Tonicity and Osmoregulation

Learning Objective	**ENE-2.H** Explain how concentration gradients affect the movement of molecules across membranes.
I can…	☐ I can explain ways that concentration gradients affect the movement of molecules across membranes. ☐ I can describe hypotonic to the cell. ☐ I can describe isotonic to the cell. ☐ I can describe hypotonic to the cell. ☐ I can determine the directionality of water flow when given solute. concentration. ☐ I can describe water potential. ☐ I can determine the directionality of water flow when given water potential.
Formula Sheet	**RELEVANT EQUATION** Water Potential: $\Psi = \Psi_p + \Psi_s$ Ψ_p = pressure potential Ψ_s = solute potential

1. What does it mean if a solution is hypotonic?
2. What does it mean if a solution is hypertonic?
3. What does it mean if a solution is isotonic?
4. Using the following chart, determine which direction the water will flow and the result to the cell.

Intracellular Environment	Extracellular Environment	Direction of Water Flow	Result to the Cell
Hypotonic	Hypertonic		
Isotonic	Isotonic		
Hypertonic	Hypotonic		

5. What is water potential?
6. How does it explain the direction of water movement?
7. Calculate the water potential of the following solutions.

Cell	Ψ_P	Ψ_S	Ψ
A	0.0 MPa	-0.2 MPa	
B	0.8 MPa	-0.4 MPa	

8. Which direction will water flow based on the information in question 7? Justify.

Learning Objective	ENE-2.I Explain how osmoregulatory mechanisms contribute to the health and survival of organisms.
I can…	☐ I can explain ways osmoregulatory mechanisms contribute to the health and survival of organisms. ☐ I can describe homeostasis. ☐ I can describe osmoregulation. ☐ I can describe mechanisms of osmoregulation. ☐ I can calculate the solute potential. ☐ I can determine the ionization constant for ionic solutes. ☐ I can determine the ionization constant for covalent solutes. ☐ I can determine direction of water flow based on concentration of solute. ☐ I can determine direction of water flow based on solute potential of a solution.
Formula Sheet	**SOLUTE POTENTIAL OF A SOLUTION** $\Psi_s = -iCRT$ where: i = ionization constant C = molar concentration R = pressure constant $\left(R = 0.0831 \frac{L \cdot bars}{mol \cdot K}\right)$ T = temperature in Kelvin (°C + 273)

9. What is homeostasis?
10. What is osmoregulation?
11. Identify two ways that the cell complete osmoregulation.
12. Identify two ways that organisms complete osmoregulation.
13. Which direction would water flow if one solution A is 0.5 M and solution B is 0.2 M?
14. Which direction would water flow if one solution A is 0.3 M and solution B is 0.6 M?
15. Calculate the solute potential of the following sucrose solutions at 25 degrees Celsius.

Solution	i	C	R	T	Ψ_s
Intracellular		0.5 M			
Extracellular		0.2 M			

16. Assuming a pressure potential of 0.0 MPa, which direction will water flow based on the information provided in question 15? Justify.
17. Calculate the solute potential of the following NaCl solutions at 27 degrees Celsius.

Solution	i	C	R	T	Ψ_s
Intracellular		0.3 M			
Extracellular		0.6 M			

18. Assuming a pressure potential of 0.0 MPa, which direction will water flow based on the information provided in question 17? Justify.

Topic 2.9: Mechanisms of Transport

Learning Objective	ENE-2.J Describe the processes that allow ions and other molecules to move across membranes.
I can…	☐ I can describe the processes that allow ions to move across membranes. ☐ I can describe passive transport. ☐ I can describe facilitated diffusion. ☐ I can describe active transport. ☐ I can describe endocytosis. ☐ I can describe exocytosis. ☐ I can compare simple diffusion to facilitated diffusion.

1. How do ions move across the membrane?
2. Describe the process of passive transport.
3. Describe the process of facilitated diffusion.
4. Describe the process of active transport.
5. Describe the process of endocytosis.
6. Describe the process of exocytosis.
7. How are simple diffusion and facilitated diffusion similar?
8. How are similar diffusion and facilitated diffusion different?

Topic 2.10: Compartmentalization

Learning Objective	ENE-2.K Describe the membrane-bound structures of the eukaryotic cell.
I can…	☐ I can describe membrane bound structures of the eukaryotic cell. ☐ I can describe how the membrane allows for intracellular metabolic processes ☐ I can describe how the membrane allows for enzymatic reactions.

1. How does the membrane of organelles allow for specific processes to take place?
    a. Identify two examples of processes that could not take place without the use of a membrane.
2. How does the membrane of organelles allow for enzymatic processes to take place?

Learning Objective	ENE-2.L Explain how internal membranes and membrane-bound organelles contribute to compartmentalization of eukaryotic cell functions.
I can…	☐ I can explain ways internal membranes contribute to compartmentalization of eukaryotic cell functions. ☐ I can explain ways membrane bound organelles contribute to compartmentalization of eukaryotic cell functions. ☐ I can describe the function of the inner membrane folding (cristae) in the mitochondria. ☐ I can describe the function of the highly folded membrane in the endoplasmic reticulum. ☐ I can describe the function of the multiple membranous sacs in the Golgi bodies/apparatus.

3. How do membrane-bound organelles allow for compartmentalization of the cell and its functions?
4. What is the function of the inner membrane folding in the mitochondria?
5. What is the function of the endoplasmic reticulum's folded membrane?
6. What is the function of thylakoid membranes in the chloroplast?
7. What is the function of the multiple membranes and sacs found in the Golgi?

Topic 2.11: Origins of Cell Compartmentalization

Learning Objective	EVO-1.A Describe similarities and/or differences in compartmentalization between prokaryotic and eukaryotic cells.
I can…	☐ I can describe the similarities in compartmentalization between prokaryotic and eukaryotic cells. ☐ I can describe the differences in compartmentalization between prokaryotic and eukaryotic cells. ☐ I can describe the compartmentalization of prokaryotic cells. ☐ I can describe the compartmentalization of eukaryotic cells. ☐ I can describe the endosymbiotic theory. ☐ I can describe the origination of membrane bound organelles.

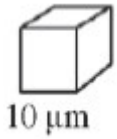
1. Identify three similarities between a prokaryotic and eukaryotic cell.
2. Identify three differences between a prokaryotic and eukaryotic cell.
3. How is a prokaryotic cell compartmentalized?
4. How is a eukaryotic cell compartmentalized?
5. What is the endosymbiotic theory?
6. How did membrane bound organelles originate in eukaryotic cells?

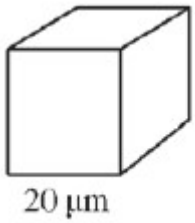
Learning Objective	EVO-1.B Describe the relationship between the functions of endosymbiotic organelles and their free-living ancestral counterparts.
I can…	☐ I can describe the relationship between mitochondria and their free-living ancestral counterparts. ☐ I can describe the relationship between chloroplasts and their free-living ancestral counterparts. ☐ I can provide evidence of endosymbiotic theory through similarities of mitochondria and ancestral species. ☐ I can provide evidence of endosymbiotic theory through similarities of chloroplasts and ancestral species.

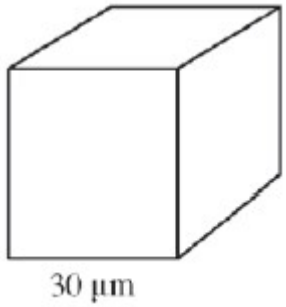
7. Identify three pieces of evidence for endosymbiotic theory by identifying three similarities between mitochondria and the ancestral species.
8. Identify three pieces of evidence for endosymbiotic theory by identifying three similarities between chloroplasts and the ancestral species.
9. Which organelle was obtained first: mitochondria or chloroplast? Justify.

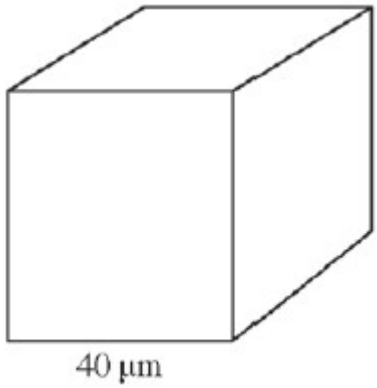
Multiple Choice Practice

1. Simple cuboidal epithelial cells line the ducts of certain human exocrine glands. Various materials are transported into or out of the cells by diffusion. (The formula for the surface area of a cube is $6 \times S^2$, and the formula for the volume of a cube is S^3, where S = the length of a side of the cube.) Which of the following cube-shaped cells would be most efficient in removing waste by diffusion?

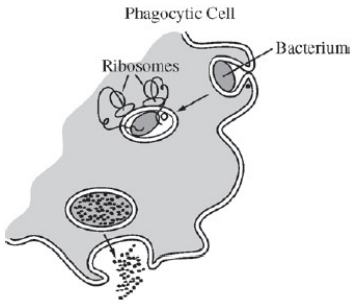
a. 

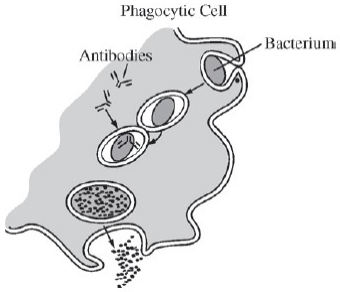
b. 

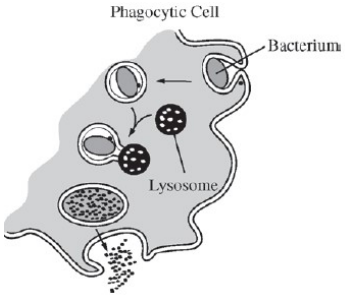
c. 

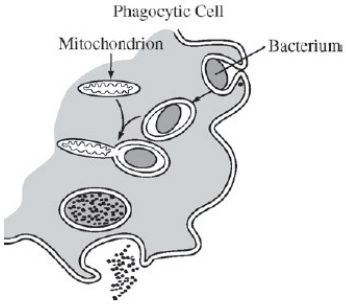
d. 

2. A pathogenic bacterium has been engulfed by a phagocytic cell as part of the nonspecific (innate) immune response. Which of the following illustrations best represents the response?

a. 

b. 

c. 

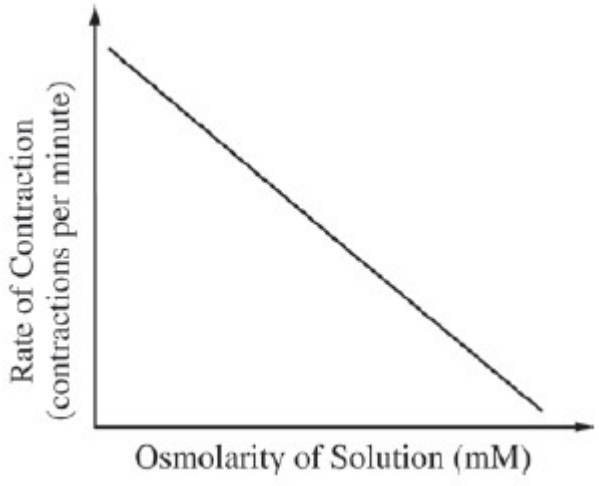
d. 

3. If ATP breakdown (hydrolysis) is inhibited, which of the following types of movement across cell membranes is also inhibited?
    a. Movement of oxygen into a cell
    b. Movement of water through aquaporins
    c. Passage of a solute against its concentration gradient
    d. Facilitated diffusion of a permeable substance

4. A human kidney filters about 200 liters of blood each day. Approximately two liters of liquid and nutrient waste are excreted as urine. The remaining fluid and dissolved substances are reabsorbed and continue to circulate throughout the body. Antidiuretic hormone (ADH) is secreted in response to reduced plasma volume. ADH targets the collecting ducts in the kidney, stimulating the insertion of aquaporins into their plasma membranes and an increased reabsorption of water.

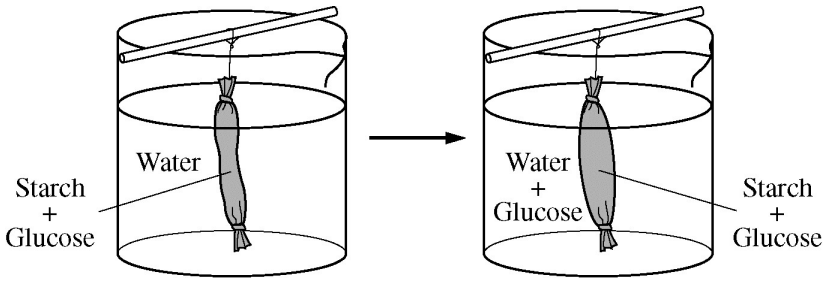
    If ADH secretion is inhibited, which of the following would initially result?
    a. The number of aquaporins would increase in response to the inhibition of ADH.
    b. The person would decrease oral water intake to compensate for the inhibition of ADH.
    c. Blood filtration would increase to compensate for the lack of aquaporins.
    d. The person would produce greater amounts of dilute urine.

5. Paramecia are unicellular protists that have contractile vacuoles to remove excess intracellular water. In an experimental investigation, paramecia were placed in salt solutions of increasing osmolarity. The rate at which the contractile vacuole contracted to pump out excess water was determined and plotted against osmolarity of the solutions, as shown in the graph. Which of the following is the correct explanation for the data?



    a. At higher osmolarity, lower rates of contraction are required because more salt diffuses into the paramecia.
    b. The contraction rate increases as the osmolarity decreases because the amount of water entering the paramecia by osmosis increases.
    c. The contractile vacuole is less efficient in solutions of high osmolarity because of the reduced amount of ATP produced from cellular respiration.
    d. In an isosmotic salt solution, there is no diffusion of water into or out of the paramecia, so the contraction rate is zero.

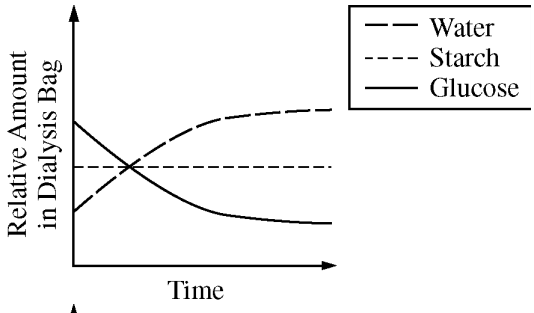
6. A common laboratory investigation involves putting a solution of starch and glucose into a dialysis bag and suspending the bag in a beaker of water, as shown in the figure below.



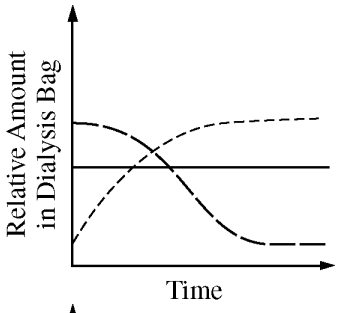
The investigation is aimed at understanding how molecular size affects movement through a membrane.

Which of the following best represents the amount of starch, water, and glucose in the dialysis bag over the course of the investigation?

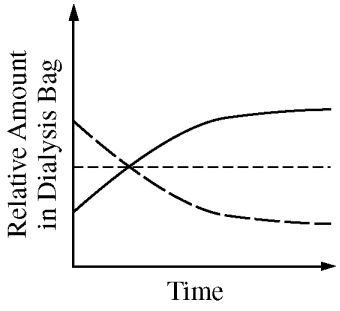
a.



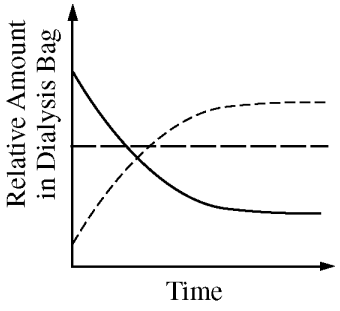
c.



b.



d.



7. A student used a microscope to observe a wet-mount slide of red onion epidermal cells that were suspended in a 1% NaCl solution. The student then added a 15% NaCL solution to the slide and observed the changes that occurred. The student's observations are represented in Figure 1.

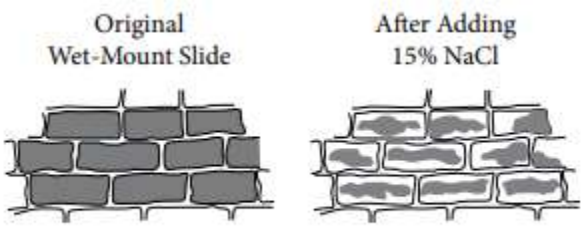


Figure 1. Student's observations of onion cells

Which of the following most directly explains the changes in the cells?

a. The degradation of DNA in the nuclei of the cells
b. The lysis of chloroplasts in the cells
c. The movement of water from the central vacuoles of the cells into the solution
d. The movement of NaCl from the solution into the cytoplasm of the cells

8. Describe the difference between rough ER and smooth ER.
    a. Rough ER compartmentalizes cell; Smooth ER functions in detox and lipid synthesis
    b. Rough ER functions in ribosome synthesis; Smooth ER functions in lipid synthesis
    c. Rough ER functions in detox and lipid synthesis; Smooth ER compartmentalizes cell
    d. Rough ER functions in lipid synthesis; Smooth ER functions in ribosome synthesis

9. Which organelle is a membrane-bound structure that functions in correct folding/chemical modification of proteins?
    a. Golgi complex
    b. Lysosome
    c. Mitochondria
    d. Chloroplast

10. Which is membrane-enclosed sacs that contain hydrolytic enzymes?
    a. Golgi complex
    b. Lysosome
    c. Mitochondria
    d. Chloroplast

11. Which is responsible for storage and release of macromolecules and cellular waster products. In plants, aids in turgor.
    a. Endoplasmic Reticulum
    b. Lysosome
    c. Mitochondria
    d. Vacuole

12. Which of the following is the location for the light-dependent reactions?
    a. grana/thylakoid membrane
    b. matrix
    c. stroma
    d. cristae

13. Which of the following is the location for the Krebs cycle?
    a. grana/thylakoid membrane
    b. matrix
    c. stroma
    d. cristae

14. Which of the following is the location for the ATP synthesis in cellular respiration?
    a. grana/thylakoid membrane
    b. matrix
    c. stroma
    d. cristae

15. Which of the following is the location for the ATP synthesis in photosynthesis?
    a. grana/thylakoid membrane
    b. matrix
    c. stroma
    d. cristae

16. Describe the relationship between cell size and SA:V ratios.
    a. As cells increase in size, the SA:V ratio increases
    b. As cells decrease in size, the SA:V ratio decreases
    c. As cells increase in size, the SA:V ratio decreases
    d. Cell size has no effect on the SA:V ratio

17. Describe the characteristics of a membrane-bound protein.
    a. Entire protein is hydrophilic
    b. Entire protein is hydrophobic
    c. Hydrophilic R group exterior cell & hydrophobic R group interior membrane
    d. Hydrophilic R group interior membrane & hydrophobic R group interior cell

18. Identify which of the following will easily pass through the membrane.
    a. Water
    b. Protein Hormone
    c. Steroid Hormone
    d. Charged Ion

19. Identify which of the following will bind to a membrane protein (and will not enter the cell).
    a. Water
    b. Protein Hormone
    c. Steroid Hormone
    d. Charged Ion

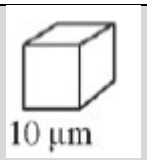
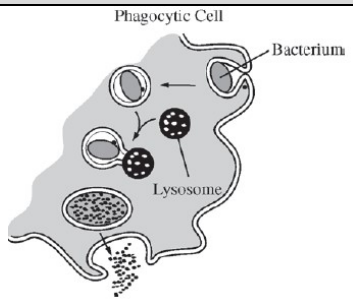
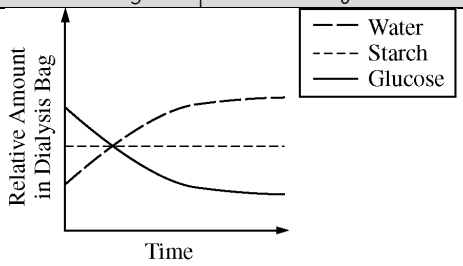
20. Which of the following requires an input of energy for membrane transport?
    a. Charged ion moving against concentration gradient
    b. Water moving into a hypertonic cell
    c. Charged ion moving with concentration gradient
    d. Water moving out of a hypotonic cell

21. What is the difference between endocytosis and exocytosis?
    a. Endocytosis involves cytoplasm of a neighboring cell entering
    b. Endocytosis involves phagocytosis or pinocytosis to bring materials in cell
    c. Exocytosis involves cytoplasm of a neighboring cell exiting
    d. Exocytosis involves phagocytosis or pinocytosis to remove material from cell

22. Which of the following correctly describe the movement of water?
    a. Cell with 0.5M concentration will gain water from the 1.0M exterior solution
    b. Cell with 0.5M concentration will gain water from the 0.5M exterior solution
    c. Cell with 1.0M concentration will gain water from the 0.5M exterior solution
    d. Cell with 0.5M concentration will lose water to the 0.5M exterior solution

23. Why is a eukaryotic cell able to be larger than a prokaryotic cell?
    a. Membrane-bound organelles compartmentalize intracellular processes
    b. Prokaryotic cells have a nucleus which decreases the volume of the cell
    c. Eukaryotic cells have a nucleus which decreases the volume of the cell
    d. Absence of membrane-bound organelles allows for enzymatic reactions.

Multiple Choice Key

Question	Correct Answer	Unit/Topic	Source
1	A. 	2.3	2012 CED #2
2	C. 	2.6	2012 CED #5
3	C. Passage of a solute against its concentration gradient	2.7	2013 #3
4	D. The person would produce greater amounts of dilute urine.	2.7	2012 CED #30
5	B. The contraction rate increases as the osmolarity decreases because the amount of water entering the paramecia by osmosis increases.	2.8	2012 CED #12
6	A. 	2.8	2013 #19
7	C. The movement of water from the central vacuoles of the cells into the solution	2.8	2020 CED #10
8	A. Rough ER compartmentalizes cell; Smooth ER functions in detox and lipid synthesis	2.1	Self
9	A. Golgi complex	2.1	Self
10	B. Lysosome	2.2	Self
11	D. Vacuoles	2.2	Self
12	A. grana/thylakoid membrane	2.2	Self
13	B. matrix	2.2	Self
14	D. cristae	2.2	Self
15	A. grana/thylakoid membrane	2.2	Self
16	C. As cells increase in size, the SA:V ratio decreases	2.3	Self
17	C. Hydrophilic R group exterior cell & hydrophobic R group interior membrane	2.4	Self
18	C. Steroid Hormone	2.5	Self
19	B. Protein Hormone	2.5	Self
20	A. Charged ion moving against concentration gradient	2.6	Self
21	B. Endocytosis involves phagocytosis or pinocytosis to bring materials in cell	2.6	Self
22	C. Cell with 1.0M concentration will gain water from the 0.5M exterior solution	2.7	Self
23	A. Membrane-bound organelles compartmentalize intracellular processes	2.10	Self

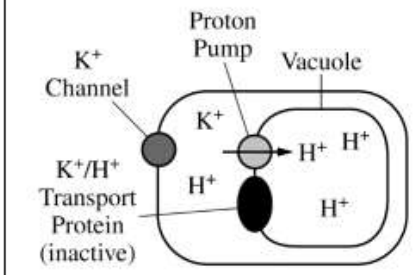
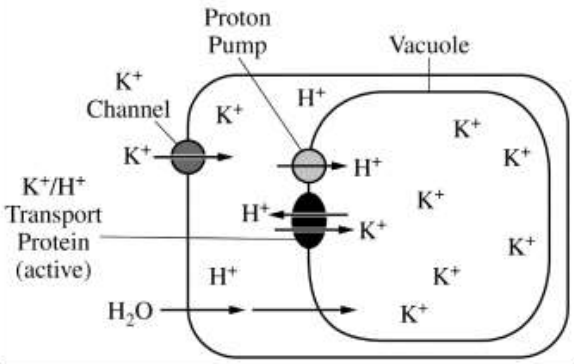
Free Response Practice

2019 #2

This question is found in Unit 8.

2019 #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.

(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.

2018 #2

This question is found in Unit 4.

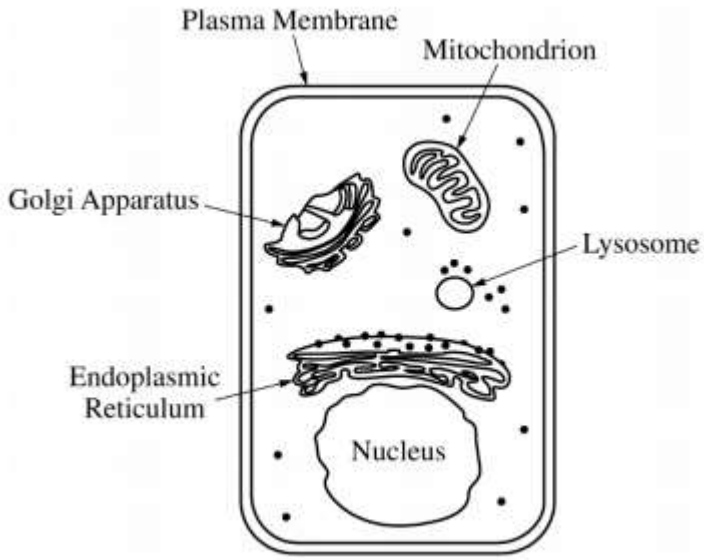
2018 #6

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.

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

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



2017 #8

Estrogens are small hydrophobic lipid hormones that promote cell division and the development of reproductive structures in mammals. Estrogens passively diffuse across the plasma membrane and bind to their receptor proteins in the cytoplasm of target cells.

(a) **Describe** ONE characteristic of the plasma membrane that allows estrogens to passively cross the membrane.

(b) In a laboratory experiment, a researcher generates antibodies that bind to purified estrogen receptors extracted from cells. The researcher uses the antibodies in an attempt to treat estrogen-dependent cancers but finds that the treatment is ineffective. **Explain** the ineffectiveness of the antibodies for treating estrogen-dependent cancers.

2016 #1

This question is found in Unit 7.

2013 #6

The following data were collected by observing subcellular structures of three different types of eukaryotic cells.

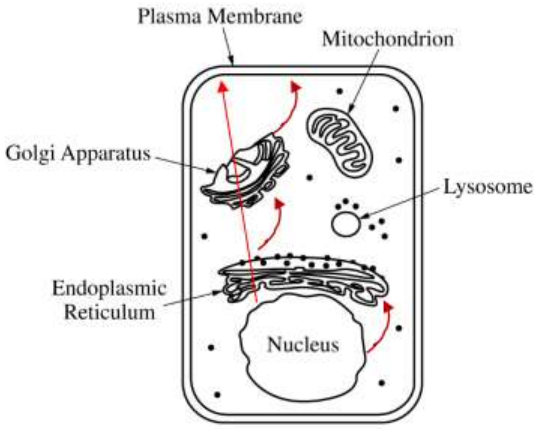
RELATIVE AMOUNTS OF ORGANELLES IN THREE CELL TYPES

Cell Type	Smooth ER	Rough ER	Mitochondria	Cilia	Golgi Bodies
X	Small amount	Small amount	Large number	Present	Small amount
Y	Large amount	Large amount	Moderate number	Absent	Large amount
Z	Absent	Absent	Absent	Absent	Absent

Based on an analysis of the data, **identify** a likely primary function of each cell type and **explain** how the data support the identification.

Free Response Scoring Guidelines

2019 #8		
Part	**Scoring Guidelines**	**Topic**
(a)	**Identification (1 point)** • (K^+ / H^+) transport protein **Description (1 point)** • It moves H^+ out of the vacuole.	2.7 2.8
(b)	**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.	2.7 2.8

2018 #6		
Part	**Scoring Guidelines**	**Topic**
(a)	**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.	2.1
(b)	**Identification (1 point)** • (Rough) Endoplasmic Reticulum/ER	2.1
(c)	**Identification (1 point)** • In the (cellular/plasma) membrane	2.7

2017 #8		
Part	**Scoring Guidelines**	**Topic**
(a)	**Description (1 point)** • Hydrophobic/nonpolar • Space between phospholipids	
(b)	**Explanation (2 points)** • Antibodies are unable to enter the cell. • (Extracellular) antibodies will not bind to (intracellular) estrogen receptors.	

2013 #6

Part	Scoring Guidelines	Topic

Cell Type	Identify function		Explain how data support identification (1 point each correct pair). NOTE: No points for identification without explanation.		
X	• Locomotion • Movement / surface transport	**AND**	Has cilia for movement and large amounts of mitochondria to provide energy for locomotion of cell itself (ciliated protist) or movement of particles (mucus /oocyte) along cell surface		
Y	• Secretion / exocytosis • Protein synthesis	**AND**	Has large amounts of rough ER and Golgi to produce and package proteins		
	• Lipid/hormone synthesis • Detoxification	**AND**	Has large amounts of smooth ER to produce lipids / hormones		
Z	• Transport	**OR**	• Oxygen transport in animal cells • Water transport in plant cells	**AND**	Does not require these organelles
	• Protection	**OR**	• Epidermal cells (stratum corneum, cork, nails)	**AND**	
	• Support	**OR**	• Ground tissue (schlerenchyma) • Vascular tissue (xylem)	**AND**	
	• Storage	**OR**	• Maximizes volume / space available (hemoglobin, oxygen)	**AND**	
	• No function	**OR**	• Is a dead cell/is undergoing apoptosis	**AND**	

Topic: 2.1

Unit 3: Cellular Energetics

Topic	Learning Objective(s)
3.1 Enzyme Structure	**ENE-1.D** Describe the properties of enzymes.
3.2 Enzyme Catalysis	**ENE-1.E** Explain how enzymes affect the rate of biological reactions.
3.3 Environmental Impacts on Enzyme Function	**ENE-1.F** Explain how changes to the structure of an enzyme may affect its function.
	ENE-1.G Explain how the cellular environment affects enzyme activity
3.4 Cellular Energy	**ENE-1.H** Describe the role of energy in living organisms.
3.5 Photosynthesis	**ENE-1.I** Describe the photosynthetic processes that allow organisms to capture and store energy.
	ENE-1.J Explain how cells capture energy from light and transfer it to biological molecules for storage and use
3.6 Cellular Respiration	**ENE-1.K** Describe the processes that allow organisms to use energy stored in biological macromolecules.
	ENE-1.L Explain how cells obtain energy from biological macromolecules in order to power cellular functions.
3.7 Fitness	**SYI-3.A** Explain the connection between variation in the number and types of molecules within cells to the ability of the organism to survive and/or reproduce in different environments.

Topic 3.1: Enzyme Structure

Learning Objective	**ENE-1.D** Describe the properties of enzymes.
I can…	☐ I can describe the monomer that makes up an enzyme. ☐ I can describe ways the enzyme changes after binding to a substrate. ☐ I can describe why the substrate binds to the enzyme. ☐ I can describe the function of an enzyme. ☐ I can describe ways an enzyme performs its function.

1. What is the monomer that makes up an enzyme?
2. How does a substrate bind to an enzyme?
3. What happens after the substrate binds to the enzyme?
4. What is the function of an enzyme?
5. How does the enzyme complete this function?
6. True or False? Enzymes affect the Gibbs Free Energy of a chemical reaction.

Topic 3.2: Enzyme Catalysis

Learning Objective	**ENE-1.E** Explain how enzymes affect the rate of biological reactions.
I can…	☐ I can explain ways that enzymes affect the rate of biological reactions. ☐ I can explain the difference between an enzyme-catalyzed and uncatalyzed reaction.

1. How does an enzyme affect the rate of biological reactions?
2. What is an enzyme-catalyzed reaction?
3. How is the activation energy of an enzyme-catalyzed reaction and an uncatalyzed reaction different?
4. How is the change in free energy of an enzyme-catalyzed reaction and an uncatalyzed reaction different?
5. How is the reaction rate of an enzyme-catalyzed reaction and an uncatalyzed reaction different?

Topic 3.3: Environmental Impacts on Enzyme Function

Learning Objective	**ENE-1.F** Explain how changes to the structure of an enzyme may affect its function.
I can…	☐ I can identify conditions that change the structure of an enzyme. ☐ I can explain ways a condition changes the structure of an enzyme. ☐ I can explain ways a change in structure of an enzyme affects its function. ☐ I can predict changes to reaction rates due to changes in structure of enzyme. ☐ I can describe ways the process of denaturation can be reversible.

1. Identify two conditions that affect the structure of an enzyme.
    a. What happens to the structure of the enzyme in these conditions?
2. How does a change in structure affect the function of an enzyme?
3. Predict the three different possible outcomes when there is a change in structure of an enzyme.
4. What is denaturation?
5. True or False? Denaturation can be reversible.
6. Identify one example of a protein that is reversible after denaturation.
7. Identify one example of a protein that is nonreversible after denaturation.

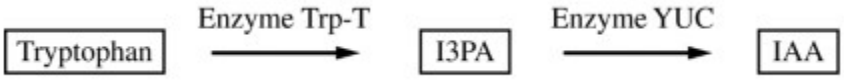
Learning Objective	ENE-1.G Explain how the cellular environment affects enzyme activity
I can…	☐ I can explain ways the cellular environment affects enzyme activity. ☐ I can explain the difference hydrogen ion concentration in varying pH. ☐ I can explain ways the concentration of reactants affects enzyme activity. ☐ I can explain ways the concentration of products affects enzyme activity. ☐ I can explain ways temperature changes affects enzyme activity. ☐ I can explain ways competitive inhibitors affect enzyme activity. ☐ I can explain ways to overcome competitive inhibitor's affect on enzyme activity. ☐ I can explain ways noncompetitive inhibitors affect enzyme activity.
Formula Sheet	**RELEVANT EQUATION** $pH = -\log[H^+]$ **EXCLUSION STATEMENT**—Students must understand the underlying concepts and applications of this equation, but performing calculations using this equation are beyond the scope of the course and the AP Exam.

8. What happens to the pH when the concentration of hydrogen ions
    a. Increases?
    b. Decreases?
9. What happens to an enzyme when the pH
    a. Increases?
    b. Decreases?
10. How does the concentration of reactants affect the reaction rate?
11. How does the concentration of products affect the reaction rate?
12. What happens to an enzyme when the temperature
    a. Increases?
    b. Decreases?
13. How does a change in temperature affect the molecules in the reaction?
14. What is a competitive inhibitor?
15. How can a researcher overcome a competitive inhibitor?
16. What is a noncompetitive inhibitor?
17. How does an inhibitor affect the reaction rate?

Topic 3.4: Cellular Energy

Learning Objective	ENE-1.H Describe the role of energy in living organisms.
I can…	☐ I can describe the role of energy in living organisms. ☐ I can describe that living system require a constant input of energy. ☐ I can describe the laws of thermodynamics. ☐ I can describe ways that order is maintained. ☐ I can describe ways that cellular processes are powered. ☐ I can describe energy coupling. ☐ I can describe the result of loss of energy or energy flow. ☐ I can describe the function of controlled energy pathways. ☐ I can describe the relationship between products of a reaction and reactants of a subsequent reaction. ☐ I can describe metabolic pathways.

1. What is the first law of thermodynamics?
2. What is the second law of thermodynamics?
3. How is order (entropy) maintained in a system?
4. How are cellular processes powered?
5. What is an endergonic reaction?
6. What is an exergonic reaction?
7. What is energy coupling?
8. What happens if an organism has a loss of energy or energy flow?
9. Why does the cell undergo the step-wise function to control energy release through cellular respiration?
10. In a metabolic pathway, how does the product of one reaction relate to the reactants of the subsequent reaction?
11. Using the given pathway from 2018 #2 free response, how is the pathway affected by:



   a. Decrease in Tryptophan
   b. Decrease in Enzyme Trp-T
   c. Decrease in I3PA
   d. Decrease in Enzyme YUC
   e. Decrease in IAA

Topic 3.5: Photosynthesis

Learning Objective	ENE-1.I Describe the photosynthetic processes that allow organisms to capture and store energy.
I can…	☐ I can describe the photosynthetic processes that allow organisms to capture and store energy. ☐ I can describe the location of photosynthesis evolution. ☐ I can provide evidence to support oxygenation to atmosphere from cyanobacteria. ☐ I can describe the light-dependent reactions. ☐ I can describe ways that ATP is synthesized in the light-dependent reactions. ☐ I can describe ways that NADPH is synthesized in the light-dependent reactions.

1. Where does the energy that fuels photosynthesis come from?
2. What organism first evolved photosynthesis?
3. Identify one piece of evidence that supports oxygenation to atmosphere from cyanobacteria.
4. What are the light-dependent reactions?
5. Where do the light-dependent reactions take place?
6. How is ATP synthesized in the light-dependent reactions?
7. How is NADPH synthesized in the light-dependent reactions?

Learning Objective	ENE-1.J Explain how cells capture energy from light and transfer it to biological molecules for storage and use
I can…	☐ I can explain ways cells capture energy from light. ☐ I can explain ways cells transfer energy from light to biological molecules for storage and use. ☐ I can describe chlorophyll. ☐ I can explain the effect on electrons after absorbing energy from light. ☐ I can describe the anatomy of the thylakoid membrane (aka the set-up of the photosystems and electron transport chains) ☐ I can describe the photosystem. ☐ I can describe the relationship between the photosystems and the electron transport chain. ☐ I can explain ways the proton gradient is produced in the electron transport chain. ☐ I can explain the relationship between the proton gradient and ATP synthesis. ☐ I can explain the relationship between the light reactions and the Calvin cycle.

8. What is chlorophyll?
9. How does chlorophyll aid in energy capture?
10. Where is chlorophyll located?
11. What happens to the electrons after absorbing energy from light?
12. How is the photosystem organized to aid in energy capture?
13. How is the thylakoid membrane organized to aid in energy capture?
14. What is the relationship between the photosystem and the electron transport chain?
15. What direction are the protons pumped during the light dependent reactions to generate the proton gradient?
16. How does the proton gradient result in ATP synthesis?
17. What is the relationship between the light reactions and the Calvin cycle?

Topic 3.6: Cellular Respiration

Learning Objective	ENE-1.K Describe the processes that allow organisms to use energy stored in biological macromolecules.
I can…	☐ I can describe the processes that allow organisms to use energy stored in biological macromolecules. ☐ I can describe fermentation. ☐ I can describe cellular respiration. ☐ I can describe the electron transport chain. ☐ I can identify locations of electron transport chains. ☐ I can describe ways that electrons are moved through the process of cellular respiration. ☐ I can identify the final electron acceptor in each electron transport chain. ☐ I can describe the process of electrons moving down the electron transport chain. ☐ I can describe the process that generates the proton gradient. ☐ I can identify the location with the high proton concentration. ☐ I can describe the effect of a high proton concentration on the pH of a region. ☐ I can compare electron transport chain in eukaryotes and prokaryotes. ☐ I can describe chemiosmosis. ☐ I can describe oxidative phosphorylation. ☐ I can describe photophosphorylation. ☐ I can describe ways that endotherms maintain their body temperature.

1. What is fermentation?
    a. Identify the products of fermentation.
2. What is the process of cellular respiration?
    a. Identify the products of cellular respiration.
3. What is the electron transport chain?
4. Identify the three locations of the electron transport chains in cells.
5. What is the pathway of electrons through the process of cellular respiration? (where do the electrons start, what carries the electrons, where do the electrons end)
6. Identify the final electron acceptor in the following electron transport chains
    a. Photosynthesis
    b. Cellular respiration
7. How do electrons move through the electron transport chain?
8. What process generates the proton gradient?
9. What direction do the protons get pumped to generate the proton gradient in cellular respiration?
10. How does the proton concentration affect the pH of the area?
11. Identify two differences between the electron transport chain in prokaryotes and eukaryotes.
12. What is chemiosmosis?
13. What is oxidative phosphorylation?
14. What is photophosphorylation?
15. What is an endotherm?
    a. How do they maintain their body temperature?
16. What is decoupling oxidative phosphorylation?
    a. How does it generate heat?

Learning Objective	ENE-1.L Explain how cells obtain energy from biological macromolecules in order to power cellular functions.
I can…	☐ I can explain ways cells obtain energy from biological macromolecules in order to power cellular functions. ☐ I can describe glycolysis. ☐ I can identify the starting materials of glycolysis. ☐ I can identify the products of glycolysis. ☐ I can identify where the parts of cellular respiration take place in the cell. ☐ I can describe the Krebs cycle. ☐ I can identify the starting materials of Krebs cycle. ☐ I can identify the products of Krebs cycle. ☐ I can describe ways electrons are transported to the electron transport chain. ☐ I can describe the result of electrons transferred between molecules in the electron transport chain. ☐ I can describe the function of fermentation. ☐ I can describe the function of ATP hydrolysis.

1. What is glycolysis?
    a. What are the starting materials?
    b. What are the products?
    c. Where does it take place in the cell?
2. Based on the location of glycolysis, what statement can be made about evolutionary history?
3. What is the Krebs cycle?
    a. What are the starting materials?
    b. What are the products?
    c. Where does it take place in the cell?
4. How are electrons transported to the electron transport chain?
5. Where is the electron transport chain located?
6. What occurs as electrons are transferred from one cytochrome to the next in the electron transport chain?
7. What is the function of fermentation?
    a. What are the products?
8. What is the function of ATP hydrolysis?

Topic 3.7: Fitness

Learning Objective	SYI-3.A Explain the connection between variation in the number and types of molecules within cells to the ability of the organism to survive and/or reproduce in different environments.
I can…	☐ I can explain the connection between variation in the number and types of molecules within cells to the ability of the organism to survive and reproduce in different environment. ☐ I can explain ways variation at the molecular level provides organisms with the ability to respond to environmental stimuli. ☐ I can explain ways variation in the number of molecules within cells provides organisms a selective advantage. ☐ I can explain ways variation in the types of molecules within cells provides organisms a selective advantage.

1. How does variation at the molecular level affect the organism's ability to respond to environmental stimuli?
2. How does this variation in number of molecules lead to a selective advantage?
3. How does this variation in types of molecules lead to a selective advantage?

Multiple Choice Practice

1. The enzyme trypsin aids in protein digestion in the small intestine. The relative activity of trypsin at different pH values is shown in Figure 1.

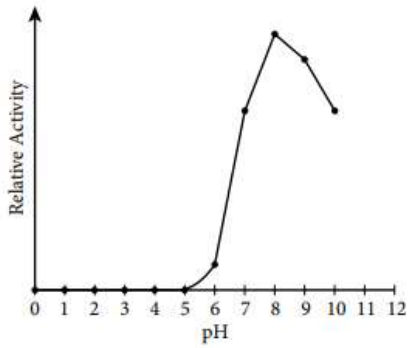


Figure 1. Effect of pH on the activity of trypsin

Which of the following statements best explains the activity levels of trypsin shown in Figure 1?

   a. The small intestine releases inhibitor molecules that block the activity of trypsin unless it is at its optimum pH.
   b. The number of effective collisions between trypsin and its substrate increase at higher pH values.
   c. As pH values increase, the substrate concentration decreases, leading to an eventual decline in the rate of the trypsin-catalyzed reaction.
   d. At extremely low pH values, trypsin is denatured and cannot function efficiently

2. It is estimated that oxygen production first evolved in photosynthetic prokaryotes approximately 2.7 billion years ago. The first photosynthetic prokaryotes are presumed to be similar to today's cyanobacteria.

   Which of the following best supports the claim that photosynthetic prokaryotes were responsible for the oxygen in Earth's atmosphere?

   a. The light reactions of photosynthesis split carbon dioxide into carbon and oxygen.
   b. The light reactions of photosynthesis split water into hydrogen ions and oxygen.
   c. The Calvin cycle splits glucose into carbon, hydrogen, and oxygen.
   d. The Calvin cycle splits water into hydrogen ions and oxygen.

3. Which of the following questions is most relevant to understanding the Calvin cycle?

   a. How does chlorophyll capture light?
   b. How is ATP used in the formation of 3-carbon carbohydrates?
   c. How is $NADP^+$ reduced to NADPH?
   d. How is ATP produced in chemiosmosis?

Use the following information to answer questions 4 & 5:

A student placed 20 tobacco seeds of the same species on moist paper towels in each of two petri dishes. Dish A was wrapped completely in an opaque cover to exclude all light. Dish B was not wrapped. The dishes were placed equidistant from a light source set to a cycle of 14 hours of light and 10 hours of dark. All other conditions were the same for both dishes. The dishes were examined after 7 days and the opaque cover was permanently removed from dish A. Both dishes were returned to the light and examined again at 14 days. The following data were obtained.

	Dish A		Dish B	
	Day 7 Covered	Day 14 Uncovered	Day 7 Uncovered	Day 14 Uncovered
Germinated seeds	12	20	20	20
Green-leaved seedlings	0	14	15	15
Yellow-leaved seedlings	12	6	5	5
Mean stem length below first set of leaves	8 mm	9 mm	3 mm	3 mm

4. According to the results of this experiment, germination of tobacco seeds during the first week is
   a. increased by exposure to light
   b. unaffected by light intensity
   c. prevented by paper towels
   d. accelerated in green-leaved seedlings

5. Additional observations were made on day 21, and no yellow-leaved seedlings were found alive in either dish. This is most likely because
   a. yellow-leaved seedlings were unable to absorb water from the paper towels
   b. taller green-leaved seedlings blocked the light and prevented photosynthesis
   c. yellow-leaved seedlings were unable to convert light energy to chemical energy
   d. a higher rate of respiration in yellow-leaved seedlings depleted their stored nutrients

Use the following information to answer questions 6 – 10:

Photosynthetic activity can be measured using chloroplasts suspended in a buffered solution containing DCPIP, a dye that can accept electrons from the electron transport chain of photosynthesis. Transfer of electrons to DCPIP decreases the relative absorbance of a specific wavelength of light (605 nm) by a solution that contains the dye.

A buffered solution containing chloroplasts and DCPIP was divided equally among six identical samples. The samples were placed at various distances from a lamp, and then all samples were exposed to white light from the lamp for 60 minutes at room temperature. Sample 3 was wrapped in foil to prevent any light from reaching the solution. At 20-minute intervals, the photosynthetic activity in each sample was determined by measuring the relative absorbance of 605 nm light. The results of the experiment are provided below.

Relative Absorbance of 605 nm Light (arbitrary units)

Sample	Distance from Lamp (cm)	0 min	20 min	40 min	60 min
1	15	0.89	0.61	0.34	0.04
2	30	0.90	0.67	0.41	0.14
3*	30	0.88	0.87	0.86	0.87
4	45	0.86	0.69	0.47	0.26
5	60	0.92	0.75	0.59	0.41
6	75	0.88	0.79	0.71	0.58
* Wrapped in foil					

6. Which of the following provides the best indication that light is required for the activation of electron transfer reactions in chloroplasts?
    a. Calculating the rate of change of the absorbance for sample 1
    b. Comparing the observed results for sample 2 and sample 3
    c. Repeating the entire experimental procedure at night
    d. Including multiple trials for all the samples

7. Which of the following can be reasonably concluded from the experimental results?
    a. Chloroplasts must be suspended in a buffer solution to function properly.
    b. The optimal temperature for activation of electron transfer is 25°C.
    c. DCPIP inhibits biochemical reactions in suspended chloroplasts.
    d. Light from a lamp can substitute for sunlight in stimulating chloroplast processes

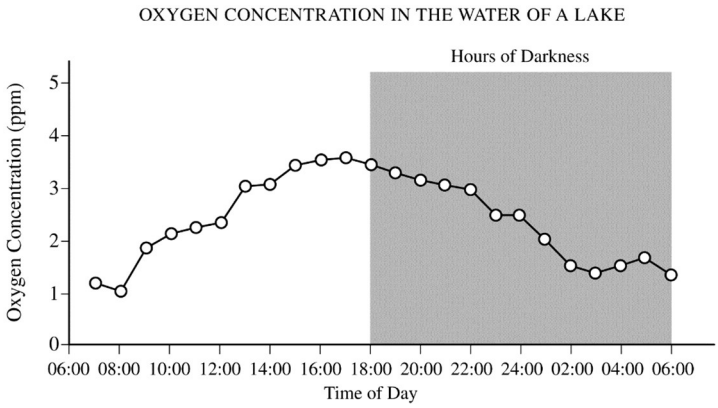
8. If an additional sample containing the chloroplast/DCPIP solution was placed at a distance of 90 cm from the lamp, which of the following predictions would be most consistent with the experimental results?
    a. The concentration of DCPIP in the solution will increase exponentially.
    b. The absorbance at 60 minutes will be roughly equal to 1.4.
    c. The change in absorbance over time in the solution will be less than that of the other samples.
    d. The temperature of the solution will exceed 75°C.

9. Which of the following descriptions of photosynthesis best explains the results of the experiment?
    a. Availability of electrons for transfer to DCPIP depends on light energy.
    b. Movement of DCPIP across chloroplast membranes occurs in less than 60 minutes.
    c. Chlorophyll molecules degrade rapidly in the presence of DCPIP.
    d. DCPIP can only be used to measure photosynthetic activity at low light levels.

10. Which of the following scientific questions could be investigated using a similar experimental setup?
    a. How much carbon dioxide is required by a plant cell to produce one molecule of glucose?
    b. What wavelength of light best activates electron transfer reactions in chloroplasts?
    c. Which molecule in chloroplasts accepts activated electrons from DCPIP during photosynthesis?
    d. Are the same genes that are expressed in chloroplasts also expressed in mitochondria?

11. What most likely causes the trends in oxygen concentration shown in the graph below?

    a. The water becomes colder at night and thus holds more oxygen.
    b. Respiration in most organisms increases at night.
    c. More organisms are respiring at night than during the day.
    d. Photosynthesis produces more oxygen than is consumed by respiration during the day.



12. The chemical reaction for photosynthesis is

$$6\ CO_2 + 12\ H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

If the input water is labeled with a radioactive isotope of oxygen, 18O, then the oxygen gas released as the reaction proceeds is also labeled with 18O. Which of the following is the most likely explanation?

a. During the light reactions of photosynthesis, water is split, the hydrogen atoms combine with the CO2, and oxygen gas is released.
b. During the light reactions of photosynthesis, water is split, removing electrons and protons, and oxygen gas is released.
c. During the Calvin cycle, water is split, regenerating NADPH from NADP+, and oxygen gas is released.
d. During the Calvin cycle, water is split, the hydrogen atoms are added to intermediates of sugar synthesis, and oxygen gas is released.

13. Students in a class measured the mass of various living organisms. They then kept the organisms in the dark for 24 hours before remeasuring them. None of the organisms were provided with nutrients during the 24-hour period. The data are as follows.

Organism	Starting Mass (g)	Final Mass (g)
Elodea (submerged aquatic plant)	15.10	14.01
Goldfish	10.10	9.84
Sea anemone	25.60	24.98

Which of the following is the best explanation for the pattern of change in mass of the organisms over time?

a. Water loss due to evaporation
b. Cellular respiration
c. The law of conservation of matter
d. Growth and reproduction

Use the following information to answer questions 14 & 15:

An experiment to measure the rate of respiration in crickets and mice at 10°C and 25°C was performed using a respirometer, an apparatus that measures changes in gas volume. Respiration was measured in mL of O_2 consumed per gram of organism over several five-minute trials and the following data were obtained.

Organism	Temperature (°C)	Average respiration (mL O_2/g/min)
Mouse	10	0.0518
Mouse	25	0.0321
Cricket	10	0.0013
Cricket	25	0.0038

14. During aerobic cellular respiration, oxygen gas is consumed at the same rate as carbon dioxide gas is produced. In order to provide accurate volumetric measurements of oxygen gas consumption, the experimental setup should include which of the following?

a. A substance that removes carbon dioxide gas
b. A plant to produce oxygen
c. A glucose reserve
d. A valve to release excess water

15. According to the data, the mice at 10°C demonstrated greater oxygen consumption per gram of tissue than did the mice at 25°C. This is most likely explained by which of the following statements?
    a. The mice at 10°C had a higher rate of ATP production than the mice at 25°C.
    b. The mice at 10°C had a lower metabolic rate than the mice at 25°C.
    c. The mice at 25°C weighed less than the mice at 10°C.
    d. The mice at 25°C were more active than the mice at 10°C.

16. Where on an enzyme does the substrate bind?
    a. active site
    b. allosteric site
    c. C-terminus
    d. N-terminus

17. Describe the effect on the free energy of doubling the amount of enzyme.
    a. double the free energy
    b. half the free energy
    c. triple the free energy
    d. no effect on free energy

18. Which structure is unaffected by denaturation?
    a. Primary
    b. Secondary
    c. Tertiary
    d. Quaternary

19. Which environmental conditions can cause denaturation of the enzyme?
    a. slight increase in temperature
    b. extreme increase in temperature
    c. decrease in temperature
    d. extreme increase in temperature and pH changes

20. Which of the following will increase the rate of the reaction?
    a. increase product
    b. increase substrate
    c. increase inhibitor
    d. increase enzyme

21. Describe why an increase in temperature increases the rate of the reaction.
    a. increase in temperature increases the speed/kinetic energy of particles
    b. increase in temperature activates more enzyme to increase the rate
    c. increase in temperature results in increase in substrate available
    d. increase in temperature allows for a tighter fit in the active site

22. Describe the difference between competitive and noncompetitive inhibitors.
    a. noncompetitive binds to active site and competitive binds to other site
    b. competitive is irreversible and noncompetitive is reversible binding
    c. competitive is irreversible and noncompetitive is reversible binding
    d. noncompetitive is irreversible and competitive is reversible binding

23. In order to maintain order and power cellular processes,
    a. energy input must exceed energy loss
    b. energy input equals energy loss
    c. energy loss must exceed energy input
    d. energy loss equals energy input

24. What is the process of an endergonic reaction being fueled by an exergonic reaction called?
    a. second law of thermodynamics
    b. energy coupling
    c. first law of thermodynamics
    d. endergonic/exergonic switch

25. Where did photosynthesis first evolve?
    a. prokaryotic organisms
    b. alien organisms
    c. eukaryotic organisms
    d. abiotic processes

26. What are the products of the light-dependent reactions of photosynthesis?
    a. ATP & NADH
    b. CO_2 & H_2O
    c. NADPH & ATP
    d. Organic Compounds & O_2

27. What is the function of the electron transport chain between Photosystem II and Photosystem I?
    a. establish electrochemical gradient of protons
    b. to funnel electrons into photosystem I for the Calvin cycle
    c. transport electrons to oxygen to make water
    d. to synthesize ATP using ATP synthase

28. Where does the Calvin cycle take place?
    a. thylakoid membrane
    b. cristae
    c. stroma
    d. matrix

29. Where does the electron transport chain take place?
    a. chloroplasts
    b. prokaryotic plasma membrane
    c. mitochondria
    d. all of the choices

30. Which of the following are electron carriers for the electron transport chain in cellular respiration?
    a. NADPH
    b. $FADH_2$
    c. NADH
    d. NADH & $FADH_2$

31. Which process releases energy in glucose to form ATP, NADH, and pyruvate?
    a. Glycolysis
    b. Oxidative Phosphorylation
    c. Krebs Cycle
    d. Fermentation

32. What is oxidation?
    a. loss of electrons
    b. loss of water
    c. gain of electrons
    d. gain of water

33. In the electron transport chain of cellular respiration, where is the electrochemical gradient of protons generated?
    a. cytosol
    b. cristae
    c. matrix
    d. intermembrane space

34. Which process does NOT require oxygen?
    a. Glycolysis
    b. Oxidative Phosphorylation
    c. Krebs Cycle
    d. Aerobic respiration

35. Describe the pathway of electrons in the light reactions.
    a. H_2O → PSI → ETC → PSII → NADPH
    b. H_2O → PSII → ETC → PSI → NADPH
    c. H_2O → PSII → ETC → PSI → NADH
    d. H_2O → PSI → ETC → PSII → NADH

Multiple Choice Key

Question	Correct Answer	Unit/Topic	Source
1	D. At extremely low pH values, trypsin is denatured and cannot function efficiently	3.3	2020 CED
2	B. The light reactions of photosynthesis split water into hydrogen ions and oxygen.	3.5	2020 CED
3	B. How is ATP used in the formation of 3-carbon carbohydrates?	3.5	2013 #5
4	A. increased by exposure to light	3.5	2012 CED #13
5	C. yellow-leaved seedlings were unable to convert light energy to chemical energy	3.5	2012 CED #15
6	B. Comparing the observed results for sample 2 and sample 3	3.5	2013 #41
7	D. Light from a lamp can substitute for sunlight in stimulating chloroplast processes	3.5	2013 #42
8	C. The change in absorbance over time in the solution will be less than that of the other samples.	3.5	2013 #43
9	A. Availability of electrons for transfer to DCPIP depends on light energy.	3.5	2013 #44
10	B. What wavelength of light best activates electron transfer reactions in chloroplasts?	3.5	2013 #45
11	D. Photosynthesis produces more oxygen than is consumed by respiration during the day.	3.5	2013 #17
12	B. During the light reactions of photosynthesis, water is split, removing electrons and protons, and oxygen gas is released.	3.5	2012 CED #36
13	B. Cellular respiration	3.6	2013 #47
14	A. A substance that removes carbon dioxide gas	3.6	2012 CED #8
15	A. The mice at 10°C had a higher rate of ATP production than the mice at 25°C.	3.6	2012 CED #9
16	A. active site	3.1	Self
17	D. no effect on free energy	3.2	Self
18	A. Primary	3.3	Self
19	D. extreme increase in temperature and pH change	3.3	Self
20	D. increase enzyme	3.3	Self
21	A. increase in temperature increases the speed/kinetic energy of particles	3.3	Self
22	C. competitive is irreversible and noncompetitive is reversible binding	3.3	Self
23	A. energy input must exceed energy loss	3.4	Self
24	B. energy coupling	3.4	Self
25	A. prokaryotic organisms	3.5	Self
26	C. NADPH & ATP	3.5	Self
27	A. establish electrochemical gradient of protons	3.5	Self
28	C. stroma	3.5	Self
29	D. all of the choices	3.6	Self
30	D. NADH & $FADH_2$	3.6	Self
31	A. Glycolysis	3.6	Self

32	A. loss of electrons	3.6	Self
33	D. intermembrane space	3.6	Self
34	A. Glycolysis	3.6	Self
35	B. H_2O → PSII → ETC → PSI → NADPH	3.6	Self

Free Response Practice

2019 #3
This question is in Unit 5.

2019 #7
This question is in Unit 6.

2017 #1
This question is in Unit 8.

2017 #5

Microcystis aeruginosis is a freshwater photosynthetic cyanobacterium. When temperatures increase and nutrients are readily available in its pond habitat, M. aeruginosis undergoes rapid cell division and forms an extremely large, visible mass of cells called an algal bloom. M. aeruginosis has a short life span and is decomposed by aerobic bacteria and fungi. Identify the metabolic pathway and the organism that is primarily responsible for the change in oxygen level in the pond between time I and II AND between times III and IV.

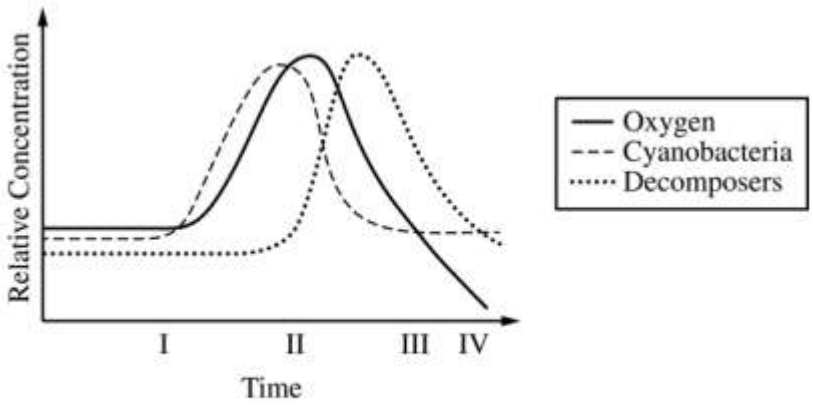


Figure 1. Characteristics of a pond community over time

2017 #7

Many species of bacteria grow in the mouths of animals and can form biofilms on teeth (plaque). Within plaque, the outer layers contain high levels of oxygen and the layers closest to the tooth contain low levels of oxygen. The surface of the tooth is covered in a hard layer of enamel, which can be dissolved under acidic conditions. When the enamel breaks down, the bacteria in plaque can extract nutrients from the tooth and cause cavities.
Certain types of bacteria (e.g. *Streptococcus mutans*) thrive in the innermost anaerobic layers of the plaque and are associated with cavities. Other types of bacteria (*Streptococcus sanguinis*) compete with *S. mutans* but are unable to thrive in acidic environments.

(a) **Identify** the biochemical pathway *S. mutans* uses for metabolizing sugar and **describe** how the pathway contributes to the low pH in the inner layers of plaque.

(b) Normal tooth brushing effectively removes much of the plaque from the flat surfaces of teeth, but cannot reach the surfaces between teeth. Many commercial toothpastes contain alkaline components, which raise the pH of the mouth. **Predict** how the population sizes of *S. mutans* AND *S. sanguinis* in the bacterial community in the plaque between the teeth are likely to change when these toothpastes are used.

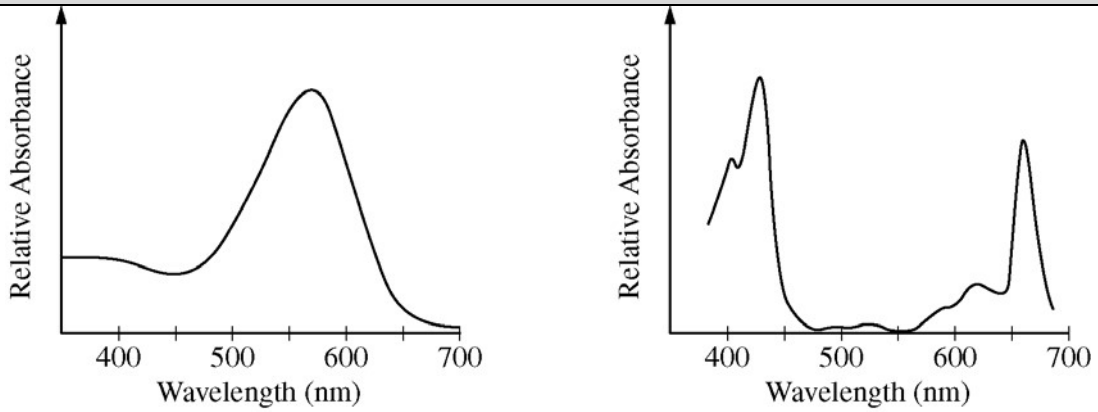
2016 #3

This question is in Unit 8.

2015 #2

This question is in Unit 7.

2013 #2



Color	Wavelength (nm)
Violet	380 – 450
Blue	450 – 475
Cyan	475 – 495
Green	495 – 570
Yellow	570 – 590
Orange	590 – 620
Red	620 - 750

An absorption spectrum indicates the relative amount of light absorbed across a range of wavelengths. The graphs above represent the absorption spectra of individual pigments isolated from two different organisms. One of the pigments is chlorophyll a, commonly found in green plants. The other pigment is bacteriorhodopsin, commonly found in purple photosynthetic bacteria. The table above shows the approximate ranges of wavelengths of different colors in the visible light spectrum.

(a) **Identify** the pigment (chlorophyll *a* or bacteriorhodopsin) used to generate the absorption spectrum in each of the graphs above. **Explain** and **justify** your answer.

(b) In an experiment, identical organisms containing the pigment from Graph II as the predominant light-capturing pigment are separated into three groups. The organisms in each group are illuminated with light of a single wavelength (650 nm for the first group, 550 nm for the second group, and 430 nm for the third group). The three light sources are of equal intensity, and all organisms are illuminated for equal lengths of time. **Predict** the relative rate of photosynthesis in each of the three groups. **Justify** your predictions.

(c) Bacteriorhodopsin has been found in aquatic organisms whose ancestors existed before the ancestors of plants evolved in the same environment. **Propose** a possible evolutionary history of plants that could have resulted in a predominant photosynthetic system that uses only some of the colors of the visible light spectrum.

2013 #4
This question is in Unit 8.

Free Response Scoring Guidelines

2017 #5

Part	Scoring Guidelines	Topic
	Identification (2 points per row; 4 points maximum) Time Period | Metabolic pathway **(1 point per box)** | Organism **(1 point per box)** I – II | Photosynthesis | Cyanobacteria (*M. aeruginosis*) III – IV | Cellular respiration | Decomposers/fungi/bacteria	3.5 3.6

2017 #7

Part	Scoring Guidelines	Topic
(a)	**Identify** the biochemical pathway *S. mutans* uses for metabolizing sugar and **describe** how the pathway contributes to the low pH in the inner layers of plaque. **(2 points; both points must be earned from the same row.)** **Identification** | **Description** fermentation | (lactic) acid/lactate anaerobic respiration | acid glycolysis | (pyruvic) acid/pyruvate	3.6
(b)	Normal tooth brushing effectively removes much of the plaque from the flat surfaces of teeth but cannot reach the surfaces between teeth. Many commercial toothpastes contain alkaline components, which raise the pH of the mouth. **Predict** how the population sizes of *S. mutans* AND *S. sanguinis* in the bacterial community in the plaque between the teeth are likely to change when these toothpastes are used. **(1 point)** **Prediction (1 point)** • *S. mutans* decreases AND *S. sanguinis* increases	3.6

2013 #2

Part	Scoring Guidelines	Topic
(a)	**Identify** the pigment (chlorophyll *a* or bacteriorhodopsin) used to generate the absorption spectrum in each of the graphs above. **Explain** and **justify** your answer. **(3 points maximum)** **1 point per box** **Identify** BOTH pigments: Graph 1 = bacteriorhodopsin AND graph 2 = chlorophyll *a* **Explain** that an organism containing bacteriorhodopsin appears purple because the pigment absorbs light in the green range of the light spectrum and/or reflects violet or red and blue light. The reflected red and blue light appears purple. **Explain** that an organism containing chlorophyll *a* appears green because the pigment absorbs light in the red and blue ranges of the light spectrum and/or reflects green light.	3.5

(b) 3.5

) In an experiment, identical organisms containing the pigment from Graph II as the predominant light-capturing pigment are separated into three groups. The organisms in each group are illuminated with light of a single wavelength (650 nm for the first group, 550 nm for the second group, and 430 nm for the third group). The three light sources are of equal intensity, and all organisms are illuminated for equal lengths of time. **Predict** the relative rate of photosynthesis in each of the three groups. **Justify** your predictions. (**5 points maximum**)

Wavelength (Group)	Prediction (**1 point each box**)	Justification (**1 point each box**)
650 nm (1st Group)	Intermediate rate	An intermediate level of absorption occurs at 650 nm (compared to 430 nm and 550 nm); *therefore*, an intermediate amount of energy is available to drive photosynthesis.
550 nm (2nd Group)	Lowest rate	The lowest level of absorption occurs at 550 nm; *therefore*, the least amount of energy is available to drive photosynthesis.
430 nm (3rd Group)	Highest rate	The highest level of absorption occurs at 430 nm; *therefore*, the greatest amount of energy is available to drive photosynthesis.

(c) 3.7

) Bacteriorhodopsin has been found in aquatic organisms whose ancestors existed before the ancestors of plants evolved in the same environment. **Propose** a possible evolutionary history of plants that could have resulted in a predominant photosynthetic system that uses only some of the colors of the visible light spectrum. (**1 point per box; 2 points maximum**)

Proposal that includes an environmental selective pressure: • Green light was being absorbed by aquatic organisms using bacteriorhodopsin. • Unabsorbed wavelengths of light were available resources that organisms could exploit. • Absorbing visible light at all wavelengths may provide too much energy to the organism. • Absorbing light from ultraviolet wavelengths (shorter wavelengths = higher energy) could cause damage to the organism. • Absorbing light with longer wavelengths may not provide sufficient energy for the organism.
Appropriate reasoning to support the proposal: • Natural selection favored organisms that rely on pigments that absorb available wavelengths of light. • Endosymbiosis: chloroplasts evolved from cyanobacteria with pigments that used only certain wavelengths. • Genetic drift eliminated pigments that absorbed certain wavelengths of light. • Mutation(s) altered the pigment(s) used by organism.

Unit 4: Cell Communication and Cell Cycle

Topic	Learning Objective(s)
4.1 Cell Communication	**IST-3.A** Describe the ways that cells can communicate with one another.
	IST-3.B Explain how cells communicate with one another over short and long distances.
4.2 Introduction to Signal Transduction	**IST-3.C** Describe the components of a signal transduction pathway.
	IST-3.D Describe the role of components of a signal transduction pathway in producing a cellular response.
4.3 Signal Transduction	**IST-3.E** Describe the role of the environment in eliciting a cellular response.
	IST-3.F Describe the different types of cellular responses elicited by a signal transduction pathway.
4.4 Changes in Signal Transduction Pathways	**IST-3.G** Explain how a change in the structure of any signaling molecule affects the activity of the signaling pathway
4.5 Feedback	**ENE-3.A** Describe positive and/ or negative feedback mechanisms.
	ENE-3.B Explain how negative feedback helps to maintain homeostasis
	ENE-3.C Explain how positive feedback affects homeostasis.
4.6 Cell Cycle	**IST-1.B** Describe the events that occur in the cell cycle.
	IST-1.C Explain how mitosis results in the transmission of chromosomes from one generation to the next.
4.7 Regulation of Cell Cycle	**IST-1.D** Describe the role of checkpoints in regulating the cell cycle.
	IST-1.E Describe the effects of disruptions to the cell cycle on the cell or organism.

Topic 4.1: Cell Communication

Learning Objective	IST-3.A Describe the ways that cells can communicate with one another.
I can…	☐ I can describe ways that cells communicate by direct cell-to-cell contact ☐ I can describe ways that cells communicate by chemical signaling

1. Identify a message communicated by direct cell-to-cell contact.
    a. What occurs during this process?
2. Identify a message communicated by chemical signaling.
    a. What occurs during this process?

Learning Objective	IST-3.B Explain how cells communicate with one another over short and long distances.
I can…	☐ I can describe ways cells communicate with one another over short distances ☐ I can describe ways cells communicate with one another over long distances ☐ I can describe ways cells release signals ☐ I can describe ways cells receive signals ☐ I can determine which cells will respond to a specific signaling molecule

3. How do cells communication over a short distance?
    a. Identify two examples.
4. How do cells communication over a long distance?
    a. Identify one example.
5. What is the process that results in the release of a chemical signal from a cell?
    a. Where are the chemical signals synthesized?
    b. Where are the chemical signals processed?
6. Reception
    a. What occurs during reception?
    b. Where is the receptor for a steroid hormone?
    c. Where is the receptor for a protein hormone?
    d. Why would the receptor be in different locations?
7. True or False: Only specific cells will respond to specific chemical signals because they have a receptor for the chemical signal.

Topic 4.2: Introduction to Signal Transduction

Learning Objective	IST-3.C Describe the components of a signal transduction pathway.
I can…	☐ I can describe the components of a signal transduction pathway ☐ I can describe the process of reception ☐ I can describe the process of transduction ☐ I can describe the process of response ☐ I can describe ways that similar signals can lead to different cellular responses in different cells ☐ I can describe phosphorylation cascades ☐ I can describe protein modification in transduction

1. What are the components of a signal transduction pathway?
2. What occurs during the process of reception?
3. What occurs during the process of transduction?
4. What is a phosphorylation cascade?
5. What is the function of a kinase?
6. What is the function of a phosphatase?
7. How are proteins modified during the process of transduction?
8. Identify three possible cellular responses.
9. Why would a different cell respond differently to the same chemical signal?

Learning Objective	IST-3.D Describe the role of components of a signal transduction pathway in producing a cellular response.
I can…	☐ I can describe the role of the ligand in a signal transduction pathway ☐ I can describe the role of the receptor in a signal transduction pathway ☐ I can describe the ligand-binding domain of a receptor ☐ I can describe a G protein-coupled receptors ☐ I can describe a tyrosine kinase receptor ☐ I can describe an ion channel receptor ☐ I can describe ways that signals are amplified in the signal transduction pathway ☐ I can describe ways that the signaling molecule initiates transduction ☐ I can describe second messengers' functions ☐ I can describe ways that secondary messengers amplify the signal ☐ I can describe ways that ligands binding to ligand-gated channels can cause cellular response

10. What is the role of the ligand in the signal transduction pathway?
11. What is the role of the receptor in the signal transduction pathway?
12. Where does the ligand bind on the receptor?
13. What occurs with a G-protein coupled receptor after binding to a ligand?
14. What occurs with a tyrosine kinase receptor after binding to a ligand?

15. What occurs with an ion channel receptor after binding to a ligand?
16. How are signals amplified after reception?
17. What occurs when the ligand binds to the receptor that initiated transduction?
18. What is a second messenger?
    a. Identify two examples.
    b. What is the function of a second messenger?
19. How does a ligand binding to a channel cause a cellular response?

Topic 4.3: Signal Transduction

Learning Objective	IST-3.E Describe the role of the environment in eliciting a cellular response.
I can…	☐ I can describe the role of the environment in causing a cellular response ☐ I can describe ways the cell responds to its environment

1. Identify two examples of a cell responding to its environment.
    a. What occurs in each of these examples?

Learning Objective	IST-3.F Describe the different types of cellular responses elicited by a signal transduction pathway.
I can…	☐ I can describe different types of cell responses due to a signal transduction pathway ☐ I can describe apoptosis ☐ I can describe ways that a signal can change gene expression ☐ I can describe ways that a signal can change phenotype

2. What is apoptosis?
3. Why would a cell undergo apoptosis?
4. What is a transcription factor?
5. How does a transcription factor change gene expression?
6. How can a signal change the phenotype of an organism?

Topic 4.4: Changes in Signal Transduction Pathways

Learning Objective	IST-3.G Explain how a change in the structure of any signaling molecule affects the activity of the signaling pathway
I can…	☐ I can explain ways a chance in structure of signaling molecule affects the activity of the pathway ☐ I can describe the effect of a mutation in the receptor protein ☐ I can describe the effect of a mutation in the transduction protein ☐ I can explain ways that chemicals may activate a signal transduction pathway ☐ I can explain ways that chemicals may inhibit a signal transduction pathway

1. What would happen if there was a mutation in the receptor protein?
    a. How would this affect the response of the cell?
2. What would happen if there was a mutation in a transduction protein?
    a. How would this affect the response of the cell?
3. How can a chemical interfere with the signaling pathway?
4. Identify one example of a chemical that activates a signaling pathway.
5. Identify one example of a chemical that inhibits a signaling pathway.

Topic 4.5: Feedback

Learning Objective	**ENE-3.A** Describe positive and/ or negative feedback mechanisms.
I can…	☐ I can describe positive feedback mechanisms. ☐ I can describe negative feedback mechanisms. ☐ I can describe ways organisms use feedback mechanisms to maintain homeostasis. ☐ I can describe ways organisms respond to internal and external environmental changes.

1. What is positive feedback?
    a. Identify two examples of positive feedback loops.
2. What is negative feedback?
    a. Identify two examples of negative feedback loops.
3. Using an internal change, describe how an organism responds using feedback loops.
4. Using an external change, describe how an organism responds using feedback loops.

Learning Objective	**ENE-3.B** Explain how negative feedback helps to maintain homeostasis
I can…	☐ I can explain ways negative feedback helps to maintain homeostasis. ☐ I can explain ways negative feedback returns a system back to target set point after disruptions.

5. Using an example, explain how negative feedback can be used to maintain homeostasis?
6. How does a cell use negative feedback to return to a target set point after a disturbance?

Learning Objective	**ENE-3.C** Explain how positive feedback affects homeostasis.
I can…	☐ I can explain ways positive feedback affects homeostasis. ☐ I can explain ways positive feedback amplifies the response.

7. Using an example, explain how positive feedback can be used to maintain homeostasis?
8. How does positive feedback amplify the response?
    a. Identify one example.

Topic 4.6: Cell Cycle

Learning Objective	IST-1.B Describe the events that occur in the cell cycle.
I can…	☐ I can describe the events of the cell cycle. ☐ I can describe the phases of interphase. ☐ I can describe the phases of mitosis. ☐ I can describe the phases of meiosis. ☐ I can describe cytokinesis. ☐ I can describe how cells divide. ☐ I can describe how cells transmit genetic information. ☐ I can describe G_0. ☐ I can describe how a cell exits the cell cycle and enters G0. ☐ I can describe how a cell exits G_0 and re-enters the cell cycle.

1. What are the three phases of the cell cycle?
    a. What occurs in each of these three phases?
2. What are the phases of interphase?
    a. What occurs in each of these phases?
3. What are the phases of mitosis?
    a. What occurs in each of these phases?
4. What are the phases of meiosis?
    a. What occurs in each of these phases?
5. What occurs during cytokinesis?
6. How is cytokinesis different in a plant versus an animal?
7. How does the cell undergo cytokinesis?
8. What is G_0?
9. What occurs at the G_1 checkpoint?
10. What occurs to re-enter the cell cycle from G_0?

Learning Objective	IST-1.C Explain how mitosis results in the transmission of chromosomes from one generation to the next.
I can…	☐ I can explain ways that mitosis results in movement of chromosomes from one generation to the next ☐ I can explain ways that mitosis ensures equal transfer of chromosomes ☐ I can explain ways that mitosis results in identical genetic information transfer ☐ I can explain roles of mitosis ☐ I can explain phases of mitosis that result in equal transfer of chromosomes

11. How do chromosomes move through the process of mitosis?
12. Identify the phase of mitosis that ensure equal transfer of chromosomes.
    a. How does this process ensure there is an equal transfer of chromosomes?
13. Identify the phase of mitosis that ensure identical genetic information is transferred?
    a. How does this process ensure that identical genetic information is transferred?
14. Identify three roles of mitosis.

Topic 4.7: Regulation of Cell Cycle

Learning Objective	IST-1.D Describe the role of checkpoints in regulating the cell cycle.
I can…	☐ I can describe the roles of the G_1 checkpoint. ☐ I can describe the role of the G_2 checkpoint. ☐ I can describe the role of the M checkpoint. ☐ I can describe the molecular components that allow for passage of checkpoints. ☐ I can describe internal controls that allow for passage of checkpoints. ☐ I can describe the interaction between cyclin and cyclin dependent kinase.

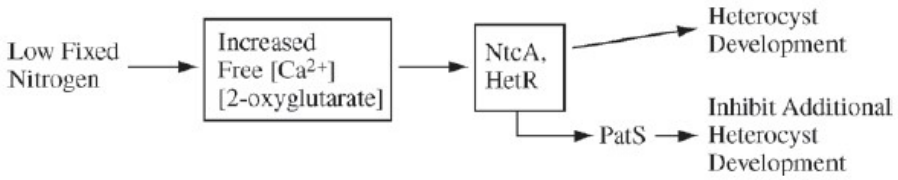
1. What occurs at the G_1 checkpoint?
2. What occurs at the G_2 checkpoint?
3. What are cyclins? What are CdKs?
    a. How do these two interact to allow passage of the G_2 checkpoint?
4. What occurs at the M checkpoint?
    a. What happens if the cell prematurely bypasses this checkpoint?
5. What process allows for the passage of the M checkpoint?

Learning Objective	IST-1.E Describe the effects of disruptions to the cell cycle on the cell or organism.
I can…	☐ I can describe the effects of disruptions on the cell cycle on the cell. ☐ I can describe the effects of disruptions on the cell cycle on the organism. ☐ I can describe the effects of cancer on the cell cycle ☐ I can describe the causes of apoptosis.

6. Identify three causes of cancer.
    a. How does each affect the cell cycle?
7. What is an oncogene?
8. What is a proto-oncogene?
9. How do the proto-oncogenes cause cancer?
10. What is a tumor suppressor gene?
11. How do the tumor-suppressor genes cause cancer?
12. What causes apoptosis?

Multiple Choice Practice

1. Anabaena is a simple multicellular photosynthetic cyanobacterium. In the absence of fixed nitrogen, certain newly developing cells along a filament express genes that code for nitrogen-fixing enzymes and become non-photosynthetic heterocysts. The specialization is advantageous because some nitrogen-fixing enzymes function best in the absence of oxygen. Heterocysts do not carry out photosynthesis but instead provide adjacent cells with fixed nitrogen, in exchange receiving fixed carbon and reduced energy carriers.

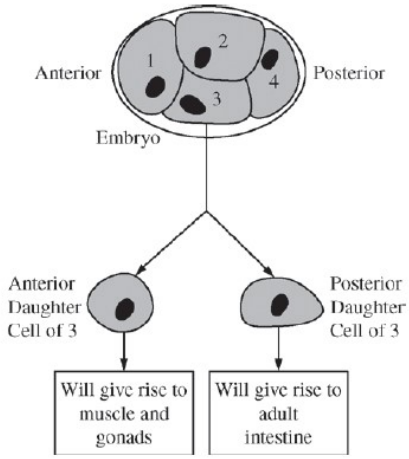


As shown in the diagram above, when there is low fixed nitrogen in the environment, an increase in the concentration of free calcium ions and 2-oxyglutarate stimulates the expression of genes that produce two transcription factors (NtcA and HetR) that promote the expression of genes responsible for heterocyst development. HetR also causes production of a signal, PatS, that prevents adjacent cells from developing as heterocysts.

Based on your understanding of the ways in which signal transmission mediates cell function, which of the following predictions is most consistent with the information given above?

a. In an environment with low fixed nitrogen, treating the Anabaena cells with a calcium-binding compound should prevent heterocyst differentiation.
b. A strain that overexpresses the patS gene should develop many more heterocysts in a low fixed nitrogen environment.
c. In an environment with abundant fixed nitrogen, free calcium levels should be high in all cells so that no heterocysts develop.
d. In environments with abundant fixed nitrogen, loss of the hetR gene should induce heterocyst development.

2. The diagram below shows a developing worm embryo at the four-cell stage. Experiments have shown that when cell 3 divides, the anterior daughter cell gives rise to muscle and gonads and the posterior daughter cell gives rise to the intestine. However, if the cells of the embryo are separated from one another early during the four-cell stage, no intestine will form. Other experiments have shown that if cell 3 and cell 4 are recombined after the initial separation, the posterior daughter cell of cell 3 will once again give rise to normal intestine.



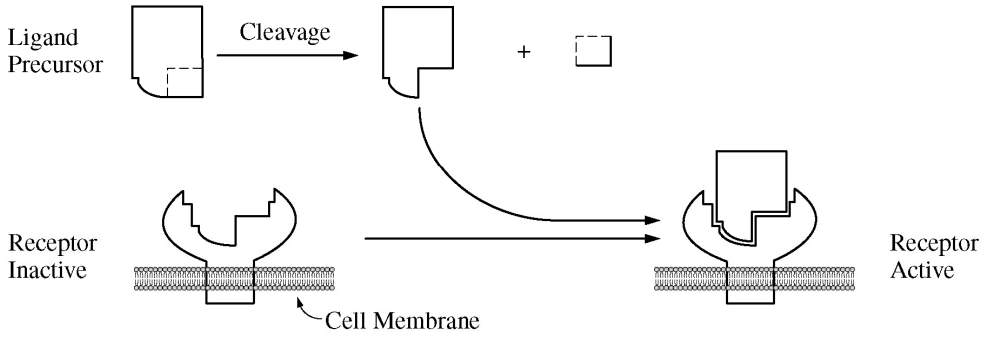
Which of the following is the most plausible explanation for these findings?

a. A cell surface protein on cell 4 signals cell 3 to induce formation of the worm's intestine.
b. The plasma membrane of cell 4 interacts with the plasma membrane of the posterior portion of cell 3, causing invaginations that become microvilli.
c. Cell 3 passes an electrical signal to cell 4, which induces differentiation in cell 4.
d. Cell 4 transfers genetic material to cell 3, which directs the development of intestinal cells.

3. The vertebrate forelimb initially develops in the embryo as a solid mass of tissue. As development progresses, the solid mass near the end of the forelimb is remodeled into individual digits. Which of the following best explains the role of apoptosis in remodeling of the forelimb?

a. Apoptosis replaces old cells with new ones that are less likely to contain mutations.
b. Apoptosis involves the regulated activation of proteins in specific cells of the developing forelimb that leads to the death of those cells.
c. Apoptosis involves the destruction of extra cells in the developing forelimb, which provides nutrients for phagocytic cells.
d. Apoptosis in the developing forelimb triggers the differentiation of cells whose fate was not already determined.

4. The figure below shows a model of a ligand precursor being cleaved to produce an active ligand that binds to a specific receptor. Which of the following is most likely to reduce the binding of the active ligand to its receptor?



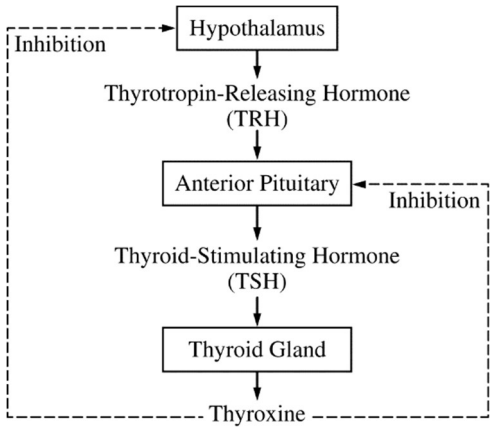
   a. A change in the cytoskeletal attachment of transmembrane proteins
   b. The presence of a large amount of the precursor form of the ligand
   c. An increase in the ratio of the number of unsaturated to the number of saturated fatty acid tails of the membrane lipids
   d. A mutation in the receptor gene that causes a substitution of a charged amino acid for a nonpolar amino acid in the ligand binding site of the receptor

5. Insulin is a protein hormone that is secreted in response to elevated blood glucose levels. When insulin binds to its receptors on liver cells, the activated receptors stimulate phosphorylation cascades that cause the translocation of glucose transporters to the plasma membrane.

   Based on the information provided, which of the following best describes the role of insulin in this liver cell signal transduction pathway?
   a. It acts as a ligand.
   b. It acts as a receptor.
   c. It acts as a secondary messenger.
   d. It acts as a protein kinase.

6. The endocrine system incorporates feedback mechanisms that maintain homeostasis. Which of the following demonstrates negative feedback by the endocrine system?
   a. During labor, the fetus exerts pressure on the uterine wall, inducing the production of oxytocin, which stimulates uterine wall contraction. The contractions cause the fetus to further push on the wall, increasing the production of oxytocin.
   b. After a meal, blood glucose levels become elevated, stimulating beta cells of the pancreas to release insulin into the blood. Excess glucose is then converted to glycogen in the liver, reducing blood glucose levels.
   c. At high elevation, atmospheric oxygen is more scarce. In response to signals that oxygen is low, the brain decreases an individual's rate of respiration to compensate for the difference.
   d. A transcription factor binds to the regulatory region of a gene, blocking the binding of another transcription factor required for expression.

7. The diagram below illustrates feedback control as exerted by the hormone thyroxine. Following surgical removal of the thyroid gland, the level of TSH in the blood will increase. Which of the following best explains this increase?



   a. Residual blood thyroxine, from prior to thyroid gland removal, will bind to cells in the anterior pituitary, signaling more TSH secretion.
   b. Thyroxine will remain bound to thyroxine receptors on various body cells, and these body cells will secrete additional hormones that stimulate the anterior pituitary to secrete TSH.
   c. Thyroxine that was stored in the anterior pituitary prior to thyroid gland removal will signal more TSH secretion.
   d. A decrease in thyroxine levels means a loss of inhibition to the hypothalamus and anterior pituitary, leading to increased TSH secretion.

8. Antidiuretic hormone (ADH) is important in maintaining homeostasis in mammals. ADH is released from the hypothalamus in response to high tissue osmolarity. In response to ADH, the collecting duct and distal tubule in the kidney become more permeable to water, which increases water reabsorption into the capillaries. The amount of hormone released is controlled by a negative feedback loop. Based on the model presented, which of the following statements expresses the proper relationship between osmolarity, ADH release, and urine production?
   a. As tissue osmolarity rises, more ADH is released, causing less water to be excreted as urine.
   b. As tissue osmolarity rises, less ADH is released, causing less water to be excreted as urine.
   c. As tissue osmolarity rises, more ADH is released, causing more water to be excreted as urine.
   d. As tissue osmolarity rises, less ADH is released, causing more water to be excreted as urine.

Use the following information to answer question 9:

Platelets are fragments of larger cells and normally circulate in the blood without adhering to blood vessel walls. When the wall of a blood vessel is damaged, collagen fibers in the wall are exposed to the interior of the blood vessel. The exposed fibers and chemicals released from the endothelial cells that line the blood vessel attract platelets, which start to form a plug and release other chemicals (Figure 1).

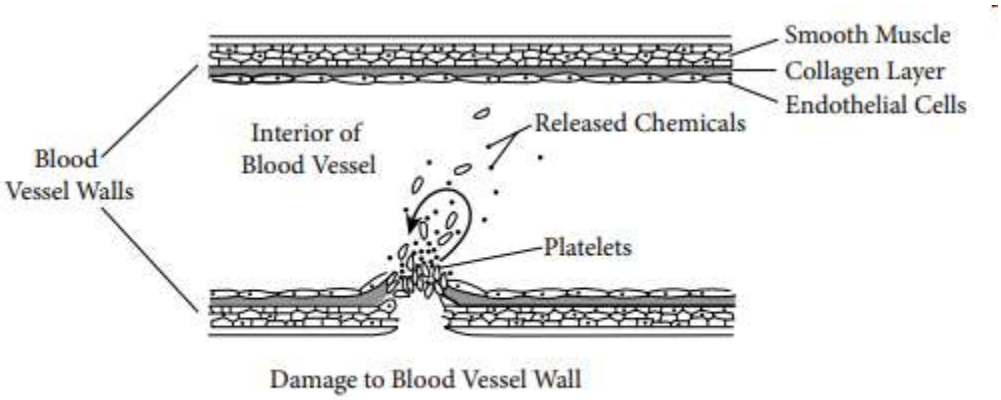
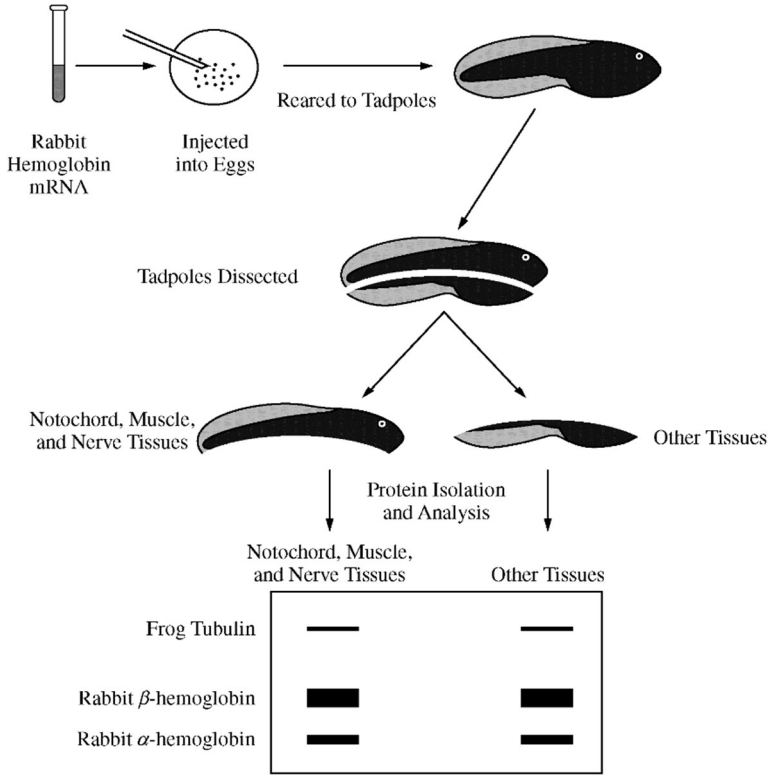


Figure 1. Formation of a platelet plug in a damaged blood vessel wall

9. Which of the following best explains the feedback mechanism illustrated in Figure 1?
    a. This is an example of positive feedback, because the few platelets that initially bind attract more platelets to the damaged area.
    b. This is an example of positive feedback, because it results from the interactions among collagen, endothelial cells, and platelets.
    c. This is an example of negative feedback, because a large clump of platelets can block the blood vessel and prevent blood flow through it.
    a. This is an example of negative feedback, because the accumulation of platelets returns the open blood vessel wall to a closed state.

Use the following information to answer question 10:

In a classic experiment from the 1970s investigating gene expression, a solution containing equal amounts of rabbit a-hemoglobin mRNA and b-hemoglobin mRNA, which encode subunits of a protein found in red blood cells, was injected into newly fertilized frog eggs. The injected mRNA was not degraded during the course of the experiment. Tadpoles that developed from the injected eggs were dissected into two fragments, one containing predominantly the notochord, muscle tissue, and nerve tissue and the other containing predominantly the other tissue types.



Equal amounts of total protein were analyzed after separation by electrophoresis to identify the relative amounts of the different proteins present in each sample. The thickness of the bands indicates the relative amounts of rabbit a-hemoglobin, rabbit b-hemoglobin, and frog tubulin (a cytoskeletal protein that is expressed at relatively constant levels in all tissues) present in each tadpole sample. The experimental protocol and results are summarized in the figure below.

10. Which of the following is the best justification for why the rabbit hemoglobin proteins were found throughout the tadpole?
    a. Rabbit mRNA is composed of nucleotides that are more stable than those in frog mRNA.
    b. Rabbit hemoglobin is synthesized more efficiently than frog hemoglobin in frog cells.
    c. After differentiation, the rabbit hemoglobin proteins move through the circulatory system of the tadpole to every cell.
    d. The mRNA injected into the newly fertilized frog eggs is distributed in the cytoplasm of every daughter cell during cell division.

11. If chemical signals in the cytoplasm control the progression of a cell to the M phase of the cell cycle, then fusion of a cell in G_1 with a cell in early M phase would most likely result in the
    a. replication of chromosomes only in the G_1 cell
    b. exiting of both cells from the cell cycle and into the G_0 phase
    c. condensation of chromatin in preparation of nuclear division in both cells
    d. transfer of organelles from the G_1 cell to the cell in the M phase

12. What are the three parts of signal transduction pathway?
    a. reception, transduction, response
    b. confirmation, transduction, transcription
    c. reception, amplification, transcription
    d. confirmation, amplification, response

13. Transduction step traditionally amplifies the signal, which of the following are NOT involved with transduction?
    a. secondary messengers
    b. protein modification
    c. phosphorylation cascade
    d. ligands

14. Which of the following is NOT a response by the cell from a signal transduction pathway?
    a. cell growth
    b. gene expression
    c. secretion of molecules
    d. all of the above are responses

15. Describe what occurs when the ligand binds to the receptor.
    a. confirmational change in shape of receptor
    b. phosphorylation of ligand
    c. ligand passes through the membrane
    d. receptor binds additional ligands

16. Describe the impact of a mutation in any domain of the protein components of the transduction signaling pathway.
    a. receptor unable to bind to ligand
    b. no changes in transduction due to initial signal transduction from ligand
    c. alters response of the cell
    d. amplification of signaling pathway to bind more ligands

17. Which feedback mechanism involves homeostasis of a particular condition by regulating physiological processes?
    a. Positive Feedback
    b. Negative Feedback

18. Which feedback mechanism involves amplifying responses and processes in biological organisms?
    a. Positive Feedback
    b. Negative Feedback

19. Which of the following is NOT a stage of the cell cycle?
    a. interphase
    b. cytokinesis
    c. mitosis
    d. apoptosis

20. Which of the following is the stage where the cell no longer divides?
    a. G_0
    b. G_1
    c. G_2
    d. S

21. Which of the following describes the order of the steps in mitosis?
    a. metaphase, telophase, anaphase, prophase
    b. prophase, metaphase, anaphase, telophase
    c. telophase, anaphase, metaphase, prophase
    d. prophase, anaphase, metaphase, telophase

22. Which of the following is NOT a role of mitosis?
    a. gametes
    b. tissue repair
    c. growth
    d. asexual reproduction

23. Which checkpoint is responsible for ensuring nondisjunction does not take place?
    a. G_1 checkpoint
    b. S checkpoint
    c. G_2 checkpoint
    d. M checkpoint

24. Describe the interaction between cyclin and CdK.
    a. cyclin interacts with CdK to initiate the mitotic phase
    b. cyclin is the precursor to CdK, when synthesized allow for mitosis proceed
    c. cyclin acts as an inhibitor to CdK to wait for all DNA to be synthesized
    d. cyclin binds to CdK to initiate DNA replication

Multiple Choice Key

Question	Correct Answer	Unit/Topic	Source
1	A. In an environment with low fixed nitrogen, treating the Anabaena cells with a calcium-binding compound should prevent heterocyst differentiation.	4.1	2012 CED #38
2	A. A cell surface protein on cell 4 signals cell 3 to induce formation of the worm's intestine.	4.1	2012 CED #31
3	B. Apoptosis involves the regulated activation of proteins in specific cells of the developing forelimb that leads to the death of those cells.	4.2	2013 #16
4	D. A mutation in the receptor gene that causes a substitution of a charged amino acid for a nonpolar amino acid in the ligand binding site of the receptor	4.2	2013 #46
5	A. It acts as a ligand.	4.2	2020 CED #1
6	B. After a meal, blood glucose levels become elevated, stimulating beta cells of the pancre-as to release insulin into the blood. Excess glucose is then converted to glycogen in the liver, reducing blood glucose levels.	4.5	2012 CED #17
7	D. A decrease in thyroxine levels means a loss of inhibition to the hypothalamus and anterior pituitary, leading to increased TSH secretion.	4.5	2013 #39
8	A. As tissue osmolarity rises, more ADH is released, causing less water to be excreted as urine.	4.5	2013 #52
9	A. This is an example of positive feedback, because the few platelets that initially bind attract more platelets to the damaged area.	4.5	2020 CED #14
10	D. The mRNA injected into the newly fertilized frog eggs is distributed in the cytoplasm of every daughter cell during cell division.	4.6	2013 #29
11	C. condensation of chromatin in preparation of nuclear division in both cells	4.6	2013 #35
12	A. reception, transduction, response	4.2	Self
13	D. ligands	4.2	Self
14	D. all of the above are responses	4.2	Self
15	A. confirmational change in shape of receptor	4.2	Self
16	C. alters response of the cell	4.4	Self
17	B. Negative Feedback	4.5	Self
18	A. Positive Feedback	4.5	Self
19	D. apoptosis	4.6	Self
20	A. G_0	4.6	Self
21	B. prophase, metaphase, anaphase, telophase	4.6	Self
22	A. gametes	4.6	Self
23	D. M checkpoint	4.7	Self
24	A. cyclin interacts with CdK to initiate the mitotic phase	4.7	Self

Free Response Practice

2019 #4

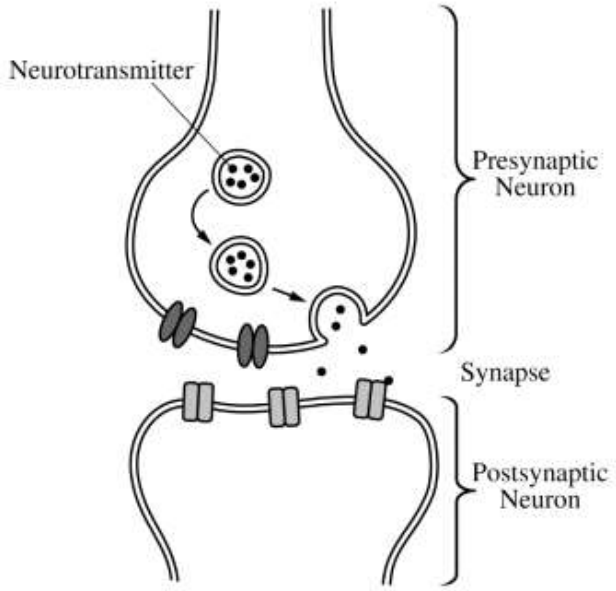


Figure 1. Release of neurotransmitters into the synapse in response to an action potential

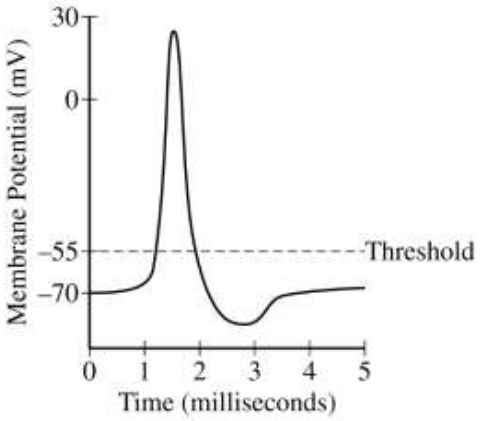


Figure 2. Model of a typical action potential in a neuron

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.

(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.

2018 #2

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

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.

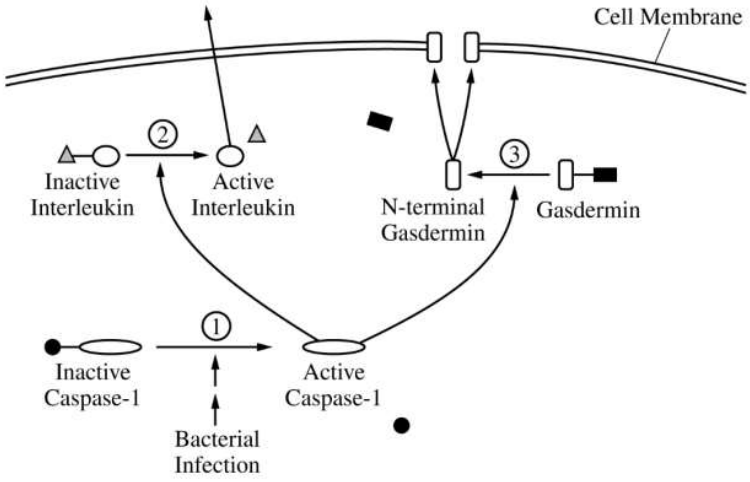


Figure 1. Cellular response to infection by pathogenic bacteria

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-κB (Immune response protein)
Whole cell sample	+	+	+	+	+
Fraction 1	+				
Fraction 2		+			+
Fraction 3			+		+
Fraction 4				+	
+ = presence of protein					

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

(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.

(c) A student claims that the NF-kB 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.

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

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

2018 #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 result 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

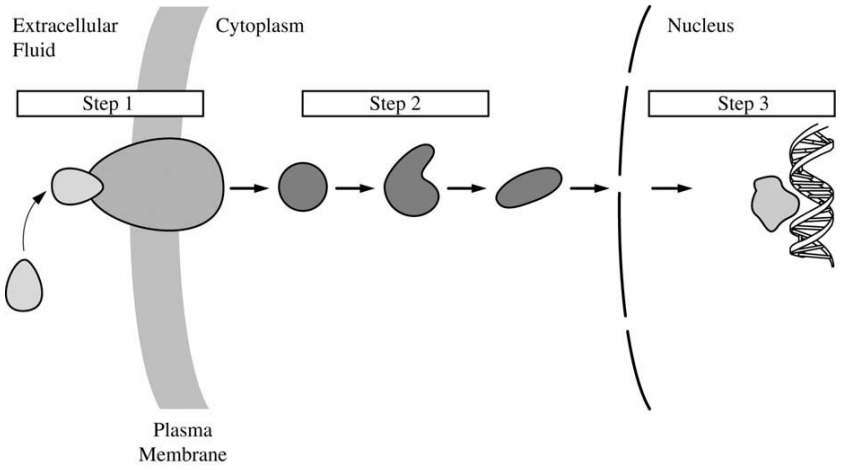
(a) **Describe** the difference in the structure AND function between AChR type 1 and AChR type 2.

(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.

2015 #7a

This question is in Unit 6.

2013 #8



The figure above represents a generalized hormone-signaling pathway. Briefly **explain** the role of each numbered step in regulating target gene expression.

Free Response Scoring Guidelines

2019 #4

Part	Scoring Guidelines	Topic
(a)	**Description (1 point)** • It will increase the number of action potentials. **Prediction (1 point)** • It will stay the same.	4.2
(b)	**(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.	4.2

2018 #2

Part	Scoring Guidelines	Topic
(a)	**Description (2 points)** • Pores will not form. • Interleukin release will not be affected/interleukin release continues.	4.2
(b)	**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.	4.2
(c)	**Justification (1 point)** • NF-*k*B and glycolytic enzymes/GAPDH are found together (in the cytoplasm). **Identification (2 points)** • Fraction 3 • Fraction 4	4.2
(d)	**Description (1 point)** • Water enters the cell.	2.8
(e)	**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).	4.2

2018 #8

<table>
<tr><th>Part</th><th>Scoring Guidelines</th><th>Topic</th></tr>
<tr><td>(a)</td><td>
Description (2 points)

Points may be earned from only one row.

<table>
<tr><th>Structure (1 point maximum)</th><th>Function (1 point maximum)</th></tr>
<tr><td>Binding sites differ in shape/ specificity/number</td><td>• 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)</td></tr>
<tr><td>Differential binding of molecules to type 1 and type 2 receptors</td><td>• Activated by one (ACh) or both (ACh and nicotine) molecules
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<tr><td>Receptors activated by one (ACh) or both (ACh and nicotine) molecules</td><td>• No difference in response (both open channels OR both result in depolarization OR both cause muscle contraction)</td></tr>
</table>
</td><td>4.4</td></tr>
<tr><td>(b)</td><td>Description (1 point)
• Continued activation
• Repeated opening of sodium channels OR repeated depolarization OR muscle spasms</td><td>4.4</td></tr>
</table>

2013 #8

Part	Scoring Guidelines	Topic
	The figure above represents a generalized hormone-signaling pathway. Briefly **explain** the role of each numbered step in regulating target gene expression. (**3 points maximum**) • Step 1 = hormone/ligand binding to receptor to initiate/trigger/induce signaling OR signal reception • Step 2 = an intracellular cascade that transduces/amplifies/transfers the signal from plasma membrane to nucleus (or other cellular effectors) • Step 3 = transcription/expression of target genes is stimulated/repressed	4.2

Unit 5: Heredity

Topic	Learning Objective(s)
5.1 Meiosis	**IST-1.F** Explain how meiosis results in the transmission of chromosomes from one generation to the next.
	IST-1.G Describe similarities and/ or differences between the phases and outcomes of mitosis and meiosis.
5.2 Meiosis and Genetic Diversity	**IST-1.H** Explain how the process of meiosis generates genetic diversity
5.3 Mendelian Genetics	**EVO-2.A** Explain how shared, conserved, fundamental processes and features support the concept of common ancestry for all organisms.
	IST-1.I Explain the inheritance of genes and traits as described by Mendel's laws
5.4 Non-Mendelian Genetics	**IST-1.J** Explain deviations from Mendel's model of the inheritance of traits.
5.5 Environmental Effects on Phenotype	**SYI-3.B** Explain how the same genotype can result in multiple phenotypes under different environmental conditions.
5.6 Chromosomal Inheritance	**SYI-3.C** Explain how chromosomal inheritance generates genetic variation in sexual reproduction.

Topic 5.1: Meiosis

Learning Objective	IST-1.F Explain how meiosis results in the transmission of chromosomes from one generation to the next.
I can…	☐ I can explain the ways that meiosis results in the movement of chromosomes from one generation to the next. ☐ I can explain the ways to reduce the chromosome number in meiosis from one generation to the next. ☐ I can explain the phases of meiosis I. ☐ I can explain the phases of meiosis II. ☐ I can explain the role of meiosis I. ☐ I can explain the role of meiosis II.

1. What are the phases of meiosis I?
2. What is the role of meiosis I?
3. What are the phases of meiosis II?
4. What is the role of meiosis II?
5. Identify three differences between meiosis I and meiosis II,
6. Identify what part of meiosis results in the reduction of chromosome number.

Learning Objective	IST-1.G Describe similarities and/ or differences between the phases and outcomes of mitosis and meiosis.
I can…	☐ I can describe the phases of mitosis. ☐ I can describe the phases of meiosis. ☐ I can describe the similarities between the phases of mitosis and meiosis. ☐ I can describe the differences between the phases of mitosis and meiosis. ☐ I can describe the similarities between the outcomes of mitosis and meiosis. ☐ I can describe the differences between the outcomes of mitosis and meiosis.

7. What are the phases of mitosis?
    a. Describe each phase.
8. Describe the daughter cells resulting from mitosis.
9. Describe the daughter cells resulting from meiosis.
10. Identify three similarities between mitosis and meiosis.
11. Identify three differences between mitosis and meiosis.

Topic 5.2: Meiosis and Genetic Diversity

Learning Objective	IST-1.H Explain how the process of meiosis generates genetic diversity
I can…	☐ I can explain the ways that meiosis generates genetic diversity. ☐ I can explain how the homologous chromosomes separate during anaphase. ☐ I can explain how daughter cells receive both maternal and paternal chromosomes. ☐ I can explain why the daughter cells after meiosis I are haploid. ☐ I can explain the process of crossing over. ☐ I can explain ways that crossing over increases genetic diversity. ☐ I can explain the process of independent assortment. ☐ I can explain ways that independent assortment increases genetic diversity. ☐ I can explain ways that random fertilization increases genetic diversity.

1. When do homologous chromosomes separate during meiosis?
2. How do homologous chromosomes separate during anaphase?
3. How do daughter cells receive both maternal and paternal chromosomes?
4. What process occurs during meiosis I that causes daughter cells to be haploid?
5. What is crossing over?
6. How does crossing over increase genetic diversity?
7. What is independent assortment?
8. How does independent assortment increase genetic diversity?
9. What is random fertilization?
10. How does random fertilization increase genetic diversity?

Topic 5.3: Mendelian Genetics

Learning Objective	EVO-2.A Explain how shared, conserved, fundamental processes and features support the concept of common ancestry for all organisms.
I can…	☐ I can explain ways shared processes support the concept of common ancestry. ☐ I can explain ways shared features support the concept of common ancestry. ☐ I can explain ways conserved processes support the concept of common ancestry. ☐ I can explain ways conserved features support the concept of common ancestry. ☐ I can explain ways fundamental processes support the concept of common ancestry for all organisms. ☐ I can explain ways fundamental functions support the concept of common ancestry for all organisms. ☐ I can identify carriers of genetic information. ☐ I can describe the cellular location of ribosomes. ☐ I can describe ways that the genetic code demonstrates common ancestry. ☐ I can identify metabolic pathways that have been conserved across all domains.

1. What substances are the carriers of genetic information?
2. What organisms have ribosomes?
    a. How does that demonstrate common ancestry?
3. How does a shared genetic code demonstrate common ancestry?
4. What metabolic process do all organisms undergo which demonstrates common ancestry?

Learning Objective	**IST-1.I** Explain the inheritance of genes and traits as described by Mendel's laws
I can…	☐ I can explain the law of independent assortment. ☐ I can explain the law of segregation. ☐ I can identify the expected ratios of a monohybrid based on Mendel's laws. ☐ I can identify the expected ratios of a dihybrid based on Mendel's laws. ☐ I can identify using quantitative analysis whether the observed phenotype is statistically significant.
Formula Sheet	**RELEVANT EQUATION** Laws of Probability— If A and B are mutually exclusive, then: $P(A \text{ or } B) = P(A) + P(B)$ If A and B are independent, then: $P(A \text{ and } B) = P(A) \times P(B)$

5. What is the law of independent assortment?
6. What is the law of segregation?
7. What is the expected ratio of a monohybrid cross based on Mendel's laws?
8. What is the expected ratio of a dihybrid cross based on Mendel's laws?
9. What is the probability of AaBbCCDd in a tetrahybrid cross?
10. What are the parent's genotype if the F1 ratio is 1:1?
11. What is complete dominance?
12. What is incomplete dominance?
13. What is codominance?
14. How are the phenotypic and genotypic ratios of a monohybrid cross different in these different levels of dominance?

Topic 5.4: Non-Mendelian Genetics

Learning Objective	IST-1.J Explain deviations from Mendel's model of the inheritance of traits.
I can…	☐ I can explain linked genes. ☐ I can determine the distance between two genes on a chromosome. ☐ I can determine inheritance of a sex-linked trait based on a pedigree. ☐ I can determine inheritance of a sex-linked trait based on data indicating parental genotypes. ☐ I can determine inheritance of a sex-linked trait based on data indicating parental phenotypes. ☐ I can determine inheritance of a sex-linked trait based on data indicating offspring genotypes. ☐ I can determine inheritance of a sex-linked trait based on data indicating offspring phenotypes. ☐ I can explain inheritance of a polygenic trait. ☐ I can identify organelles other than the nucleus that contain DNA. ☐ I can determine inheritance of a mitochondrial linked trait based on a pedigree. ☐ I can determine inheritance of a chloroplast linked trait based on a pedigree.

1. What are linked genes?
    a. How are the predicted ratios different in linked genes?
2. If the recombination frequency is 15%, how far apart are the two genes?
3. If a male is affected with a sex-linked trait with unaffected parents, what are the genotypes of the parents?
4. What type of sex-linked cross would result in a 2 normal females, 1 normal male, and 1 affected male?
5. What is a polygenic trait?
6. What organelles contain DNA?
    a. How does this support the endosymbiotic theory?
7. If a trait is mitochondrially linked, what is the mode of inheritance?
8. If a trait is found on the DNA in a chloroplast, what is the mode of inheritance?
9. What would you look for in a pedigree to identify if the trait is dominant or recessive?
10. What would you look for in a pedigree to identify if the trait is autosomal or sex-linked?
11. What would you look for in a pedigree to identify if the trait is due to non-nuclear inheritance?

Topic 5.5: Environmental Effects on Phenotype

Learning Objective	SYI-3.B Explain how the same genotype can result in multiple phenotypes under different environmental conditions.
I can…	☐ I can explain ways the same genotype can result in multiple phenotypes under different environmental conditions. ☐ I can describe phenotype plasticity. ☐ I can provide examples of phenotype plasticity. ☐ I can describe ways environmental factors influence gene expression.

1. What is phenotype plasticity?
    a. Identify two examples of phenotype plasticity,
    b. What is the evolutionary significance of phenotype plasticity?
2. How do environmental factors affect gene expression?

Topic 5.6: Chromosomal Inheritance

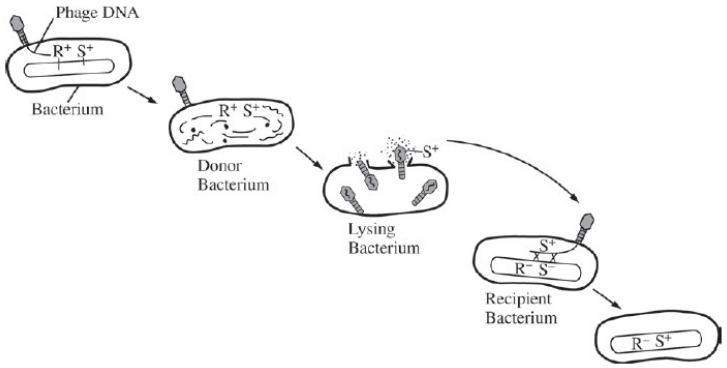
Learning Objective	SYI-3.C Explain how chromosomal inheritance generates genetic variation in sexual reproduction.
I can…	☐ I can explain ways chromosomal inheritance generates genetic variation in sexual reproduction. ☐ I can describe segregation in meiosis. ☐ I can describe independent assortment in meiosis. ☐ I can describe fertilization in meiosis. ☐ I can describe ways that segregation, independent assortment, and fertilization lead to genetic variation. ☐ I can describe the chromosomal basis of inheritance. ☐ I can describe ways genetic disorders result from a single affected allele. ☐ I can describe ways genetic disorders result from chromosomal changes. ☐ I can describe nondisjunction. ☐ I can predict the results of nondisjunction.

1. What occurs during segregation in meiosis?
    a. What phase does it take place in?
2. What occurs during independent assortment in meiosis?
    a. What phase does it take place in?
3. What is fertilization?
4. How does segregation lead to genetic variation?
5. How does independent assortment lead to genetic variation?
6. How does fertilization lead to genetic variation?
7. What is the chromosomal basis of inheritance?
8. Identify two genetic disorders resulting from a single affected allele.
9. Identify two genetic disorders resulting from a chromosomal change.
10. What is nondisjunction?
11. Identify two genetic disorder resulting from nondisjunction.

Multiple Choice Practice

1. Humans have a diploid number ("2n") of 46. Which of the following statements best predicts the consequence if meiosis did not occur during gametogenesis?
    a. The gametes would get larger from one generation to the next.
    b. The chromosome number would double with each generation.
    c. The chromosome number would be halved with each generation.
    d. The chromosome number would triple with each generation.

2. The figure below shows several steps in the process of bacteriophage transduction in bacteria. Which of the following explains how genetic variation in a population of bacteria results from this process?



    a. Bacterial proteins transferred from the donor bacterium by the phage to the recipient bacterium recombine with genes on the recipient's chromosome.
    b. The recipient bacterium incorporates the transduced genetic material coding for phage proteins into its chromosome and synthesizes the corresponding proteins.
    c. The phage infection of the recipient bacterium and the introduction of DNA carried by the phage cause increased random point mutations of the bacterial chromosome.
    d. DNA of the recipient bacterial chromosome undergoes recombination with DNA introduced by the phage from the donor bacterium, leading to a change in the recipient's genotype.

3. In 1944 Avery, MacLeod, and McCarty performed transformation experiments using live, harmless bacteria and extracts from virulent bacteria treated with various enzymes. Which of the following enzymes were used and why?
    a. Proteases and RNases to rule out protein and RNA as the transforming factors
    b. Lipase (an enzyme that facilitates the breakdown of lipids) to rule out lipoproteins as the transforming factor
    c. Kinase (an enzyme that facilitates transfer of a phosphate group from ATP to a substrate molecule) to show that transformation is phosphorylation dependent
    d. ATPase to show that transformation is not dependent on ATP

Use the following information to answer question 4:

The following figures display data collected while studying a family, some members of which have sickle-cell disease—a rare genetic disorder caused by a mutation in the hemoglobin beta gene (HBB). There are at least two alleles of the HBB gene: the HbA allele encodes wild-type hemoglobin and the HbS allele encodes the sickle-cell form of hemoglobin. Genetic testing provided insight into the inheritance pattern for sickle-cell disease.

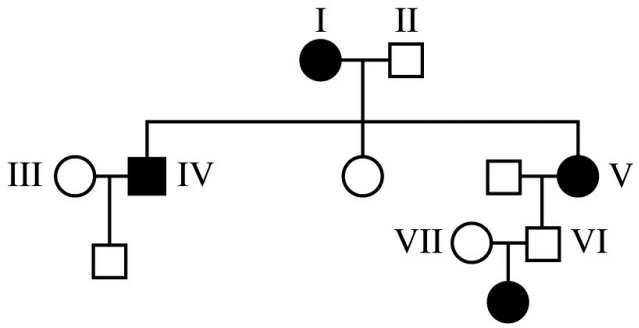


Figure 1. Pedigree of a family with affected individuals. Squares represent males, circles represent females, shaded symbols represent individuals with sickle-cell disease.

5' CTG ACT CCT GAG GAG AAG TCT 3'	Non-template Strand
3' GAC TGA GGA CTC CTC TTC AGA 5'	Template Strand

Figure 2. A portion of the DNA sequence from the wild-type hemoglobin allele (HbA) that codes for normal hemoglobin.

Second Base in Codon

First Base in Codon	U	C	A	G	Third Base in Codon
U	UUU Phe UUC UUA Leu UUG	UCU UCC UCA Ser UCG	UAU Tyr UAC UAA Stop UAG Stop	UGU Cys UGC UGA Stop UGG Trp	U C A G
C	CUU CUC CUA Leu CUG	CCU CCC CCA Pro CCG	CAU His CAC CAA Gln CAG	CGU CGC CGA Arg CGG	U C A G
A	AUU AUC Ile AUA AUG Met or Start	ACU ACC ACA Thr ACG	AAU Asn AAC AAA Lys AAG	AGU Ser AGC AGA Arg AGG	U C A G
G	GUU GUC GUA Val GUG	GCU GCC GCA Ala GCG	GAU Asp GAC GAA Glu GAG	GGU GGC GGA Gly GGG	U C A G

Figure 3. Codon table showing nucleotide sequences for each amino acid.

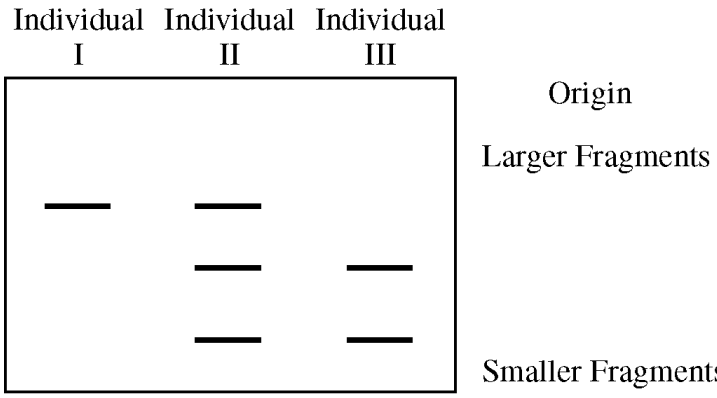


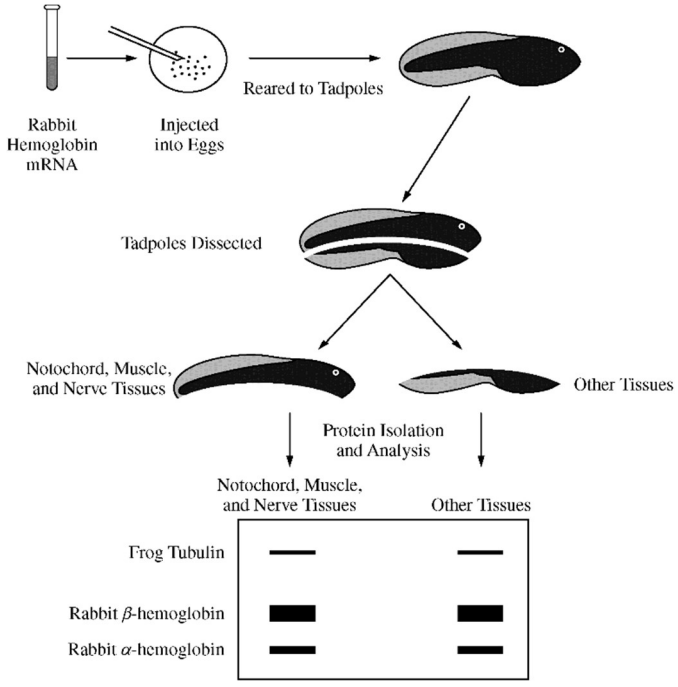
Figure 4. Image of a gel following electrophoretic separation of DNA fragments of the HBB gene from three individuals in the pedigree in Figure 1.

4. Based on the data shown in Figure 1, which of the following best describes the genotypes of individual family members in the pedigree?
    a. All affected individuals possess at least one dominant allele of the hemoglobin beta gene.
    b. Healthy individuals may possess one mutant allele (HbS) of the hemoglobin beta gene.
    c. Individuals IV and V must be heterozygous for the HbS (mutant) allele.
    d. Individuals II and VI possess two copies of the HbA (wild-type) allele.

Use the following information to answer question 5:

In a classic experiment from the 1970s investigating gene expression, a solution containing equal amounts of rabbit a-hemoglobin mRNA and b-hemoglobin mRNA, which encode subunits of a protein found in red blood cells, was injected into newly fertilized frog eggs. The injected mRNA was not degraded during the course of the experiment. Tadpoles that developed from the injected eggs were dissected into two fragments, one containing predominantly the notochord, muscle tissue, and nerve tissue and the other containing predominantly the other tissue types.

Equal amounts of total protein were analyzed after separation by electrophoresis to identify the relative amounts of the different proteins present in each sample. The thickness of the bands indicates the relative amounts of rabbit a-hemoglobin, rabbit b-hemoglobin, and frog tubulin (a cytoskeletal protein that is expressed at relatively constant levels in all tissues) present in each tadpole sample. The experimental protocol and results are summarized in the figure below.



5. The observation that the rabbit mRNA was successfully translated in the frog tissues supports which of the following conclusions?
    a. Frog cells are able to replace their own hemoglobin with rabbit hemoglobin.
    b. Undeveloped frog eggs can be induced to form genetically identical copies of a rabbit.
    c. Rabbit hemoglobin can induce an immune response in frogs.
    d. Rabbits and frogs share a common genetic code for expressing heritable information.

6. The tiny blue-eyed Mary flower is often one of the first flowers seen in the spring in some regions of the United States. The flower is normally blue, but sometimes a white or pink flower variation is found. The following data were obtained after several crosses.

Parents	F_1	F_2
Blue x White	Blue	196 Blue, 63 White
Blue x Pink	Blue	149 Blue, 52 Pink
Pink x White	Blue	226 Blue, 98 White, 77 Pink

Which of the following statements best explains the data?
    a. The appearance of blue in the F1 generation of the pink and white cross demonstrates that flower color is not an inherited trait but is determined by the environment.
    b. Flower color depends on stages of flower development, and young flowers are white, advancing to pink and then blue.
    c. Since the F1 and F2 phenotypes of the pink and white cross do not fit the expected genotypic and phenotypic ratios, blue-eyed Mary must reproduce by vegetative propagation.
    d. Flower color is an inherited trait, and the F1 and F2 phenotypes of the flowers arising from the pink and white cross can best be explained by another gene product that influences the phenotypic expression.

7. A student in a biology class crossed a male Drosophila melanogaster having a gray body and long wings with a female D. melanogaster having a black body and apterous wings. The following distribution of traits was observed in the offspring.

Phenotype	Number of Offspring
Gray body, long wings	42
Black body, apterous wings	41
Gray body, apterous wings	9
Black body, long wings	8

Which of the following is supported by the data?
    a. The alleles for gray body and long wings are dominant.
    b. The alleles for gray body and long wings are recessive.
    c. Genes for the two traits are located on two different chromosomes, and independent assortment occurred.
    d. Genes for the two traits are located close together on the same chromosome and crossing over occurred between the two gene loci.

Use the following information for question 8:

A student placed 20 tobacco seeds of the same species on moist paper towels in each of two petri dishes. Dish A was wrapped completely in an opaque cover to exclude all light. Dish B was not wrapped. The dishes were placed equidistant from a light source set to a cycle of 14 hours of light and 10 hours of dark. All other conditions were the same for both dishes. The dishes were examined after 7 days and the opaque cover was permanently removed from dish A. Both dishes were returned to the light and examined again at 14 days. The following data were obtained.

	Dish A		Dish B	
	Day 7 Covered	Day 14 Uncovered	Day 7 Uncovered	Day 14 Uncovered
Germinated seeds	12	20	20	20
Green-leaved seedlings	0	14	15	15
Yellow-leaved seedlings	12	6	5	5
Mean stem length below first set of leaves	8 mm	9 mm	3 mm	3 mm

8. Which of the following best supports the hypothesis that the difference in leaf color is genetically controlled?
   a. The number of yellow-leaved seedlings in dish A on day 7
   b. The number of germinated seeds in dish A on days 7 and 14
   c. The death of all the yellow-leaved seedlings
   d. The existence of yellow-leaved seedlings as well as green-leaved ones on day 14 in dish B

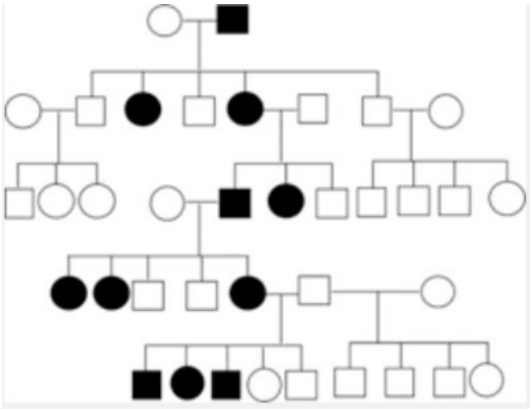
9. Mitosis results in...
   a. 2 identical diploid cells
   b. 4 unique diploid cells
   c. 2 unique haploid cells
   d. 4 identical haploid cells

10. Meiosis results in _____ because there is/are _____.
    a. 2 identical haploid cells, 1 round of division
    b. 4 identical diploid cells, 2 rounds of division
    c. 4 unique haploid cells, 2 rounds of division
    d. 2 unique diploid cells, 1 round of division

11. Which of the following does NOT increase variation in gamete formation?
    a. crossing over
    b. fertilization of gametes
    c. random assortment of chromosomes
    d. condensation of chromatin

12. This process involves homologous chromatids exchanging genetic material to increase genetic diversity.
    a. crossing over
    b. random fertilization
    c. independent assortment
    d. gene flow

13. Which of the following does NOT support the concept of common ancestry for all organisms?
    a. DNA/RNA (genetic code) are shared by all living systems
    b. Ribosomes are found in all forms of life
    c. Glycolysis takes place in all organisms
    d. All organisms undergo sexual reproduction



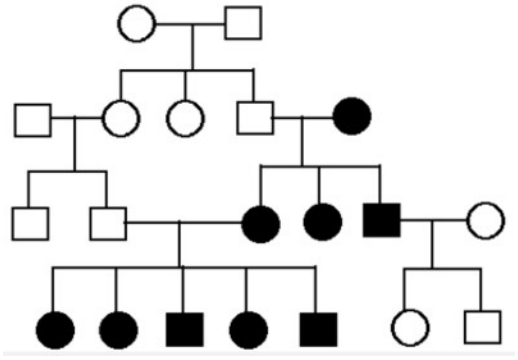
14. Which of the following best describes the inheritance pattern of the shown pedigree?
    a. Autosomal Dominant
    b. Sex-Linked Dominant
    c. Autosomal Recessive
    d. Sex-Linked Recessive

15. Which of the following best describes the phenotypic ratio of 6:3:3:2:1:1?
    a. Incomplete dominance & complete dominance on dihybrid cross
    b. Incomplete dominance on dihybrid cross
    c. Complete dominance on dihybrid cross
    d. Epistasis on dihybrid cross

16. Describe the cause of a cross resulting in greater than 50% parental phenotypes and less then 50% recombinant phenotypes
    a. Genes are linked on the same chromosome
    b. Genes are located on different arms of the same chromosome
    c. Gene are on different chromosomes
    d. Gene are found in different gametes

17. In animals, traits determine by the mitochondrial DNA are inherited from the _____.
    a. mother
    b. brother
    c. father
    d. sister

18. Identify the type of inheritance of the pedigree.



    a. Sex-Linked
    b. Mitochondrial
    c. Autosomal
    d. Random

19. Snowshoe hares are brown in summer and white in winter, describe this event.
    a. Hares undergo phenotypic plasticity & environment influences gene express
    b. Hares are white in winter due to the snow binding to hair follicles
    c. Hares are brown from exposed dirt in summer
    d. Hares remain hidden in the winter months inhibiting fur darken from sun

20. Describe the process of nondisjunction.
    a. Homologous chromosomes exchange genetic information
    b. The alignment of the chromosomes on the metaphase plate
    c. Homologous chromosomes or sister chromatids remain attached during anaphase
    d. The process of sperm and egg fusing to create a zygote

21. When does the process of independent assortment take place?
    a. prophase I
    b. metaphase I
    c. anaphase I
    d. telophase I

22. When does the process of crossing over take place?
    a. prophase I
    b. metaphase I
    c. anaphase I
    d. telophase I

23. What phase of meiosis describes the law of segregation?
    a. telophase I
    b. anaphase I
    c. telophase II
    d. anaphase II

24. Which of the following is the predicted ratio of a testcross with a dihybrid?
    a. 9:3:3:1
    b. 9:6:1
    c. 1:2:1
    d. 1:1:1:1

25. Which of the following is a predicted ratio of a dihybrid cross?
    a. 9:3:3:1
    b. 9:3:4
    c. 1:2:1
    d. 1:1:1:1

26. Describe why a male is more likely to be affected by a sex-linked trait?
    a. Males have only 1 Y chromosome
    b. Females have only 1 Y chromosome
    c. Males have only 1 X chromosome
    d. Females have only 1 X chromosomes

Multiple Choice Key

Question	Correct Answer	Unit/Topic	Source
1	B. The chromosome number would double with each generation.	5.1	2020 CED #2
2	D. DNA of the recipient bacterial chromosome undergoes recombination with DNA introduced by the phage from the donor bacterium, leading to a change in the recipient's genotype.	5.2	2012 CED #39
3	A. Proteases and RNases to rule out protein and RNA as the transforming factors	5.3	2013 #9
4	B. Healthy individuals may possess one mutant allele (HbS) of the hemoglobin beta gene.	5.3	2013 #48
5	D. Rabbits and frogs share a common genetic code for expressing heritable information.	5.3	2013 #27
6	D. Flower color is an inherited trait, and the F1 and F2 phenotypes of the flowers arising from the pink and white cross can best be explained by another gene product that influences the phenotypic expression.	5.4	2012 CED #32
7	D. Genes for the two traits are located close together on the same chromosome and crossing over occurred between the two gene loci.	5.4	2013 #33
8	D. The existence of yellow-leaved seedlings as well as green-leaved ones on day 14 in dish B	5.5	2012 CED #8
9	A. 2 identical diploid cells	5.1	Self
10	C. 4 unique haploid cells, 2 rounds of division	5.1	Self
11	D. condensation of chromatin	5.2	Self
12	A. crossing over	5.2	Self
13	D. All organisms undergo sexual reproduction	5.3	Self
14	A. Autosomal Dominant	5.3	Self
15	A. Incomplete dominance & complete dominance on dihybrid cross	5.3	Self
16	A. Genes are linked on the same chromosome	5.4	Self
17	A. mother	5.4	Self
18	B. Mitochondrial	5.4	Self
19	A. Hares undergo phenotypic plasticity & environment influences gene express	5.5	Self
20	C. Homologous chromosomes or sister chromatids remain attached during anaphase	5.6	Self
21	B. metaphase I	5.3	Self
22	A. prophase I	5.3	Self
23	B. anaphase I	5.3	Self
24	D. 1:1:1:1	5.3	Self
25	A. 9:3:3:1	5.3	Self
26	C. Males have only 1 X chromosome	5.4	Self

Free Response Practice

2019 #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.

(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.

(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.

2019 #6

This question is in Unit 6.

2018 #1

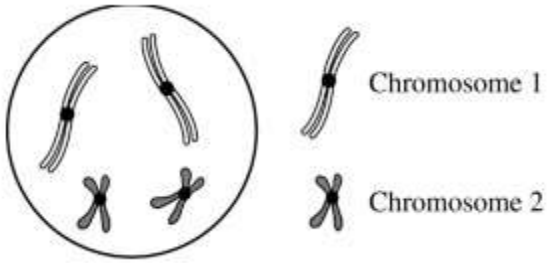
This question is in Unit 7.

2018 #8

This question is in Unit 8.

2016 #7

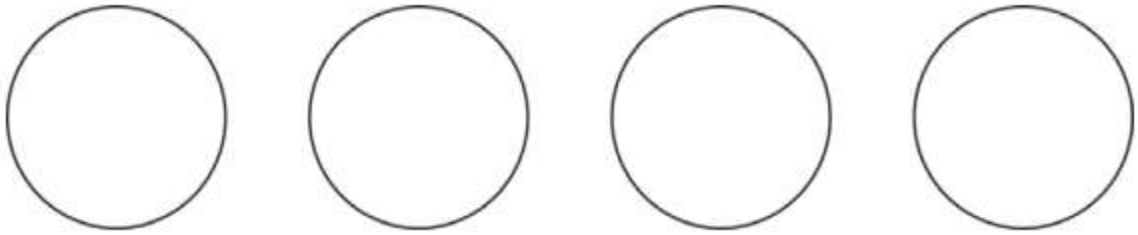
In a certain species of plant, the diploid number of chromosomes is 4 (2n = 4). Flower color is controlled by a single gene in which the green allele (G) is dominant to the purple allele (g). Plant height is controlled by a different gene in which the dwarf allele (D) is dominant to the tall allele (d). 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 flow color is on chromosome 1.

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

(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.



2015 #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.

(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.

2014 #8

This question is in Unit 7.

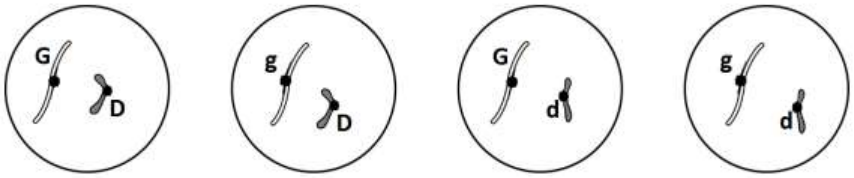
Free Response Scoring Guidelines

2019 #3

Part	Scoring Guidelines	Topic
(a)	**Identification (1 point)** • Mitochondria • Mitochondrial matrix	3.5
(b)	**(1 point per row; 2 points max.)** See table below	3.5
(c)	**Calculation (1 point)** • The probability of inheritance is 0. • The offspring cannot/will not have PDC deficiency.	5.4

	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.

2016 #7

Part	Scoring Guidelines	Topic
(a)	**Construct diagram (1 point)** • Diagram must include all of the following: o Each cell has one unduplicated chromosome 1 (with G or g). o Each cell has one unduplicated chromosome 2 (with D or d). o Genotype combinations should be: GD, Gd, gD, gd. 	5.1
(b)	**Prediction (1 point)** • 1 green dwarf: 1 green tall: 1 purple dwarf: 1 purple tall	5.3
(c)	**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	5.4

<table>
<tr><th colspan="3">2015 #4</th></tr>
<tr><th>Part</th><th>Scoring Guidelines</th><th>Topic</th></tr>
<tr><td>(a)</td><td>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</td><td>5.1</td></tr>
<tr><td>(b)</td><td><table><tr><th rowspan="2">Feature</th><th colspan="2">Description (1 point each row; 2 points maximum)</th></tr><tr><th>Mitosis</th><th>Meiosis</th></tr><tr><td>Number of divisions/ number of resulting cells</td><td>1 division/ 2 cells result</td><td>2 divisions/ 4 cells result</td></tr><tr><td>Ploidy of daughter cells</td><td>• Same as parent cell
• Diploid
• (2n-->2n or n-->n)</td><td>• Half of parent cell
• Haploid
• (4n-->2n; 2n-->n)</td></tr><tr><td>Chromatids separate</td><td>Occurs</td><td>Not in meiosis I/only in meiosis II</td></tr><tr><td>Crossing over</td><td>Does not occur</td><td>Occurs</td></tr><tr><td>Homologous chromosomes separate/independently assort</td><td>Does not occur</td><td>Occurs</td></tr></table></td><td>5.2</td></tr>
</table>

Unit 6: Gene Expression and Regulation

Topic	Learning Objective(s)
6.1 DNA and RNA Structure	**IST-1.K** Describe the structures involved in passing hereditary information from one generation to the next.
	IST-1.L Describe the characteristics of DNA that allow it to be used as the hereditary material
6.2 Replication	**IST-1.M** Describe the mechanisms by which genetic information is copied for transmission between generations.
6.3 Transcription and RNA Processing	**IST-1.N** Describe the mechanisms by which genetic information flows from DNA to RNA to protein.
6.4 Translation	**IST-1.O** Explain how the phenotype of an organism is determined by its genotype
6.5 Regulation of Gene Expression	**IST-2.A** Describe the types of interactions that regulate gene expression.
	IST-2.B Explain how the location of regulatory sequences relates to their function.
6.6 Gene Expression and Cell Specialization	**IST-2.C** Explain how the binding of transcription factors to promoter regions affects gene expression and/or the phenotype of the organism.
	IST-2.D Explain the connection between the regulation of gene expression and phenotypic differences in cells and organisms.
6.7 Mutations	**IST-2.E** Describe the various types of mutation
	IST-4.A Explain how changes in genotype may result in changes in phenotype.
	IST-4.B Explain how alterations in DNA sequences contribute to variation that can be subject to natural selection.
6.8 Biotechnology	**IST-1.P** Explain the use of genetic engineering techniques in analyzing or manipulating DNA.

Topic 6.1: DNA and RNA Structure

Learning Objective	IST-1.K Describe the structures involved in passing hereditary information from one generation to the next.
I can…	☐ I can describe the structures involved in passing hereditary information from one generation to the next. ☐ I can identify DNA as the primary source of heritable information. ☐ I can describe ways that genetic information is transmitted from one generation to the next ☐ I can describe how DNA is stored ☐ I can identify differences between prokaryote and eukaryote genome shapes ☐ I can identify differences between amount prokaryote and eukaryotes genome ☐ I can describe plasmids ☐ I can describe functions of plasmids ☐ I can describe biotechnology uses for plasmids

1. What is the primary source of heritable information?
2. How is genetic information transmitted from one generation to the next?
3. What is DNA?
    a. How is DNA stored?
4. How is prokaryotic DNA shaped?
5. How is eukaryotic DNA shaped?
6. How is the amount of DNA different between a prokaryote and a eukaryote?
7. What is a plasmid?
8. Identify two functions of plasmids.
9. Identify two biotechnical uses for plasmids.

Learning Objective	IST-1.L Describe the characteristics of DNA that allow it to be used as the hereditary material
I can…	☐ I can describe the characteristics of DNA ☐ I can describe characteristics of DNA that allow it to be used as hereditary material ☐ I can describe the nucleotide base pairing ☐ I can describe the structure of purines ☐ I can describe the structure of pyrimidines ☐ I can determine the number of other nucleotides based on a given number of one nucleotide.

10. Why is DNA a better hereditary material than RNA?
11. What are the nucleotide base pairing rules?
12. What is the structure of a purine?
    a. Which of the nitrogenous bases are purines?
13. What is the structure of a pyrimidine?
    a. Which of the nitrogenous bases are pyrimidines?

14. Why does a purine always pair with a pyrimidine?
15. If there is 20% thymine in a DNA strand, how much cytosine is there?

Topic 6.2: Replication

Learning Objective	IST-1.M Describe the mechanisms by which genetic information is copied for transmission between generations.
I can…	☐ I can describe the mechanisms that genetic information is copied ☐ I can describe the directionality of DNA synthesis ☐ I can describe the process of DNA replication ☐ I can describe the function of helicase ☐ I can describe the function of topoisomerase ☐ I can describe the function of RNA primers ☐ I can describe the function of Primase ☐ I can describe the differences between the leading and lagging strand ☐ I can describe the function of DNA ligase

1. What direction is DNA synthesized?
    a. What direction does the DNA polymerase READ the DNA template?
2. What is the function of helicase?
3. What is the function of topoisomerase?
4. What is the function of DNA polymerase?
5. What is the function of RNA primers and primase?
6. Why are RNA primers required for DNA replication?
7. How does the leading and the lagging strand differ?
8. What is the function of DNA ligase?
9. Describe the process of DNA replication using the enzymes described above (helicase, topoisomerase, DNA polymerase, primase, RNA primers, and DNA ligase)

Topic 6.3: Transcription and RNA Processing

Learning Objective	IST-1.N Describe the mechanisms by which genetic information flows from DNA to RNA to protein.
I can…	☐ I can describe the process of transcription. ☐ I can describe the central dogma. ☐ I can describe the function of mRNA ☐ I can describe the function of tRNA ☐ I can describe the function of rRNA ☐ I can describe the interaction between rRNA, mRNA, and tRNA ☐ I can describe ways the DNA sequence determines the RNA sequence ☐ I can describe the function of RNA polymerase ☐ I can determine the template strand of DNA ☐ I can identify that the noncoding strand, minus strand, and antisense strand are the template strand ☐ I can describe the directionality of transcription ☐ I can describe post-transcriptional modifications ☐ I can describe the function of the poly-A tail ☐ I can describe the function of the GTP cap ☐ I can describe the function of RNA splicing ☐ I can describe alternative splicing

1. What is transcription?
2. What is the central dogma?
3. What is the function of mRNA?
4. What is the function of tRNA?
5. What is the function of rRNA?
6. How does the mRNA, tRNA, and rRNA all interact?
7. How does the DNA sequence determine the RNA sequence?
8. What is the function of RNA polymerase?
9. Which strand is the template strand?
10. What are the other names of the template strand?
11. Which direction does transcription take place (which direction is the RNA synthesized)?
    a. Which direction is the template strand READ?
12. Describe the process that takes place during transcription.
13. Identify three post-transcriptional modifications that alter the pre-mRNA prior to its release from the nucleus.
14. What is the function of the poly-A tail?
15. What is the function of the GTP cap?
16. What is the function of RNA splicing?
17. How can multiple proteins be synthesized from the same mRNA transcript?

Topic 6.4: Translation

Learning Objective	IST-1.0 Explain how the phenotype of an organism is determined by its genotype
I can…	☐ I can describe ways the phenotype of an organism is determined by the phenotype ☐ I can identify the location of translation ☐ I can describe differences between location of translation in prokaryotes and eukaryotes ☐ I can describe why prokaryotes complete translation concurrently with transcription ☐ I can describe the process of translation. ☐ I can describe the initiation step of translation ☐ I can describe the elongation step of translation ☐ I can describe the termination step of translation ☐ I can identify where translation starts ☐ I can describe a codon ☐ I can determine the appropriate amino acid for a codon ☐ I can describe why multiple codons are able to code for the same amino acid ☐ I can use genetic code as evidence for common ancestry ☐ I can describe the three sites of a ribosome ☐ I can describe the chemical process that releases the growing polypeptide ☐ I can describe ways that retroviruses violate the central dogma ☐ I can describe the function of reverse transcriptase ☐ I can describe the ways that retroviruses incorporate viral genome in host genome ☐ I can describe how new viruses are formed

1. Where does translation take place?
2. How does the location of translation differ between a prokaryote and a eukaryote?
    a. How does the location of translation affect gene expression in a prokaryote?
3. What are the three steps of translation?
4. What are the three sites found on a ribosome and what is their function?
5. What happens in the initiation step of translation?
6. What happens in the elongation step of translation?
7. What happens in the termination step of translation?
8. What chemical process releases the growing polypeptide?
9. Where does translation start?
10. What is a codon?
    a. How many nucleotides make up a codon?
11. Practice using a codon chart:
    a. What amino acid is coded by UAU?
    b. What codons code for lysine?
12. How are multiple codons able to code for the same amino acids?
13. True or False: One codon can code for more than one amino acid.
14. How does the genetic code demonstrate common ancestry?
15. What is the central dogma?
    a. How does a retrovirus violate this process?

b. Identify two examples of retroviruses.

16. What is the function of reverse transcriptase?
17. How does a virus incorporate its viral genome into a host genome?
18. How does a virus form progeny viruses?

Topic 6.5: Regulation of Gene Expression

Learning Objective	IST-2.A Describe the types of interactions that regulate gene expression.
I can…	☐ I can describe the types of interactions that regulate gene expression. ☐ I can describe the function of regulatory sequences ☐ I can describe modifications to DNA to regulate gene expression ☐ I can describe modifications to histones to regulate gene expression ☐ I can describe epigenetic changes ☐ I can describe cell differentiation ☐ I can explain why different phenotypes appear at different levels of gene expression ☐ I can describe the function of transcription factors

1. What are regulatory sequences?
2. What is the promoter region?
3. What is the TATA box?
4. What is the enhancer region?
5. What are epigenetic changes?
6. How is DNA modified to initiate transcription (to regulate gene expression)?
7. How is DNA modified to inhibit transcription (to regulate gene expression)?
8. How are histones modified to initiate transcription (to regulate gene expression)?
9. How are histone modified to inhibit transcription (to regulate gene expression)?
10. True or False: All somatic cells have the same DNA.
11. What is cell differentiation?
12. Why can different phenotypes result from different levels of gene expression?
13. What is the function of transcription factors?

Learning Objective	IST-2.B Explain how the location of regulatory sequences relates to their function.
I can…	☐ I can explain how the location of regulatory sequences relates to their function ☐ I can explain ways prokaryote gene expression is regulated ☐ I can explain ways eukaryote gene expression is regulated ☐ I can describe the function of an operon ☐ I can explain the interaction between repressors and promoters

14. What is an operon?
15. What is a repressor?
16. What is a promoter?
17. How does the repressor interact with the promoter?
18. Describe the lac operon.
    a. What happens when lactose is present?
    b. What happens when lactose is absent?
    c. Is this operon repressible or inducible?
19. Describe the trp operon.
    a. What happens when tryptophan is present?
    b. What happens when tryptophan is absent?
    c. Is this operon repressible or inducible?

Topic 6.6: Gene Expression and Cell Specialization

Learning Objective	IST-2.C Explain how the binding of transcription factors to promoter regions affects gene expression and/or the phenotype of the organism.
I can…	☐ I can explain how the binding of transcription factors to promoter regions affect gene expression ☐ I can explain how the binding of transcription factors to promoter regions affect the phenotype of the organism ☐ I can explain the function of the promoter ☐ I can explain the function of transcription factors ☐ I can explain the function of RNA polymerase ☐ I can explain ways negative regulatory molecules inhibit gene expression

1. What is the function of the promoter?
2. What is the function of transcription factors?
3. How do transcription factors affect the binding at the promoter?
4. What is the function of RNA polymerase?
5. How do negative regulatory molecule inhibit gene expression?

Learning Objective	IST-2.D Explain the connection between the regulation of gene expression and phenotypic differences in cells and organisms.
I can…	☐ I can explain the connection between the regulation of gene expression and phenotypic differences in cells ☐ I can explain the connection between the regulation of gene expression and phenotypic differences in organisms ☐ I can describe differential gene expression ☐ I can explain the influence of differential gene expression on cell products ☐ I can explain the influence of differential gene expression on cell function ☐ I can describe the regulatory functions of RNA on gene expression

6. What is differential gene expression?
7. How can differential gene expression affect the cellular products?
8. How can differential gene expression affect the cellular functions?
9. What is siRNA?
10. What is mrRNA?
11. How do siRNA and miRNA affect gene expression?

Topic 6.7: Mutations

Learning Objective	IST-2.E Describe the various types of mutation
I can…	☐ I can describe the various types of mutations ☐ I can describe why changes in genotype result in change in phenotype ☐ I can describe ways that disruptions of genes can cause new phenotypes ☐ I can describe ways that disruptions of genes can affect gene products ☐ I can describe alterations in a DNA sequence that leads to a change in type of protein ☐ I can describe alterations in a DNA sequence that leads to a change in the amount of protein produced ☐ I can describe ways a mutation can have a neutral effect on the protein produced ☐ I can describe ways a mutation can have a negative effect on the protein produced ☐ I can describe ways a mutation can have a positive effect on the protein produced

1. How does the genotype influence the phenotype?
2. How do new phenotypes originate?
3. How do mutations affect gene products?
4. What are the three types of substitution point mutations?
    a. How does each affect the protein product?
    b. How does each affect the amount of the protein product?
5. What happens if an insertion or deletion occurs at a nucleotide base pair?
    a. How does this affect the protein product?
    b. How does this affect the amount of the protein product?
6. How can a mutation have a neutral effect on the product produced?
7. How can a mutation have a positive effect on the product produced?
8. How can a mutation have a negative effect on the product produced?

Learning Objective	IST-4.A Explain how changes in genotype may result in changes in phenotype.
I can…	☐ I can explain ways that changes in genotype may result in a change in phenotype ☐ I can describe causes of errors in DNA replication ☐ I can describe DNA repair mechanisms ☐ I can describe why a mutation can be detrimental, beneficial, or neutral ☐ I can identify mutations as a cause of genetic variation ☐ I can describe errors in mitosis that result in changes in phenotype ☐ I can describe errors in meiosis that result in changes in phenotype ☐ I can describe triploid ☐ I can describe why triploid organisms are usually sterile ☐ I can describe ways incorrect chromosome numbers results in human disorders ☐ I can describe the cause of Down syndrome/Trisomy 21 ☐ I can describe the cause of Turner Syndrome ☐ I can describe the cause of Klinefelter males

9. What causes errors in DNA replication?
10. What is involved in the cell's DNA repair mechanisms?
11. How can a mutation be…
    a. Detrimental? b. Beneficial? c. Neutral?
12. What is the cause of new genetic variation?
13. Identify an error in mitosis that leads to a change in phenotype.
14. Identify an error in meiosis that leads to a change in phenotype.
15. What does it mean if an organism is a triploid?
16. How do triploids form?
17. Why is a triploid organism usually sterile?
18. Why
19. What causes Down syndrome/Trisomy 21?
20. What causes Turner syndrome?

Learning Objective	IST-4.B Explain how alterations in DNA sequences contribute to variation that can be subject to natural selection.
I can…	☐ I can explain ways alterations in DNA sequences contribute to variation subject to natural selection ☐ I can explain ways changes in genotype affects phenotypes ☐ I can explain ways phenotypes are subject to natural selection ☐ I can explain ways genotypes are subject to natural selection ☐ I can explain ways that genetic changes enhance survival and are selected for ☐ I can describe ways horizontal transfer of genetic information increases variation ☐ I can describe transformation ☐ I can describe transduction ☐ I can describe conjugation ☐ I can describe transposition ☐ I can describe ways related viruses can recombine genetic information ☐ I can describe reproductive processes that increase genetic variation and are evolutionarily conserved

21. How does a change in genotype affect the phenotype?
22. True or False: Natural selection acts on genotype.
23. How does natural selection affect phenotypes?
24. How does natural selection affect genotypes?
25. How does a genetic change enhance survival?
26. What is horizontal transfer?
27. How does horizontal transfer increase variation?
28. What is transformation?
29. What is transduction?
30. What is conjugation?
31. What is transposition?
32. How do viruses recombine genetic information?
33. What reproductive processes increase genetic variation?

Topic 6.8: Biotechnology

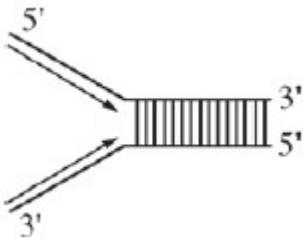
Learning Objective	IST-1.P Explain the use of genetic engineering techniques in analyzing or manipulating DNA.
I can…	☐ I can explain the use of genetic engineering in analyzing DNA ☐ I can explain the use of genetic engineering in manipulating DNA ☐ I can describe the function of electrophoresis ☐ I can describe the function of PCR ☐ I can describe the function of bacterial transformation ☐ I can determine the function of DNA sequencing ☐ I can determine the most appropriate technique for application

1. How is genetic engineering used to analyze DNA?
2. How is genetic engineering used to manipulate DNA?
3. What is gel electrophoresis?
    a. What is the function of gel electrophoresis?
    b. What occurs during gel electrophoresis?
    c. What information can be drawn from a gel electrophoresis?
    d. Identify an example of when a gel electrophoresis should be done.
4. What is PCR?
    a. What is the function of PCR?
    b. What occurs during a PCR?
    c. Identify an example of when a PCR should be done.
5. What is bacterial transformation?
    a. What is the function of bacterial transformation?
    b. What occurs during a bacterial transformation?
    c. What information can be drawn from a bacterial transformation?
    d. Identify an example of when a bacterial transformation should be done.
6. What is DNA sequencing?
    a. What is the function of DNA sequencing?
    b. What occurs during the process of DNA sequencing?
    c. What information can be drawn from DNA sequencing?
    d. Identify an example of when DNA sequencing should be done.

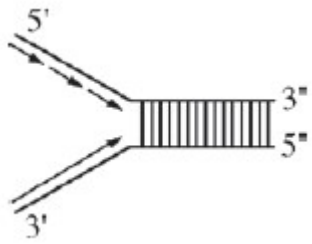
Multiple Choice Practice

1. When DNA replicates, each strand of the original DNA molecule is used as a template for the synthesis of a second, complementary strand. Which of the following figures most accurately illustrates enzyme-mediated synthesis of new DNA at a replication fork?

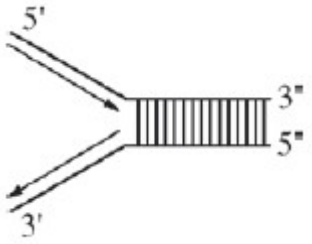
a.



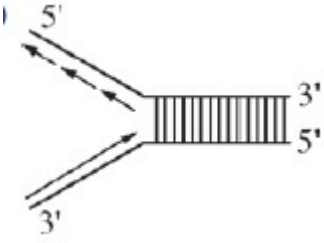
b.



c.

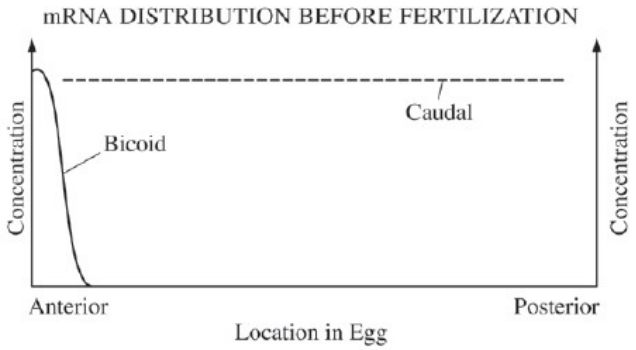


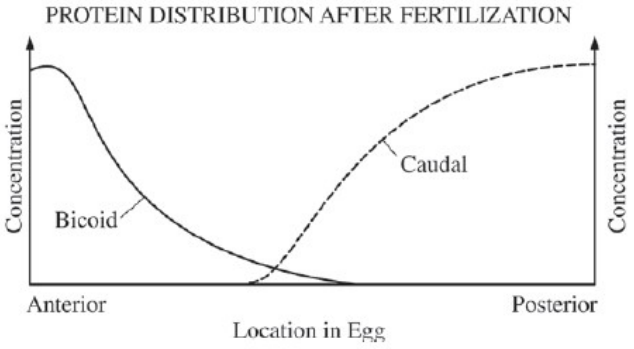
d.



2. The human TPM1 gene encodes members of the tropomyosin family of cytoskeletal proteins. Which of the following best explains how different proteins can be made in different cell types from the one TPM1 gene?
   a. Different introns are selectively converted to exons.
   b. Different exons are retained or spliced out of the primary transcript.
   c. The GTP cap is selectively added to and activates different exons.
   d. Different portions of the primary transcript remain bound to the template DNA.

3. The first diagram below shows the levels of mRNA from two different genes (bicoid and caudal) at different positions along the anterior-posterior axis of a Drosophila egg immediately before fertilization. The second diagram shows the levels of the two corresponding proteins along the anterior-posterior axis shortly after fertilization.





Which of the following conclusions is best supported by the data?

a. Bicoid protein inhibits translation of caudal mRNA.
b. Bicoid protein stabilizes caudal mRNA.
c. Translation of bicoid mRNA produces caudal protein.
d. Caudal protein stimulates development of anterior structures.

Use the following information to answer questions 4 & 5:

The following figures display data collected while studying a family, some members of which have sickle-cell disease—a rare genetic disorder caused by a mutation in the hemoglobin beta gene (HBB). There are at least two alleles of the HBB gene: the HbA allele encodes wild-type hemoglobin and the HbS allele encodes the sickle-cell form of hemoglobin. Genetic testing provided insight into the inheritance pattern for sickle-cell disease.

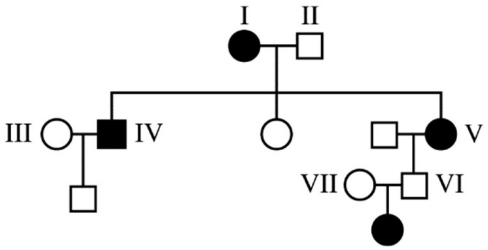


Figure 1. Pedigree of a family with affected individuals. Squares represent males, circles represent females, shaded symbols represent individuals with sickle-cell disease.

5' CTG ACT CCT GAG GAG AAG TCT 3' Non-template Strand
3' GAC TGA GGA CTC CTC TTC AGA 5' Template Strand

Figure 2. A portion of the DNA sequence from the wild-type hemoglobin allele (HbA) that codes for normal hemoglobin.

Second Base in Codon

First Base in Codon	U	C	A	G	Third Base in Codon
U	UUU Phe UUC UUA Leu UUG	UCU UCC UCA Ser UCG	UAU Tyr UAC UAA Stop UAG Stop	UGU Cys UGC UGA Stop UGG Trp	U C A G
C	CUU CUC CUA Leu CUG	CCU CCC CCA Pro CCG	CAU His CAC CAA Gln CAG	CGU CGC CGA Arg CGG	U C A G
A	AUU AUC Ile AUA AUG Met or Start	ACU ACC ACA Thr ACG	AAU Asn AAC AAA Lys AAG	AGU Ser AGC AGA Arg AGG	U C A G
G	GUU GUC GUA Val GUG	GCU GCC GCA Ala GCG	GAU Asp GAC GAA Glu GAG	GGU GGC GGA Gly GGG	U C A G

Figure 3. Codon table showing nucleotide sequences for each amino acid.

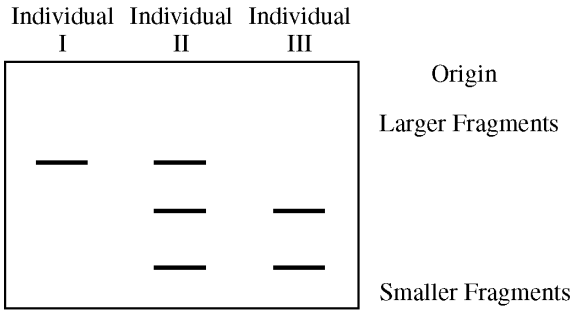
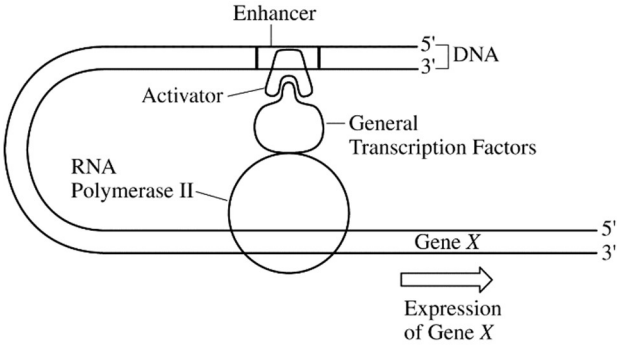


Figure 4. Image of a gel following electrophoretic separation of DNA fragments of the HBB gene from three individuals in the pedigree in Figure 1.

4. The HbS allele, which causes sickle-cell disease, results from a mutation in the DNA sequence shown in Figure 2 that produces a valine (val) in the place of a glutamic acid (glu) residue in the hemoglobin protein. Which of the following mRNA sequences is derived from the HbS allele?
    a. 5' GAC TGA GGA CTC CTC TTC AGA 3'
    b. 5' UCU GAA GAG GAA UCC UCA GUC 3'
    c. 5' AGA CTT CTC CTC AGG AGT CAG 3'
    d. 5' CUG ACU CCU GUG GAG AAG UCU 3'

5. The restriction endonuclease Mst II recognizes the sequence 5' CCT(N)AG (where N = any nucleotide) and cuts DNA at that site, producing separate fragments. Which of the following best explains the banding patterns exhibited in Figure 4?
    a. The HbA DNA contains a recognition site for the Mst II restriction enzyme.
    b. The HbA/HbS DNA contains three recognition sites for the Mst II restriction endonuclease.
    c. Individual I has only one copy of the hemoglobin gene; therefore there is only one band on the gel.
    d. The HbS/HbA DNA contains three different alleles for sickle-cell disease.

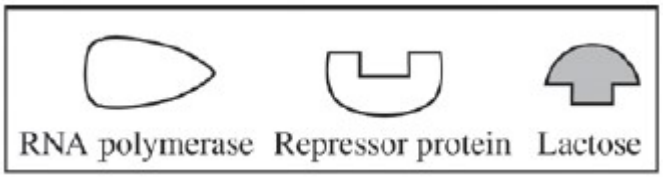
6. The figure to the right depicts the DNA-protein complex that is assembled at the transcriptional start site of gene X when the expression of gene X is activated in liver cells. Previous studies have shown that gene X is never expressed in nerve cells. Based on the diagram, which of the following most likely contributes to the specific expression pattern of gene X?



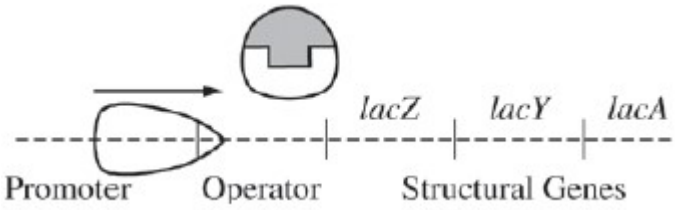
    a. Expression of gene X produces large amounts of tRNA but undetectable amounts of mRNA.
    b. The general transcription factors inhibit the activation of gene X in liver cells by blocking the activator from binding to RNA polymerase II.
    c. The activator is a sequence-specific DNA-binding protein that is present in some tissues but not in other tissues.
    d. The enhancer is a unique DNA segment that is added to the nuclear DNA of some cells of an organism during the process of mitotic cell division but not other cells.

7. Lactose digestion in E. coli begins with its hydrolysis by the enzyme b-galactosidase. The gene encoding b-galactosidase, lacZ, is part of a coordinately regulated operon containing other genes required for lactose utilization.

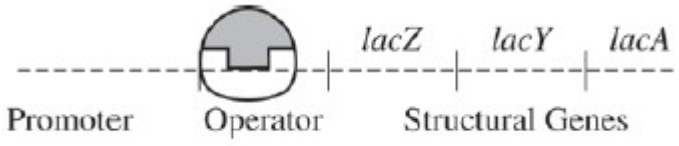
   Which of the following figures correctly depicts the interactions at the lac operon when lactose is NOT being utilized? (The legend below defines the shapes of the molecules illustrated in the options.)



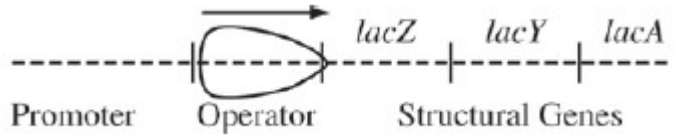
a.



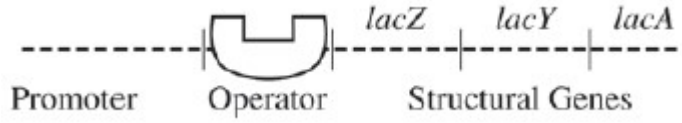
b.



c.



d.



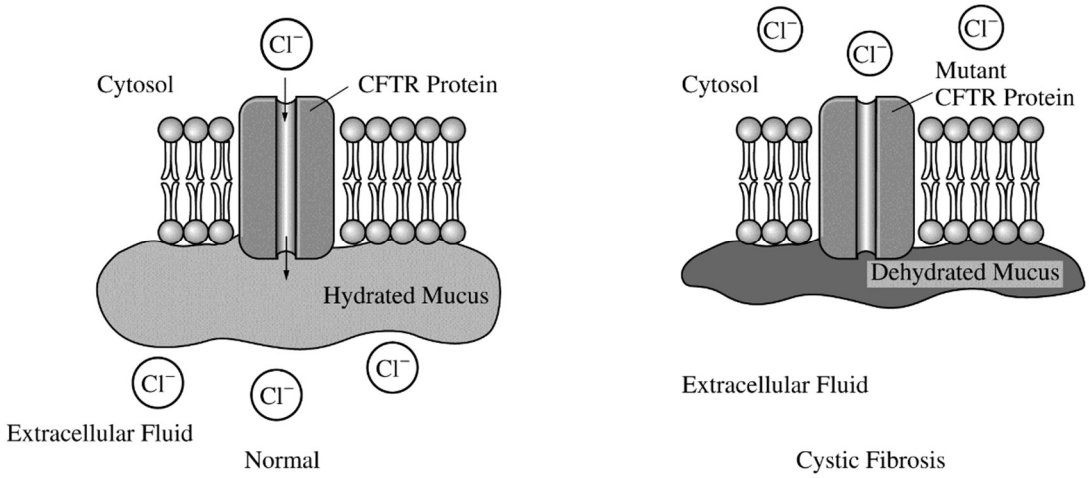
8. Mutations in the MYO6 and POU4F3 genes have been associated with a form of hereditary hearing loss in humans. Researchers studying the genes have proposed that POU4F3 encodes a transcription factor that influences the regulation of MYO6.

   Which of the following questions will best help guide the researchers toward a direct test of their proposal?

   a. Have mutations in other genes also been associated with hearing loss?
   b. In what types of cells are the mutant forms of the POU4F3 gene expressed?
   c. Are mutations in the MYO6 and POU4F3 genes also found in mice?
   d. Do mutations in the POU4F3 gene affect MYO6 mRNA levels in cells?

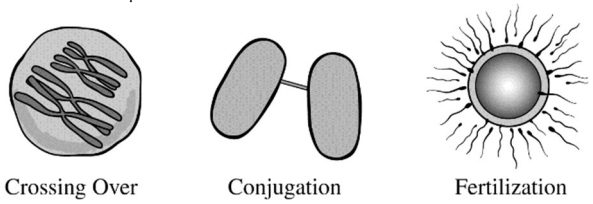
9. Sickle-cell anemia results from a point mutation in the HBB gene. The mutation results in the replacement of an amino acid that has a hydrophilic R-group with an amino acid that has a hydrophobic R-group on the exterior of the hemoglobin protein. Such a mutation would most likely result in altered
    a. properties of the molecule as a result of abnormal interactions between adjacent hemoglobin molecules
    b. DNA structure as a result of abnormal hydrogen bonding between nitrogenous bases
    c. fatty acid structure as a result of changes in ionic interactions between adjacent fatty acid chains
    d. protein secondary structure as a result of abnormal hydrophobic interactions between R-groups in the backbone of the protein

10. Cystic fibrosis is a recessively inherited disorder that results from a mutation in the gene encoding CFTR chloride ion channels located on the surface of many epithelial cells. As shown in the figure, the mutation prevents the normal movement of chloride ions from the cytosol of the cell to the extracellular fluid. As a consequence of the mutation, the mucus layer that is normally present on the surface of the cells becomes exceptionally dehydrated and viscous.



An answer to which of the following questions would provide the most information about the association between the CFTR mutation and the viscous mucus?
    a. Is the mucus also secreted from the cells through the CFTR proteins?
    b. How does the disrupted chloride movement affect the movement of sodium ions and water by the cell?
    c. How does the mutation alter the structure of the CFTR proteins?
    d. What is the change in nucleotide sequence that results in the CFTR mutation?

11. The processes illustrated in the models depicted below all result in which of the following?

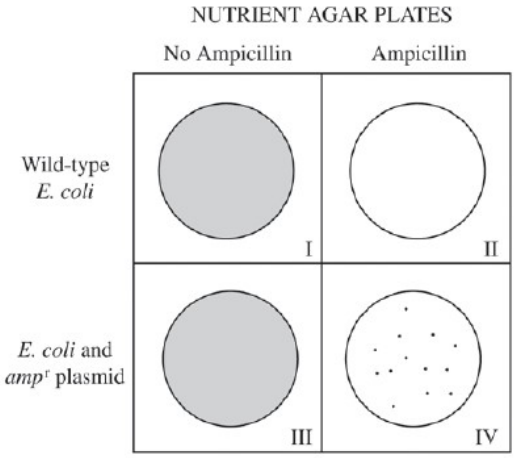


    a. Transcription
    b. An increase in genetic variation
    c. An increase in the chromosome number
    d. Horizontal gene transfer

12. A new mutation that arose in one copy of gene X in a somatic cell resulted in the formation of a tumor. Which of the following pieces of evidence best describes how the new mutation directly caused the tumor?
    a. Protein X normally stimulates cell division, and the mutation created an overactive version of protein X.
    b. Protein X normally activates a growth hormone receptor, and the mutation decreased the stability of protein X.
    c. Protein X normally prevents passage through the cell cycle, and the mutation created an overactive version of protein X.
    d. Protein X normally regulates gene expression, and the mutation created an underactive version of protein X that blocked the cell cycle.

Use the following information for questions 13-17:

In a transformation experiment, a sample of E. coli bacteria was mixed with a plasmid containing the gene for resistance to the antibiotic ampicillin (amp^r). Plasmid was not added to a second sample. Samples were plated on nutrient agar plates, some of which were supplemented with the antibiotic ampicillin. The results of E. coli growth are summarized below. The shaded area represents extensive growth of bacteria; dots represent individual colonies of bacteria.



13. Plates that have only ampicillin-resistant bacteria growing include which of the following?
    a. I only
    b. III only
    c. IV only
    d. I and II

14. Which of the following best explains why there is no growth on plate II?
    a. The initial E. coli culture was not ampicillin- resistant.
    b. The transformation procedure killed the bacteria.
    c. Nutrient agar inhibits E. coli growth.
    d. The bacteria on the plate were transformed.

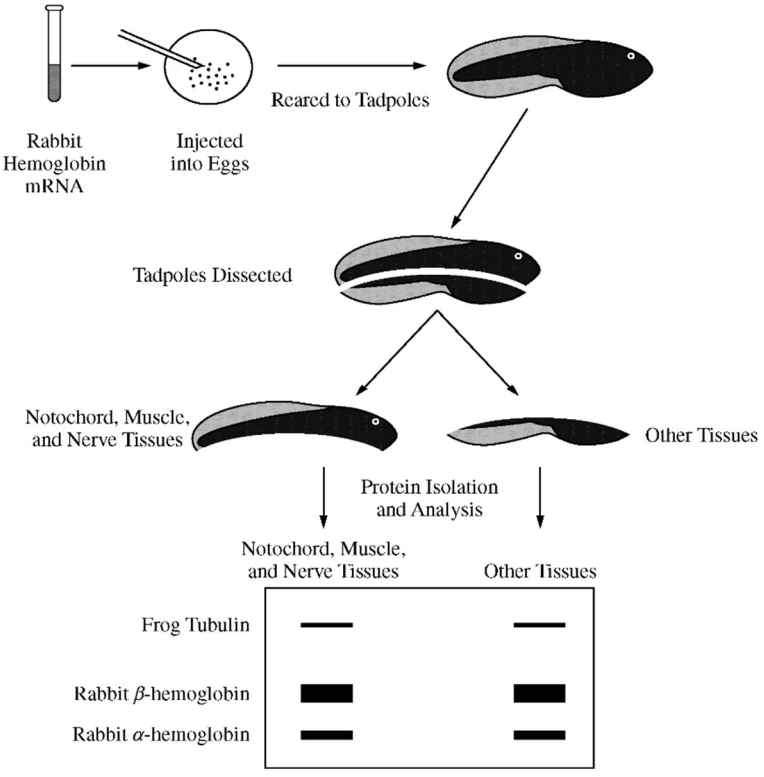
15. Plates I and III were included in the experimental design in order to
    a. demonstrate that the E. coli cultures were viable
    b. demonstrate that the plasmid can lose its amp^r gene
    c. demonstrate that the plasmid is needed for E. coli growth
    d. prepare the E. coli for transformation

16. Which of the following statements best explains why there are fewer colonies on plate IV than on plate III?
    a. Plate IV is the positive control.
    b. Not all E. coli cells are successfully transformed.
    c. The bacteria on plate III did not mutate.
    d. The plasmid inhibits E. coli growth.

17. In a second experiment, the plasmid contained the gene for human insulin as well as the amp^r gene. Which of the following plates would have the highest percentage of bacteria that are expected to produce insulin?
    a. I only
    b. III only
    c. IV only
    d. I and III

Use the following information for questions 18-20:

In a classic experiment from the 1970s investigating gene expression, a solution containing equal amounts of rabbit a-hemoglobin mRNA and b-hemoglobin mRNA, which encode subunits of a protein found in red blood cells, was injected into newly fertilized frog eggs. The injected mRNA was not degraded during the course of the experiment. Tadpoles that developed from the injected eggs were dissected into two fragments, one containing predominantly the notochord, muscle tissue, and nerve tissue and the other containing predominantly the other tissue types.



Equal amounts of total protein were analyzed after separation by electrophoresis to identify the relative amounts of the different proteins present in each sample. The thickness of the bands indicates the relative amounts of rabbit α-hemoglobin, rabbit β-hemoglobin, and frog tubulin (a cytoskeletal protein that is expressed at relatively constant levels in all tissues) present in each tadpole sample. The experimental protocol and results are summarized in the figure below.

18. The electrophoresis results best support which of the following conclusions?
    a. Cell specialization during development results in some cells losing the ability to synthesize proteins.
    b. Cells from different tissues share a common ability to use genetic material from a foreign source to produce protein.
    c. In comparison with other cells, nerve cells have a superior ability to produce cytoskeletal proteins.
    d. Muscle cells produce more b-hemoglobin than do cells from the other tissues in a tadpole.

19. Which of the following conclusions is most consistent with the results of the experiment?
    a. Rabbit mRNA is composed of nucleotides that are absent from frog mRNA.
    b. A larger volume of blood circulates through a rabbit than through a frog.
    c. The subunits of hemoglobin differ in size, shape, or charge.
    d. Synthesis of β-hemoglobin occurs at a faster rate in muscle cells than in other body cells.

20. Given that equal amounts of the different mRNAs were injected into fertilized frog eggs, which of the following conclusions is most consistent with the electrophoresis results?
    a. β-hemoglobin mRNA is translated more efficiently than is α-hemoglobin mRNA.
    b. α-hemoglobin is present only in cells where β-hemoglobin is absent.
    c. α-hemoglobin mRNA is more stable than β-hemoglobin mRNA.
    d. Tubulin inhibits translation of hemoglobin mRNA.

21. How does the DNA in a prokaryote differ from a eukaryote?
    a. Prokaryote has circular DNA, Eukaryotes has linear DNA
    b. Prokaryote has single stranded DNA, Eukaryotes has double stranded DNA
    c. Prokaryote has linear DNA, Eukaryotes has prokaryote DNA
    d. Prokaryote has double stranded DNA, Eukaryotes has single stranded DNA

22. Both eukaryotes and prokaryotes have plasmids. What are plasmids?
    a. large extra-chromosomal, double-stranded, linear DNA molecules
    b. large extra-chromosomal, double-stranded, circular DNA molecules
    c. small extra-chromosomal, double-stranded, circular DNA molecules
    d. small extra-chromosomal, double-stranded, linear DNA molecules

23. Identify which of the following best describes purines and pyrimidines.
    a. Purines (C, T, & U) have single ring, Pyrimidines (A & G) have double ring
    b. Purines (C, T, & U) have double ring, Pyrimidines (A & G) have single ring
    c. Purines (A & G) have single ring, Pyrimidines (C, T, & U) have double ring
    d. Purines (A & G) have double ring, Pyrimidines (C, T, & U) have single ring

24. Which of the following demonstrates base pairing rules to 5' - CAGGT - 3'
    a. 3' - TGGAC - 5'
    b. 3' - GTCCA - 5'
    c. 5' - GTCCA - 3'
    d. 5' - CAGGT - 3'

25. Which enzyme is responsible for relaxing supercoiling in front of the replication fork?
    a. helicase
    b. DNA polymerase
    c. topoisomerase
    d. ligase

26. Which enzyme is responsible for unwinding the DNA strands?
    a. helicase
    b. DNA polymerase
    c. topoisomerase
    d. ligase

27. Which enzyme is requires RNA primers to initiate DNA synthesis?
    a. helicase
    b. DNA polymerase
    c. topoisomerase
    d. ligase

28. Which enzyme is responsible for joining the fragments on the lagging strand?
    a. helicase
    b. DNA polymerase
    c. topoisomerase
    d. ligase

29. Describe the difference between the synthesis of the leading and lagging strands.
    a. directionality: leading = 3' -> 5', lagging = 5' -> 3'
    b. synthesis continuity: leading = discontinuous & lagging = continuous
    c. directionality: leading = 5' -> 3', lagging = 3' -> 5'
    d. synthesis continuity: leading = continuous & lagging = discontinuous

30. How do the three types of RNA work together?
    a. mRNA carries message, tRNA carries amino acids, and rRNA makes ribosome
    b. mRNA makes ribosomes, tRNA carries amino acids, and rRNA relays information
    c. mRNA carries amino acids, tRNA transfer message, and rRNA makes ribosome
    d. mRNA is made, tRNA holds the DNA in place, and rRNA removes the deoxyribose

31. Which of the following are NOT post-transcriptional modifications?
    a. 5' cap
    b. intron removal
    c. poly-A tail
    d. TATA box

32. During transcription, what is the relationship between DNA and RNA?
    a. Template DNA is the noncoding strand, RNA reads DNA in 3' -> 5' direction
    b. Template DNA is the coding strand, RNA reads DNA in 3' -> 5' direction
    c. Template DNA is the noncoding strand, RNA reads DNA in 5' -> 3' direction
    d. Template DNA is the coding strand, RNA reads DNA in 5' -> 3' direction

33. Where does translation take place in prokaryotes & eukaryotes?
    a. Prokaryotes - cytosol; Eukaryotes - cytosol or nucleus
    b. Prokaryotes - cytosol or rough ER; Eukaryotes - cytosol
    c. Prokaryotes - cytosol; Eukaryotes - cytosol or rough ER
    d. Prokaryotes - cytosol or nucleus; Eukaryotes – cytosol

34. What is the sequence of nucleotides on mRNA read in triplets called?
    a. anticodon
    b. codon
    c. triplet box
    d. wobble

35. How do retroviruses violate the central dogma?
    a. Retroviruses are responsible for using DNA to synthesize more viral RNA
    b. Retroviruses are pre-historic and existed prior to the central dogma
    c. Retroviruses use enzymes to make DNA from RNA & integrate into host DNA
    d. Retroviruses use host DNA to make viral RNA, then incorporate into host DNA

36. Which of the following describes epigenetic changes that affect gene expression?
    a. alternative RNA splicing
    b. post-transcriptional modification
    c. DNA methylation or histone acetylation
    d. operon inhibition

37. Identify which molecules bind to the promoter region
    a. Ligase
    b. Topoisomerase
    c. DNA polymerase
    d. RNA polymerase
    e.

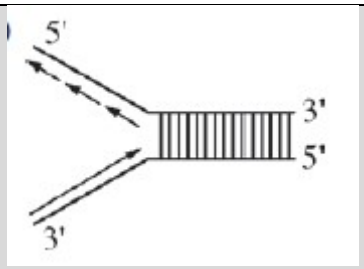
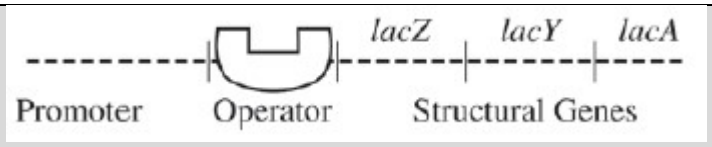
38. Identify the primary source of genetic variation
    a. crossing over
    b. mutations
    c. random fertilization
    d. independent assortment

39. What determines the level of effect of a mutation?
    a. environmental context
    b. codon-anticodon pairing
    c. structure of protein
    d. process of meiosis

40. Which of the following is NOT a process of horizontal acquisition of genetic information by prokaryotes?
    a. transformation
    b. transposition
    c. transduction
    d. transjugation

41. Which of the following genetic engineering techniques is incorrectly described?
    a. Electrophoresis separates molecules based on size & charge
    b. Bacterial transformation introduces DNA to bacterial cells
    c. PCR allows for DNA fragments to be stabilized for engineering processes
    d. DNA sequencing determines the order of nucleotides in a DNA molecule

Multiple Choice Key

Question	Correct Answer	Unit/Topic	Source
1	D. 	6.2	2012 CED #3
2	B. Different exons are retained or spliced out of the primary transcript.	6.3	2020 CED #11
3	A. Bicoid protein inhibits translation of caudal mRNA.	6.3	2012 CED #19
4	D. 5' CUG ACU CCU GUG GAG AAG UCU 3'	6.3	2013 #49
5	A. The HbA DNA contains a recognition site for the Mst II restriction enzyme.	6.8	2013 #50
6	C. The activator is a sequence-specific DNA-binding protein that is present in some tissues but not in other tissues.	6.5	2013 #38
7	D. 	6.5	2012 CED #7
8	D. Do mutations in the POU4F3 gene affect MYO6 mRNA levels in cells?	6.6	2020 CED #3
9	A. properties of the molecule as a result of abnormal interactions between adjacent hemoglobin molecules	6.7	2012 CED #20
10	B. How does the disrupted chloride movement affect the movement of sodium ions and water by the cell?	6.7	2013 #26
11	B. An increase in genetic variation	6.7	2013 #15
12	A. Protein X normally stimulates cell division, and the mutation created an overactive version of protein X.	6.7	2013 #25
13	C. IV only	6.8	2012 CED #24
14	A. The initial E. coli culture was not ampicillin- resistant.	6.8	2012 CED #25
15	A. demonstrate that the E. coli cultures were viable	6.8	2012 CED #26
16	B. Not all E. coli cells are successfully transformed.	6.8	2012 CED #27
17	C. IV only	6.8	2012 CED #28
18	B. Cells from different tissues share a common ability to use genetic material from a foreign source to produce protein.	6.8	2013 #26
19	C. The subunits of hemoglobin differ in size, shape, or charge.	6.8	2013 #30

20	A. β-hemoglobin mRNA is translated more efficiently than is α-hemoglobin mRNA.	6.4	2013 #31
21	A. Prokaryote has circular DNA, Eukaryotes has linear DNA	6.1	Self
22	C. small extra-chromosomal, double-stranded, circular DNA molecules	6.1	Self
23	D. Purines (A & G) have double ring, Pyrimidines (C, T, & U) have single ring	6.1	Self
24	B. 3' - GTCCA - 5'	6.1	Self
25	C. topoisomerase	6.2	Self
26	A. helicase	6.2	Self
27	B. DNA polymerase	6.2	Self
28	D. ligase	6.2	Self
29	D. synthesis continuity: leading = continuous & lagging = discontinuous	6.2	Self
30	A. mRNA carries message, tRNA carries amino acids, and rRNA makes ribosome	6.3	Self
31	D. TATA box	6.3	Self
32	A. Template DNA is the noncoding strand, RNA reads DNA in 3' -> 5' direction	6.3	Self
33	D. Prokaryotes - cytosol or nucleus; Eukaryotes - cytosol	6.4	Self
34	B. codon	6.4	Self
35	C. Retroviruses use enzymes to make DNA from RNA & integrate into host DNA	6.4	Self
36	C. DNA methylation or histone acetylation	6.5	Self
37	D. RNA polymerase	6.6	Self
38	B. mutations	6.7	Self
39	A. environmental context	6.7	Self
40	D. transjugation	6.7	Self
41	C. PCR allows for DNA fragments to be stabilized for engineering processes	6.8	Self

Free Response Practice

2019 #1

This question is in Unit 8.

2019 #6

		STRAINS		
	MEDIUM	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.

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

(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.

		STRAINS			
	MEDIUM	Wild Type (haploid)	Mutant 1 (haploid)	Mutant 2 (haploid)	Diploid Cells Produced by Mating Mutant 1 and 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	+	+	–	

2019 #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.

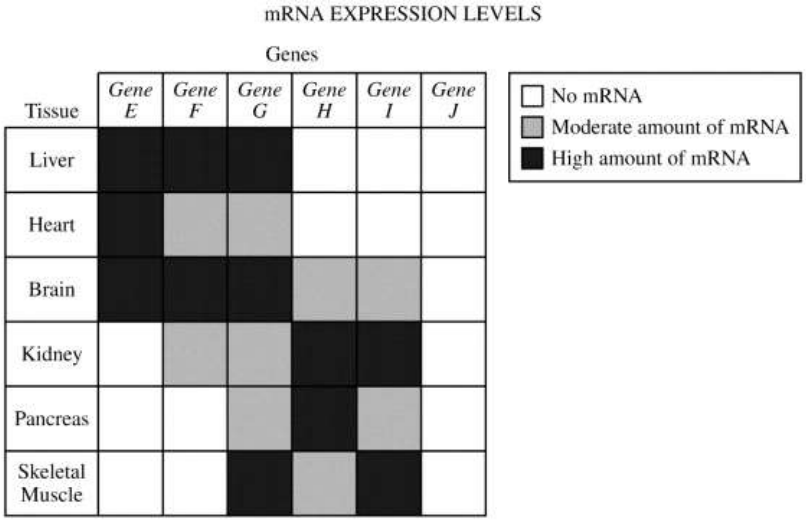


Figure 1. mRNA expression levels of six genes

(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.

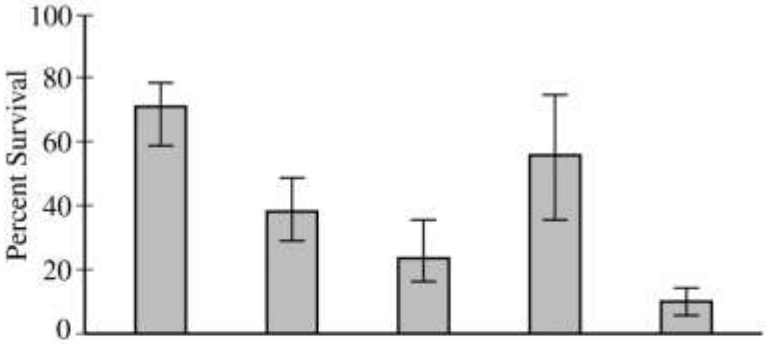
(b) The researcher observed that tissues with a high level of *gene H* mRNA did not always have gene H protein. **Provide reasoning** to explain how tissues with high *gene H* mRNA levels can have no gene H protein.

2018 #1

This question is found in Unit 7.

2018 #4

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.



Strain	I	II	III	IV	V
P450	+	–	+	+	–
Abc8	+	+	–	+	–
Cps	+	+	+	–	+

+ = Wildtype
– = Deletion

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.

(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.

(b) *P450* encodes an enzyme that detoxifies insecticide. *Abc8* encodes a transporter protein that pumps insecticides out of cells. *Cps* encodes external structural protein located in the exoskeleton that 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.

2017 #3

Gibberellin is the primary plant hormone that promotes stem elongation. GA 3-beta-hydrozylase (*GA3H*) is the enzyme that catalyzes the reaction that converts a precursor of gibberellin to the active form of gibberellin. A mutation in the *GA3H* gene results in a short plant phenotype. When a pure-breeding tall plant is crossed with a pure-breeding short plant, all offspring in the F_1 generation are tall. When the F_1 plants are crossed with each other, 75 percent of the plants in the F_2 generation are tall and 25 percent of the plants are short.

Second Base in Codon

First Base in Codon	U	C	A	G	Third Base in Codon
U	UUU, UUC: Phe; UUA, UUG: Leu	UCU, UCC, UCA, UCG: Ser	UAU, UAC: Tyr; UAA Stop; UAG Stop	UGU, UGC: Cys; UGA Stop; UGG Trp	U C A G
C	CUU, CUC, CUA, CUG: Leu	CCU, CCC, CCA, CCG: Pro	CAU, CAC: His; CAA, CAG: Gln	CGU, CGC, CGA, CGG: Arg	U C A G
A	AUU, AUC, AUA: Ile; AUG: Met or Start	ACU, ACC, ACA, ACG: Thr	AAU, AAC: Asn; AAA, AAG: Lys	AGU, AGC: Ser; AGA, AGG: Arg	U C A G
G	GUU, GUC, GUA, GUG: Val	GCU, GCC, GCA, GCG: Ala	GAU, GAC: Asp; GAA, GAG: Glu	GGU, GGC, GGA, GGG: Gly	U C A G

Figure 1. The universal genetic code

(a) The wild-type allele encodes a GA3H enzyme with alanine (Ala), a nonpolar amino acid, at position 229. The mutant allele encodes a GA3H enzyme with threonine (Thr), a polar amino acid, at position 229. **Describe** the effect of the mutation on the enzyme and **provide reasoning** to support how this mutation results in a short plant phenotype in homozygous recessive plants.

(b) Using the codon chart provided, **predict** the change in the codon sequence that resulted in the substitution of alanine for threonine at amino acid position 229.

(c) **Describe** how individuals with one (heterozygous) or two (homozygous) copies of the wild-type *GA3H* allele can have the same phenotype.

2017 #6

A comet assay is a technique used to determine the amount of double-stranded breaks in DNA (DNA damage) in cells. The nucleus of an individual cell is placed on a microscope slide coated with an agarose gel. An electric current is applied to the gel that causes DNA to move (electrophoresis), and the DNA is stained with a fluorescent dye. When viewed using a microscope, undamaged DNA from the nucleus appears as a round shape (the head), and the fragments of damaged DNA extend out from the head (the tail). The length of the tail corresponds to the amount of the damage in the DNA (see Figure 1).

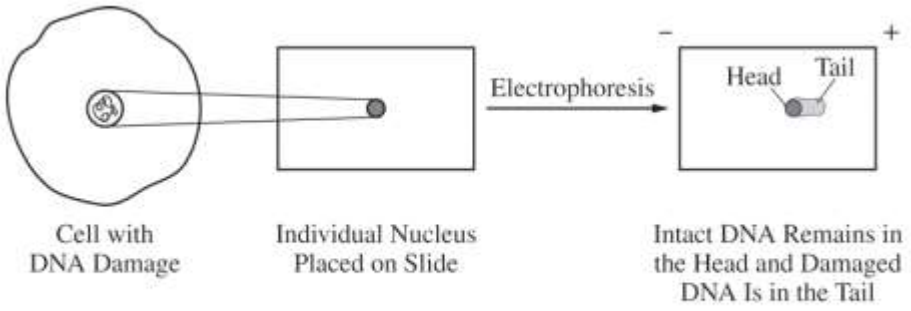


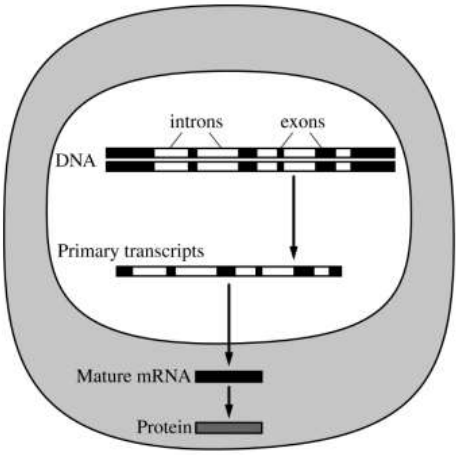
Figure 1. Comet assay to detect double-stranded breaks in DNA

(a) To explain the movement of DNA fragments in the comet assay, **identify** one property of DNA and **provide reasoning** to support how the property contributes to the movement during the comet assay technique.

(b) In a different experiment, cells are treated with a chemical mutagen that causes only nucleotide substitutions in DNA. **Predict** the likely results of a comet assay from this treatment.

2016 #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 7kb 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.

(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.

2016 #6

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).

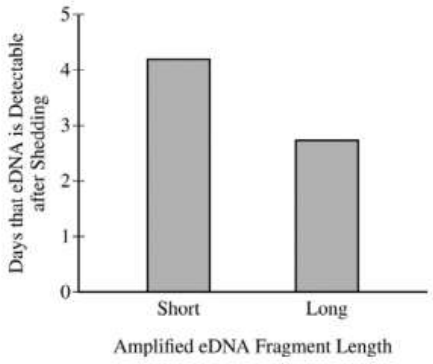


Figure 1. Detectability of eDNA fragments of varying lengths

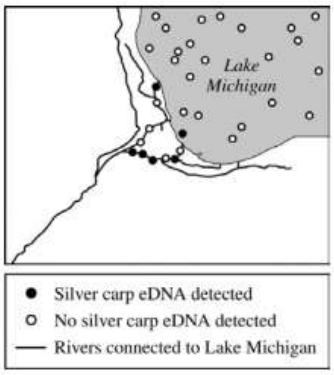


Figure 2. Map of the waterways that connect a nearby river system to Lake Michigan

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 whether many different species of fish are found. **Propose** ONE advantage of identifying long eDNA fragments as opposed to short fragments for detecting silver carp.

(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 simple positive sample was a false positive and that no silver carp had entered Lake Michigan. **Provide reasoning** other than human error to support the researcher's claim.

2015 #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 activated olfactory sensory neuron to the interneuron that transmits the information to the brain.

(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 answer.

2014 #5

This question is in Unit 8.

2014 #8

This question is in Unit 7.

2013 #5

The table below shows the amino acid sequence of the carboxyl-terminal segment of a conserved polypeptide from four different, but related, species. Each amino acid is represented by a three-letter abbreviation, and the amino acid residues in the polypeptide chains are numbered from the amino end to the carboxyl end. Empty cells indicate no amino acid is present.

	Relative Amino Acid Position									
Species	1	2	3	4	5	6	7	8	9	10
I	Val	His	Leu	Val	Glu	Glu	His	Val	Glu	His
II	Val	His	Leu	Lys	Glu	Glu	His	Val	Glu	His
III	Val	His	Leu	Val	Glu	Glu	His	Val		
IV	Val	His	Leu	Val	Arg	Trp	Ala	Cys	Met	Asp

(a) Assuming that species I is the ancestral species of the group, **explain** the most likely genetic change that produced the polypeptide in species II and the most likely genetic change that produced the polypeptide in species III.

(b) **Predict** the effects of the mutation on the structure and function of the resulting protein in species IV. **Justify** your prediction.

Free Response Scoring Guidelines

2019 #6

Part	Scoring Guidelines	Topic
(a)	**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.	5.2
(b)	**Reasoning (1 point)** • Mutant 1 can use methionine when it is present in the medium, but Mutant 1 cannot synthesize methionine.	6.7
(c)	**Prediction (1 Point)** • There will be growth (+) in all four cells of the fourth column.	5.2

2019 #7

Part	Scoring Guidelines	Topic
(a)	**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.	3.6
(b)	**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.	6.4

2018 #4

Part	Scoring Guidelines	Topic
(a)	**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.	6.7
(b)	**Explanation (1 point per row; 2 points maximum)** Strain | *P450* and *Abc8* | *Cps* 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.	6.7

2017 #3

Part	Scoring Guidelines	Topic
(a)	**Description (1 point)**: The amino acid substitution changes the shape/structure/function of the protein. **Reasoning (1 point)**: The mutation decreases/eliminates gibberellin production.	6.7
(b)	**Prediction (1 point maximum)** • G ↔ A in the first position (of the codon) • 5′-GCN-3′ ↔ 5′-ACN-3′ • 5′-NGC-3′ ↔ 5′-NGT-3′ in the template strand of DNA	6.7
(c)	**Description (1 point)** • Enough active enzyme is produced from one wild-type/dominant allele. • Enough gibberellin is produced in the presence of one wild-type/dominant allele.	6.4

2017 #6

Part	Scoring Guidelines	Topic
(a)	**Identification (1 point)**: DNA has a (negative) charge. DNA can be different sizes. **Reasoning (1 point)**: DNA moves toward the positive/oppositely charged pole. (Different size DNA fragments) move at different rates.	6.8
(b)	**Prediction (1 point)** • Head (only) OR (head with) no tail. • Tail will be shorter than a cell with double-stranded breaks in DNA.	6.8

2016 #4

Part	Scoring Guidelines	Topic
(a)	**Describe process (1 point)** • Removal of introns • RNA processing **Identification (1 point)** • Nucleus	6.3
(b)	**Prediction (1 point)** • 15 kb • Longer than the mature mRNA in the eukaryote **Justification (1 point)** • mRNA processing typically does not occur in prokaryotes	6.3

2016 #6

Part	Scoring Guidelines	Topic
(a)	**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.	6.8
(b)	**Reasoning (1 point)** • eDNA entered the lake by means other than the fish (e.g., river flow, boats, waste from predators).	6.8

2015 #7

Part	Scoring Guidelines	Topic
(a)	**Description (1 point)** • Neurotransmitters are released from the olfactory neuron and bind to receptors in the postsynaptic neuron.	4.2
(b)	<table><tr><th></th><th>Explanation (1 point)</th><th>Support (1 point)</th></tr><tr><td>Molecular</td><td>• One odorant molecule can be recognized by more than one odorant receptor • One odorant receptor can bind to more than one odorant molecule</td><td>Mathematical combinations expand possible odors detected</td></tr><tr><td>CNS Control</td><td>Signals integrated in the brain</td><td>Multiple interactions among neurons in the brain</td></tr><tr><td>Genetic</td><td>Alternate processing/splicing (of pre-mRNA/primary transcript)</td><td>Multiple receptors can be produced from a gene</td></tr></table> *Note: The nervous system is no longer in scope*	6.3

2013 #5

Part	Scoring Guidelines	Topic
(a)	Explanation: **1 point per row** NOTE: Specific names of mutation types are not required. <table><tr><th>Species</th><th>Genetic Change in DNA / Bases</th><th>Result of Change to Polypeptide / Protein</th></tr><tr><td>II</td><td>mutation / substitution / point mutation / missense mutation</td><td>an amino acid change only at position 4 (Val to Lys)</td></tr><tr><td>III</td><td>mutation (e.g., substitution / insertion / deletion / point mutation / frameshift mutation / nonsense mutation) that introduces a stop codon after the codon for Val</td><td>termination of the polypeptide after the Val at position 8</td></tr></table>	6.7

(b)

Predicted Change (**1 point maximum**)	Justification of Prediction (**1 point maximum**)
Protein may have a different structure and a change in function.	Change in amino acid sequence of the protein starting at position 5 could alter the overall structure or local structural regions, interfering with function of the protein.
Protein may have a different structure and no change in function.	Change in amino acid sequence alters the shape / conformation / folding / binding region / regulatory region of the protein, but does not affect the critical functional region(s) of the protein.
Protein structure and function may not be affected.	Change in amino acid sequence does not alter the protein shape / conformation / folding and does not alter function.

6.7

Unit 7: Natural Selection

Topic	Learning Objective(s)
7.1 Introduction to Natural Selection	**EVO-1.C** Describe the causes of natural selection.
	EVO-1.D Explain how natural selection affects populations.
7.2 Natural Selection	**EVO-1.E** Describe the importance of phenotypic variation in a population.
7.3 Artificial Selection	**EVO-1.F** Explain how humans can affect diversity within a population.
	EVO-1.G Explain the relationship between changes in the environment and evolutionary changes in the population.
7.4 Population Genetics	**EVO-1.H** Explain how random occurrences affect the genetic makeup of a population.
	EVO-1.I Describe the role of random processes in the evolution of specific populations.
	EVO-1.J Describe the change in the genetic makeup of a population over time.
7.5 Hardy-Weinberg Equilibrium	**EVO-1.K** Describe the conditions under which allele and genotype frequencies will change in populations.
	EVO-1.L Explain the impacts on the population if any of the conditions of Hardy-Weinberg are not met.
7.6 Evidence of Evolution	**EVO-1.M** Describe the types of data that provide evidence for evolution.
	EVO-1.N Explain how morphological, biochemical, and geological data provide evidence that organisms have changed over time.
	EVO-2.B Describe the fundamental molecular and cellular features shared across all domains of life, which provide evidence of common ancestry.
7.7 Common Ancestry	**EVO-2.C** Describe structural and functional evidence on cellular and molecular levels that provides evidence for the common ancestry of all eukaryotes.
7.8 Continuing Evolution	**EVO-3.A** Explain how evolution is an ongoing process in all living organisms.
7.9 Phylogeny	**EVO-3.B** Describe the types of evidence that can be used to infer an evolutionary relationship.
	EVO-3.C Explain how a phylogenetic tree and/or cladogram can be used to infer evolutionary relatedness.
7.10 Speciation	**EVO-3.D** Describe the conditions under which new species may arise.
	EVO-3.E Describe the rate of evolution and speciation under different ecological conditions.
	EVO-3.F Explain the processes and mechanisms that drive speciation.
7.11 Extinction	**EVO-3.G** Describe factors that lead to the extinction of a population.
	EVO-3.H Explain how the risk of extinction is affected by changes in the environment.
	EVO-3.I Explain species diversity in an ecosystem as a function of speciation and extinction rates.
	EVO-3.J Explain how extinction can make new environments available for adaptive radiation.

7.12 Variations in Populations	**SYI-3.D** Explain how the genetic diversity of a species or population affects its ability to withstand environmental pressures.
7.13 Origin of Life on Earth	**SYI-3.E** Describe the scientific evidence that provides support for models of the origin of life on Earth.

Topic 7.1: Introduction to Natural Selection

Learning Objective	**EVO-1.C** Describe the causes of natural selection.
I can…	☐ I can describe the causes of natural selection. ☐ I can describe how natural selection leads to evolution. ☐ I can describe Darwin's theory of natural selection. ☐ I can apply differential survival in a situation of competition for limited resources.

1. What is natural selection?
2. How does natural selection lead to evolution?
3. What is Darwin's theory of natural selection?
4. What does differential survival mean?
5. Why do organisms require competition for limited resources to allow for natural selection?

Learning Objective	**EVO-1.D** Explain how natural selection affects populations.
I can…	☐ I can explain how natural selection affects populations. ☐ I can explain how evolutionary fitness is measured. ☐ I can explain reproductive success. ☐ I can explain ways biotic environments can affect the direction of evolution. ☐ I can explain ways biotic environments can affect the rate of evolution. ☐ I can explain ways abiotic environments can affect the direction of evolution. ☐ I can explain ways abiotic environments can affect the rate of evolution.

6. What is evolutionary fitness?
7. How is evolutionary fitness measured?
8. What is reproductive success?
9. How does reproductive success lead to natural selection?
10. What does biotic and abiotic mean?
11. How does a biotic environment affect the direction of evolution?
12. How does an abiotic environment affect the direction of evolution?
13. How does a biotic environment affect the rate of evolution?
14. How does an abiotic environment affect the rate of evolution?

Topic 7.2: Natural Selection

Learning Objective	**EVO-1.E** Describe the importance of phenotypic variation in a population.
I can…	☐ I can describe the importance of phenotypic variation in a population. ☐ I can describe what natural selection acts on. ☐ I can describe ways an environment applies selective pressure to a population. ☐ I can describe ways a phenotypic variation can increase fitness of an organism in a particular environment. ☐ I can describe ways a phenotypic variation can decrease fitness of an organism in a particular environment.

1. What is phenotype?
2. What does natural selection act on … PHENOTYPE or GENOTYPE?
3. What does natural selection modify … PHENOTYPE or GENOTYPE?
4. How does natural selection act on and modify different levels of genes?
5. What are selective pressures?
6. How does an environment apply a selective pressure to a population?
7. Identify two examples of a phenotypic variation that increases fitness of an organism in a particular environment.
8. Identify two examples of a phenotypic variation that decreases fitness of an organism in a particular environment.

Topic 7.3: Artificial Selection

Learning Objective	**EVO-1.F** Explain how humans can affect diversity within a population.
I can…	☐ I can explain ways humans affect diversity within a population. ☐ I can describe artificial selection. ☐ I can describe ways artificial selection affects variation in a species.

1. What is artificial selection?
2. How does artificial selection modify the variation in a species?
3. Identify two examples of artificial selection due to humans.
    a. How has this modified the species?

Learning Objective	**EVO-1.G** Explain the relationship between changes in the environment and evolutionary changes in the population.
I can…	☐ I can explain the relationship between changes in the environment and evolutionary changes in the population. ☐ I can explain convergent evolution. ☐ I can explain ways selective pressures result in similar phenotypic adaptations in different populations.

4. What is convergent evolution?
5. Identify two examples of organisms that demonstrate convergent evolution.
6. How do selective pressures result in similar phenotypic adaptations?

Topic 7.4: Population Genetics

Learning Objective	EVO-1.H Explain how random occurrences affect the genetic makeup of a population.
I can…	☐ I can explain ways random occurrences affect the genetic makeup of a population. ☐ I can explain the different types of mutations ☐ I can explain ways that mutations affect genetic makeup of a population. ☐ I can explain genetic drift. ☐ I can explain bottleneck. ☐ I can explain ways bottleneck affects genetic makeup of a population. ☐ I can explain founder effect. ☐ I can explain ways founder effect affects genetic makeup of a population. ☐ I can explain gene flow. ☐ I can explain ways gene flow affects genetic makeup of a population.

1. What are mutations?
2. Identify two examples of mutations that potentially could affect phenotype.
3. How do mutations affect genetic makeup of a population?
4. What is genetic drift?
5. What is the bottleneck effect?
6. How does the bottleneck effect modify genetic makeup of a population?
7. Identify one example of a population that has undergone the bottleneck effect.
8. What is the founder's effect?
9. How does the founder's effect modify genetic makeup of a population?
10. Identify one example of a population that has undergone the founder's effect.
11. What is gene flow?
12. How does gene flow modify genetic makeup of a population?
13. Identify one example of a population that has undergone gene flow.

Learning Objective	EVO-1.I Describe the role of random processes in the evolution of specific populations.
I can…	☐ I can describe the role of random processes in the evolution of specific populations. ☐ I can describe the effect of decrease in genetic variation in a population on the differences between other populations of the same species.

14. What is genetic variation?
15. Why is genetic variation important for a population's survivability?
16. How does a decrease in genetic variation affect a population?
17. When there is a decrease in genetic variation, how does the population compare to other populations of the same species?

Learning Objective	EVO-1.J Describe the change in the genetic makeup of a population over time.
I can…	☐ I can describe the change in genetic makeup of a population over time. ☐ I can describe ways that mutations cause genetic variation. ☐ I can describe ways that genetic variation provides different phenotypes. ☐ I can describe ways natural selection acts on phenotypes. ☐ I can describe directional selection. ☐ I can describe stabilizing selection. ☐ I can describe disruptive selection.

18. What is the effect of mutations on genetic variation?
19. How does genetic variation lead to a variation in phenotypes?
20. Identify two examples of natural selection acting on phenotypes.
21. What are the three types of selection?
    a. Identify an example of each of type of selection.

Topic 7.5: Hardy-Weinberg Equilibrium

Learning Objective	**EVO-1.K** Describe the conditions under which allele and genotype frequencies will change in populations.
I can…	☐ I can describe the conditions under which allele frequencies will change in populations. ☐ I can describe the conditions under which genotypes frequencies will change in populations. ☐ I can describe a population demonstrating Hardy-Weinberg. ☐ I can calculate allele frequencies from genotype frequencies. ☐ I can identify the variables in Hardy-Weinberg equation.
Formula Sheet	**RELEVANT EQUATION** Hardy-Weinberg Equation— $p^2 + 2pq + q^2 = 1$ $p + q = 1$ where: p = frequency of allele 1 in the population q = frequency of allele 2 in the population

1. What is Hardy-Weinberg equilibrium?
2. What are the five conditions that must be TRUE for Hardy-Weinberg equilibrium?
   - Note: If you have not watched the "Five Fingers of Evolution" from TedEd – I highly recommend it
3. What is allele frequency?
4. What is genotypic frequency?
5. What is the equation for Hardy-Weinberg equilibrium?
   a. Identify all the variables in the equation.
6. There are two ways to solve for the variables in the equation.
   a. Option one: Solve for the alleles
      There are three colors of snapdragons, solve for all the values if there are 100 red flowers, 800 pink flowers, and 100 white flowers.

p	q	p^2	2pq	q^2

   b. Option two: Solve for q^2, then solve for other values
      Flowers can either be purple (dominant) or white (recessive). Solve for all the values if 75% of the flowers are purple.

p	q	p^2	2pq	q^2

Learning Objective	EVO-1.L Explain the impacts on the population if any of the conditions of Hardy-Weinberg are not met.
I can…	☐ I can explain the impacts on the population if any of the conditions of Hardy Weinberg are not met. ☐ I can explain ways that small populations are more susceptible to changes in allele frequency.

7. What does it mean if the allele frequency changes from one generation to the next?
8. What does it mean if the genotype frequency stays the same from one generation to the next?
9. Why are small populations more susceptible to changes in allele frequency?

Topic 7.6: Evidence of Evolution

Learning Objective	EVO-1.M Describe the types of data that provide evidence for evolution.
I can…	☐ I can describe the types of data that provide evidence for evolution. ☐ I can use geographical data to support evolution. ☐ I can use geological data to support evolution. ☐ I can use physical data to support evolution. ☐ I can use biochemical data to support evolution. ☐ I can use mathematical data to support evolution.

1. What is biogeography?
2. How does geographical data support evolution?
    a. Provide one example geographical data.
3. How does geological data support evolution?
    a. Provide one example of geological data.
4. How does physical data support evolution?
    a. Provide one example of physical data.
5. How does biochemical data support evolution?
    a. Provide one example of biological data.
6. How does mathematical data support evolution?
    a. Provide one example of mathematical data.

Learning Objective	EVO-1.N Explain how morphological, biochemical, and geological data provide evidence that organisms have changed over time.
I can…	☐ I can explain ways morphological data provide evidence that organisms have changed over time. ☐ I can explain ways biochemical data provide evidence that organisms have changed over time. ☐ I can explain ways geological data provide evidence that organisms have changed over time. ☐ I can date fossils using information about the age of rocks layers where it is found. ☐ I can date fossils using carbon-14 decay. ☐ I can date fossils using geographical data. ☐ I can compare DNA nucleotide sequences to provide evidence for evolution and common ancestry. ☐ I can compare protein amino acid sequences to provide evidence for evolution and common ancestry.

7. What are fossils?
8. How can fossils be used as evidence of evolution?
9. What is carbon-14 decay?
    a. How can carbon-14 decay be used to date fossils?

10. How do the rock layers allow for dating of fossils?
11. How can geographical data be used to date fossils?
12. DNA and proteins can be used as evidence of evolution. Which is more accurate to determine most recent common ancestor? DNA or PROTEINS
13. How do the number of differences of nucleotides or amino acids demonstrate ancestry of organisms?

Learning Objective	**EVO-2.B** Describe the fundamental molecular and cellular features shared across all domains of life, which provide evidence of common ancestry.
I can…	☐ I can describe the fundamental features shared across all domains of life, which provide evidence of common ancestry. ☐ I can describe the molecular features shared across all domains of life, which provide evidence of common ancestry. ☐ I can describe the cellular features shared across all domains of life, which provide evidence of common ancestry. ☐ I can use structural evidence to support relatedness of organisms in all domains. ☐ I can use functional evidence to support relatedness of organisms in all domains.

14. Identify two molecular features shared across organisms.
15. Identify two cellular features shared across organisms.
16. What are homologous structures?
17. What are analogous structures?
18. What is embryology?
19. Which results from convergent evolution (not representing common ancestry)? HOMOLOGOUS or ANALOGOUS
20. How does structural evidence support relatedness of organisms?
21. How does functional evidence support relatedness of organisms?

Topic 7.7: Common Ancestry

Learning Objective	EVO-2.C Describe structural and functional evidence on cellular and molecular levels that provides evidence for the common ancestry of all eukaryotes.
I can…	☐ I can describe structural evidence on the cellular level that provides evidence for the common ancestry of all eukaryotes. ☐ I can describe functional evidence on the cellular level that provides evidence for the common ancestry of all eukaryotes. ☐ I can describe structural evidence on the molecular level that provides evidence for the common ancestry of all eukaryotes. ☐ I can describe functional evidence on the molecular level that provides evidence for the common ancestry of all eukaryotes. ☐ I can describe ways that membrane-bound organelles indicate common ancestry of all eukaryotes. ☐ I can describe ways that linear chromosomes indicate common ancestry of all eukaryotes. ☐ I can describe ways that genes containing introns indicate common ancestry of all eukaryotes.

1. What are membrane-bound organelles?
2. What type of cells have membrane-bound organelles? EUKARYOTIC or PROKARYOTIC
3. How did membrane-bound organelles originate?
4. How do membrane-bound organelles indicate common ancestry for all eukaryotes?
5. Describe a linear chromosome.
6. How are prokaryotic chromosomes organized?
7. How are eukaryotic chromosomes organized?
8. How do linear chromosomes indicate common ancestry for all eukaryotes?
9. What is an intron?
10. When are introns removed?
11. What type of cells have introns? EUKARYOTIC or PROKARYOTIC
12. How do genes containing introns indicate common ancestry for all eukaryotes?

Topic 7.8: Continuing Evolution

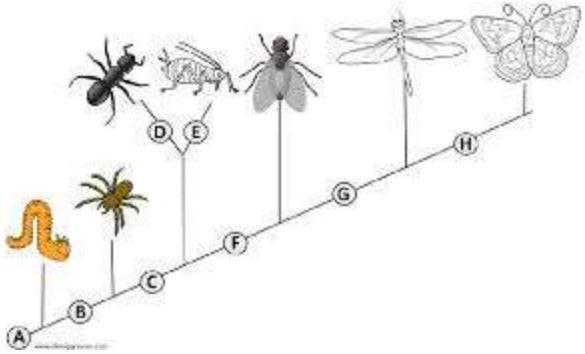
Learning Objective	EVO-3.A Explain how evolution is an ongoing process in all living organisms.
I can…	☐ I can explain ways to show that evolution is an ongoing process in all living organisms. ☐ I can explain ways to show that population of organisms continue to evolve. ☐ I can use genomic changes over time to support the claim that all species have evolved and continue to evolve. ☐ I can use continuous change in the fossil record to support the claim that all species have evolved and continue to evolve. ☐ I can use evolution of resistance to antibiotics, pesticides, herbicides, or chemotherapy drugs to support the claim that all species have evolved and continue to evolve. ☐ I can use pathogen evolution and causation of emergent disease to support the claim that all species have evolved and continue to evolve.

1. What evolves? INDIVIDUALS or POPULATIONS
2. True or False: Once a population of organisms are perfect, they will cease evolving.
3. How can scientists use genomes to prove that all species continue to evolve?
4. How can scientists use fossil record to prove that all species continue to evolve?
5. What does it mean if a population of bacteria is antibiotic resistant?
6. How does a population of bacteria become antibiotic resistant?
7. How does this resistance to antibiotics support the claim that all species have evolved and continue to evolve?
   - Note this should be applicable to pesticides, herbicides, or chemotherapy drugs.
8. Why do you need to get the influenza vaccine every year?
9. How does the fact that viruses and other pathogens change over time support the claim that all species have evolved and continue to evolve?

Topic 7.9: Phylogeny

Learning Objective	EVO-3.B Describe the types of evidence that can be used to infer an evolutionary relationship.
I can…	☐ I can describe the types of evidence that can be used to infer an evolutionary relationship. ☐ I can use phylogenetic trees and cladograms to show evolutionary relationships among lineages. ☐ I can compare the data provided by a phylogenetic tree and cladogram. ☐ I can contrast the data provided by a phylogenetic tree and cladogram. ☐ I can use trait gained or lost during evolution to construct a phylogenetic tree or cladogram. ☐ I can describe shared characters. ☐ I can describe shared, derived characters. ☐ I can describe the outgroup. ☐ I can identify the outgroup in a phylogenetic tree or cladogram. ☐ I can describe the most accurate and reliable data for the construction of phylogenetic tree or cladogram.

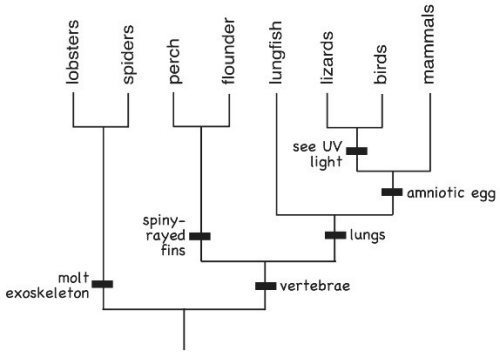
1. What is a phylogenetic tree?
2. What is a cladogram?
3. Identify one similarity about the data presented in a phylogenetic tree and cladogram.
4. Identify one difference about the data presented in a phylogenetic tree and cladogram.
5. Where would you see a gained or lost trait on a cladogram or phylogenetic tree?
    a. For example: Using the following cladogram, identify at what point wings were gained?



6. What are shared characters?
7. What are derived characters?
8. What is an outgroup?
    a. How do you identify the outgroup on a cladogram?
9. Which if the most accurate and reliable data for construction of phylogenetic tree or cladogram? MOLECULAR DATA or MORPHOLOGICAL TRAITS
    a. Justify why this type of data is the most accurate and reliable.

Learning Objective	EVO-3.C Explain how a phylogenetic tree and/or cladogram can be used to infer evolutionary relatedness.
I can…	☐ I can explain ways a phylogenetic tree and/or cladogram can be used to infer evolutionary relatedness. ☐ I can determine when speciation occurred using a phylogenetic tree and/or cladogram. ☐ I can determine the most recent common ancestor of any two groups or lineages on a phylogenetic tree and/or cladogram. ☐ I can describe evidence used to construct a phylogenetic tree and/or cladogram. ☐ I can use DNA/protein sequences to develop a phylogenetic tree and/or cladogram. ☐ I can use fossil evidence to develop a phylogenetic tree and/or cladogram. ☐ I can use evidence to revise a phylogenetic tree and/or cladogram.

10. What does a branch point in a cladogram or phylogenetic tree represent?
11. How do you determine the most recent common ancestor on a cladogram or phylogenetic tree?
    a. For example: Identify the most recent common ancestor of lizards and mammals.



12. In the above example, what organism is most closely related to:
    a. Spiders?
    b. Perch?
    c. Birds?
13. What evidence is used to develop a cladogram or phylogenetic tree?
14. When using molecular evidence, how do you determine if two organisms are closely related?
15. When using fossil evidence, how do you determine if two organisms are closely related?

Topic 7.10: Speciation

Learning Objective	EVO-3.D Describe the conditions under which new species may arise.
I can…	☐ I can describe the conditions under which new species may arise. ☐ I can describe speciation. ☐ I can describe the types of reproductive isolation. ☐ I can describe the biological species concept. ☐ I can determine whether two organisms are from the same species.

1. What is speciation?
2. What is reproductive isolation?
3. What is the biological species concept?
4. How can you determine if two organisms are from the same species?

Learning Objective	EVO-3.E Describe the rate of evolution and speciation under different ecological conditions.
I can…	☐ I can describe the rate of evolution and speciation under different ecological conditions. ☐ I can describe punctuated equilibrium. ☐ I can describe gradualism. ☐ I can describe divergent evolution. ☐ I can describe the effect of adaptive radiation on speciation rates.

5. What is punctuated equilibrium?
    a. Identify an example of an organism that underwent punctuated equilibrium.
6. What is gradualism?
    a. Identify an example of an organism that underwent gradualism.
7. What is divergent evolution?
    a. What term do we use when two organisms have similar characteristics due to divergent evolution?
8. What is adaptive radiation?
9. What is the effect of adaptive radiation on speciation rates?

Learning Objective	**EVO-3.F** Explain the processes and mechanisms that drive speciation.
I can…	☐ I can explain the processes that drive speciation. ☐ I can explain the mechanisms that drive speciation. ☐ I can describe the results of speciation. ☐ I can describe sympatric speciation. ☐ I can describe allopatric speciation. ☐ I can identify prezygotic barriers. ☐ I can describe habitat/ecological isolation. ☐ I can describe temporal isolation. ☐ I can describe behavioral isolation. ☐ I can describe gametic isolation. ☐ I can describe geographical isolation. ☐ I can identify postzygotic barriers. ☐ I can describe hybrid breakdown. ☐ I can describe reduced hybrid viability. ☐ I can describe reduced hybrid fertility. ☐ I can describe ways that reproductive barriers cause speciation.

10. What are the results of speciation?
11. What is sympatric speciation?
12. What mechanisms lead to speciation in sympatric speciation?
13. What is allopatric speciation?
14. What mechanisms lead to speciation in allopatric speciation?
15. What is the difference between pre- and post- zygotic reproductive barriers?
16. Using the following chart, describe the types of pre- and post- zygotic reproductive barriers with examples.

Prezygotic Reproductive Barriers		
Reproductive Isolation Type	Description	Example
Habitat/Ecological Isolation		
Temporal Isolation		
Behavioral Isolation		
Gametic Isolation		
Geographical Isolation		
Postzygotic Reproductive Barriers		
Reproductive Isolation Type	Description	Example
Hybrid Breakdown		
Reduced Hybrid Viability		
Reduced Hybrid Fertility		

17. How does reproductive isolation lead to speciation?
18. What three potential results occur when two species come in contact in the hybrid zone?

Topic 7.11: Extinction

Learning Objective	EVO-3.G Describe factors that lead to the extinction of a population.
I can…	☐ I can describe factors that lead to the extinction of a population. ☐ I can describe extinctions that have occurred throughout Earth's history. ☐ I can describe the effect on extinction rates of ecological stress.

1. Identify two extinctions that have occurred in Earth's history?
2. What lead to the extinctions that you identified?
3. How does extinction rates effect ecological stress?

Learning Objective	EVO-3.H Explain how the risk of extinction is affected by changes in the environment.
I can…	☐ I can explain ways the risk of extinction is affected by changes in the environment. ☐ I can explain ways that human activity is driving changes in ecosystems. ☐ I can explain ways that changes in the ecosystems is causing extinctions.

4. Identify two ways that human activities are driving changes in ecosystems leading to extinctions.
5. What changes in environments lead to extinction of organisms?

Learning Objective	EVO-3.I Explain species diversity in an ecosystem as a function of speciation and extinction rates.
I can…	☐ I can explain species diversity in an ecosystem as a function of speciation and extinction rates. ☐ I can predict the effect on species diversity based on rate of speciation and rate of extinction changes.

6. What is species diversity?
7. How does species diversity impact the rate of speciation?
8. How does species diversity impact the rate of extinction?

Learning Objective	EVO-3.J Explain how extinction can make new environments available for adaptive radiation.
I can…	☐ I can explain ways extinctions can make new environments available for adaptive radiation. ☐ I can describe the effect of newly available niches on speciation.

9. How do extinctions affect available niches in an ecosystem?
10. How do changes in available niches affect organisms in an ecosystem?

Topic 7.12: Variation in Populations

Learning Objective	SYI-3.D Explain how the genetic diversity of a species or population affects its ability to withstand environmental pressures.
I can…	☐ I can explain ways the genetic diversity of a species affects its ability to withstand environmental pressures. ☐ I can explain ways the genetic diversity of a population affects its ability to withstand environmental pressures. ☐ I can explain why a species/population with little genetic diversity are at risk of decline or extinction. ☐ I can predict a population's ability to respond to changes in the environment based on population diversity. ☐ I can describe the advantage of generic diversity in times of environmental perturbation. ☐ I can explain ways alleles can affect individuals differently in different environments.

1. What is genetic diversity?
2. Why are populations with little genetic diversity at risk of decline or extinction?
3. If a population is more genetically diverse, how do they respond to environmental changes?
4. What is the advantage of a population being genetically diverse?
5. True or False: Alleles that are helpful in one environment will be helpful in another environment.
6. Why do allele affect individuals differently in different environments?

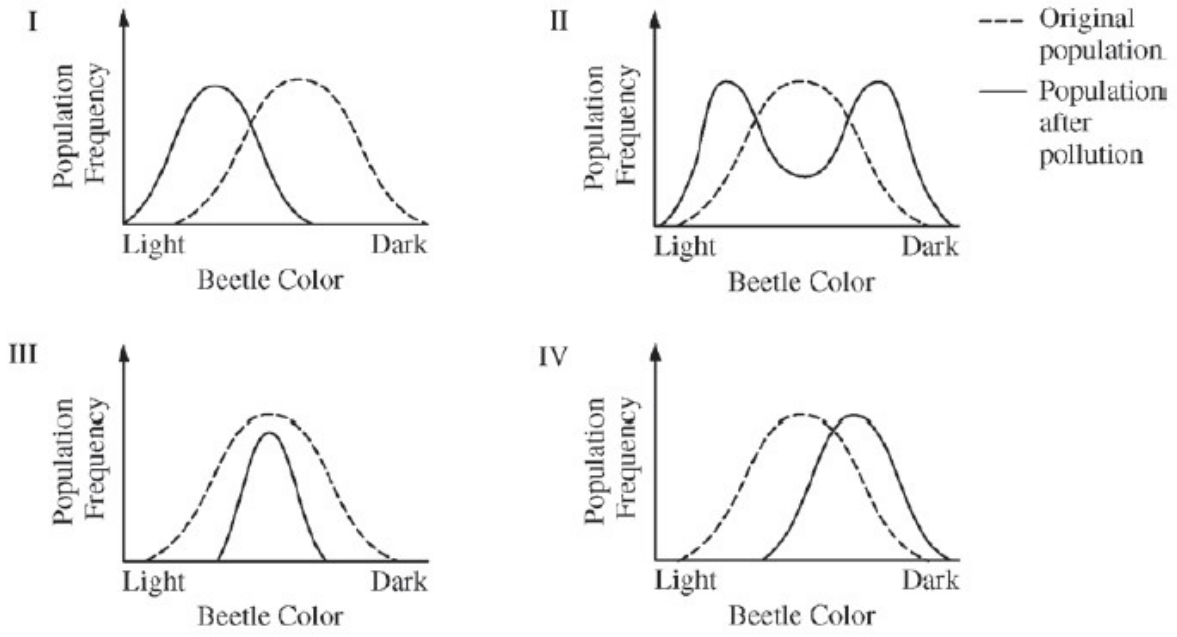
Topic 7.13: Origin of Life on Earth

Learning Objective	**SYI-3.E** Describe the scientific evidence that provides support for models of the origin of life on Earth.
I can…	☐ I can describe the scientific evidence that provides support for models of the origin of life on Earth. ☐ I can use geological evidence to support the model of the origin of life on Earth. ☐ I can identify approximately when Earth was formed. ☐ I can identify approximately when the environment on Earth was no longer considered hostile for life. ☐ I can identify approximately when the earliest fossil evidence for life was dated to. ☐ I can describe primitive earth. ☐ I can describe where organic molecules originated. ☐ I can describe chemical experiment that have shown it is possible for form complex organic from inorganic molecules in the absence of life. ☐ I can describe ways polymers formed from monomers. ☐ I can describe the RNA World Hypothesis.

1. What geological evidence provide support for the origin of Earth?
2. Approximately when did the Earth form?
3. Approximately when was Earth no longer hostile for life?
4. Approximately when does the earliest fossil date?
5. What were the characteristics of primitive Earth?
6. Where did organic molecules originate?
7. What occurred in Stanley Miller's experiment regarding primitive Earth?
    a. What was concluded?
8. What is the monomer of a protein?
9. What is the monomer of a nucleic acid?
10. How do monomers make polymers?
11. How could this process take place on primitive Earth?
12. What is the RNA World Hypothesis?
13. Identify two supports for the RNA World Hypothesis.

Multiple Choice Practice

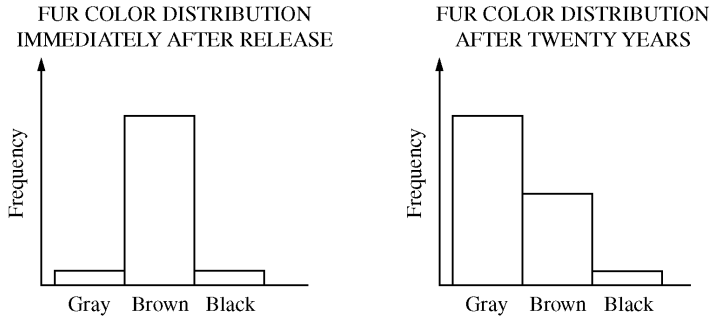
1. In a hypothetical population of beetles, there is a wide variety of color, matching the range of coloration of the tree trunks on which the beetles hide from predators. The graphs below illustrate four possible changes to the beetle population as a result of a change in the environment due to pollution that darkened the tree trunks.



Which of the following includes the most likely change in the coloration of the beetle population after pollution and a correct rationale for the change?

a. The coloration range shifted toward more light-colored beetles, as in diagram I. The pollution helped the predators find the darkened tree trunks.
b. The coloration in the population split into two extremes, as in diagram II. Both the lighter-colored and the darker-colored beetles were able to hide on the darker tree trunks.
c. The coloration range became narrower, as in diagram III. The predators selected beetles at the color extremes.
d. The coloration in the population shifted toward more darker-colored beetles, as in diagram IV. The lighter-colored beetles were found more easily by the predators than were the darker-colored beetles.

2. A group of mice was released into a large field to which no other mice had access. Immediately after the release, a representative sample of the mice was captured, and the fur color of each individual in the sample was observed and recorded. The mice were then returned to the field. After twenty years, another representative sample of the mice was captured, and the fur color of each individual in the sample was again recorded. Which of the following best explains the change in the frequency distribution of fur color phenotypes in the mouse population, as shown in the figures above?



   a. The allele for gray fur color is unstable, and over twenty years most of those alleles mutated to become alleles for black fur.
   b. The field was composed primarily of light-colored soil and little vegetation, affording gray mice protection from predators.
   c. Sexual selection led to increased mating frequency of black and brown versus gray and brown.
   d. The gray mice were hardest to capture and so were underrepresented in the twenty-year sample.

Use the following information to answer question 3:

The following figures display data collected while studying a family, some members of which have sickle-cell disease—a rare genetic disorder caused by a mutation in the hemoglobin beta gene (HBB). There are at least two alleles of the HBB gene: the HbA allele encodes wild-type hemoglobin and the HbS allele encodes the sickle-cell form of hemoglobin. Genetic testing provided insight into the inheritance pattern for sickle-cell disease.

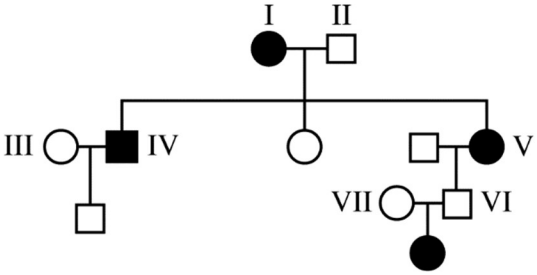


Figure 1. Pedigree of a family with affected individuals. Squares represent males, circles represent females, shaded symbols represent individuals with sickle-cell disease.

5' CTG ACT CCT GAG GAG AAG TCT 3' Non-template Strand
3' GAC TGA GGA CTC CTC TTC AGA 5' Template Strand

Figure 2. A portion of the DNA sequence from the wild-type hemoglobin allele (HbA) that codes for normal hemoglobin.

Second Base in Codon

First Base in Codon	U	C	A	G	Third Base in Codon
U	UUU Phe UUC Phe UUA Leu UUG Leu	UCU Ser UCC Ser UCA Ser UCG Ser	UAU Tyr UAC Tyr UAA Stop UAG Stop	UGU Cys UGC Cys UGA Stop UGG Trp	U C A G
C	CUU Leu CUC Leu CUA Leu CUG Leu	CCU Pro CCC Pro CCA Pro CCG Pro	CAU His CAC His CAA Gln CAG Gln	CGU Arg CGC Arg CGA Arg CGG Arg	U C A G
A	AUU Ile AUC Ile AUA Ile AUG Met or Start	ACU Thr ACC Thr ACA Thr ACG Thr	AAU Asn AAC Asn AAA Lys AAG Lys	AGU Ser AGC Ser AGA Arg AGG Arg	U C A G
G	GUU Val GUC Val GUA Val GUG Val	GCU Ala GCC Ala GCA Ala GCG Ala	GAU Asp GAC Asp GAA Glu GAG Glu	GGU Gly GGC Gly GGA Gly GGG Gly	U C A G

Figure 3. Codon table showing nucleotide sequences for each amino acid.

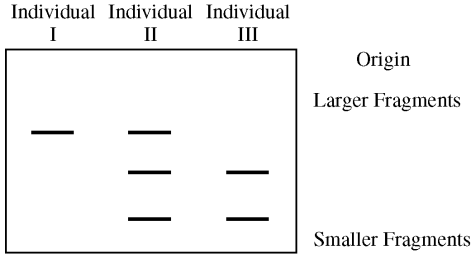
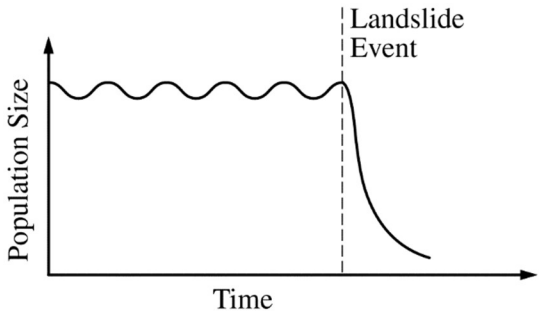


Figure 4. Image of a gel following electrophoretic separation of DNA fragments of the HBB gene from three individuals in the pedigree in Figure 1.

3. Possessing a single copy of the HbS allele has been shown to provide some resistance to infection by Plasmodium falciparum, the parasite that causes malaria. Which of the following individuals represented in the pedigree would have the greatest selective advantage in an area where malaria is common?
   a. I
   b. II
   c. III
   d. V

4. Undersea landslides can disrupt marine habitats by burying organisms that live on the ocean floor. The graph above shows the size of a population of a certain organism that lives on the ocean floor. The population was affected by a recent landslide at the time indicated on the graph. Which of the following best predicts how the population will be affected by the landslide?



   a. The surviving organisms will evolve into a new species.
   b. The reduced population will likely have allelic frequencies that are different from the initial population.
   c. The population will adapt to deeper waters to avoid future landslides.
   d. The reduced population will have a greater number of different genes than the initial population.

5. The data below demonstrate the frequency of tasters and non-tasters of a certain compound in four isolated populations that are in Hardy-Weinberg equilibrium. The allele for non-tasters is recessive. In which population is the frequency of the recessive allele highest?

Letter Choice	Populations	Tasters	Non-tasters	Size of Population
A	1	110	32	142
B	2	8,235	4,328	12,563
C	3	215	500	715
D	4	11,489	2,596	14,085

6. Ellis-van Creveld syndrome is a recessive genetic disorder that includes the characteristics of short stature and extra fingers or toes. In the general population, this syndrome occurs in approximately 1 in 150,000 live births. In a particular isolated population, however, the incidence of this syndrome among live births is 1 in 500.

   Assume that both the isolated population and the general population are in Hardy-Weinberg equilibrium with respect to this syndrome. Which of the following best describes the difference between the frequency of the allele that causes the syndrome in the general population and the frequency of the allele in the isolated population?
   a. The frequency of the Ellis-van Creveld allele is 0.002 in the isolated population and 0.0000066 in the general population, which suggests that selection for this trait is occurring in both populations.
   b. The frequency of the Ellis-van Creveld allele is 0.0447 in the isolated population and 0.0026 in the general population, showing that the rate of genetic mutation is highest among individuals in the isolated population.
   c. The frequency of the Ellis-van Creveld allele is 0.002 in the isolated population and 0.0000066 in the general population, which demonstrates gametic incompatibility between the populations.
   d. The frequency of the Ellis-van Creveld allele is 0.0447 in the isolated population and 0.0026 in the general population, which suggests that genetic drift has occurred in the isolated population.

Use the following information for question 7:

Different photosynthetic organisms have different types of chlorophyll molecules. The distribution of chlorophylls in several different groups of organisms is shown in Table 1. A plus sign (+) in the table indicates the presence of a chlorophyll, while a minus sign (-) indicates its absence.

Table 1. The distribution of chlorophylls in several groups of organisms

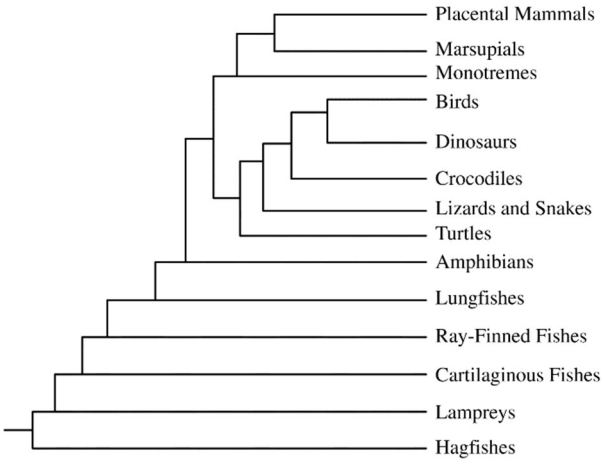
	Chlorophyll *a*	Chlorophyll *b*	Chlorophyll *c*	Chlorophyll *d*
Flowering plants	+	+	–	–
Green algae	+	+	–	–
Brown algae	+	–	+	–
Red algae	+	–	–	+
Cyanobacteria	+	–	–	–

7. Based on the data, which of the following most likely describes the evolutionary relationship among the organisms?
    a. Because brown algae, red algae, and cyanobacteria lack chlorophyll b, they evolved before green algae and flowering plants did.
    b. Because green algae and flowering plants contain chloroplasts, they evolved more recently than brown algae, red algae, and cyanobacteria did.
    c. Because increasingly complex forms of chlorophyll are found in red algae, brown algae, green algae, and flowering plants, respectively, this reflects the order of their appearance.
    d. Because all of the organisms contain chlorophyll a, the organisms share a common ancestor.

8. Experimental evidence shows that the process of glycolysis is present and virtually identical in organisms from all three domains, Archaea, Bacteria, and Eukarya. Which of the following hypotheses could be best supported by this evidence?
    a. All organisms carry out glycolysis in mitochondria.
    b. Glycolysis is a universal energy-releasing process and therefore suggests a common ancestor for all forms of life.
    c. Across the three domains, all organisms depend solely on the process of anaerobic respiration for ATP production.
    d. The presence of glycolysis as an energy- releasing process in all organisms suggests that convergent evolution occurred.

9. To determine the evolutionary history and relationships among organisms, scientists gather evidence from a wide variety of sources including paleontology, embryology, morphology, behavior, and molecular biology. A phylogenetic tree of vertebrates is shown.

    Which of the following statements is most consistent with the phylogenetic tree shown?



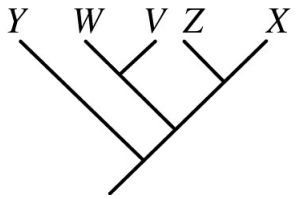
    a. Birds and turtles evolved their own means of gas exchange independently of the other vertebrates.
    b. Mammals are most closely related to birds because they share a direct common ancestor.
    c. The common ancestor of reptiles, birds, and mammals produced amniotic eggs.
    d. Crocodiles are direct descendants of ray-finned fishes since they live in the same environment.

10. Data regarding the presence (+) or absence (-) of five derived traits in several different species are shown in the table below.

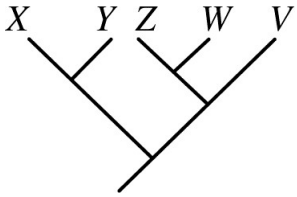
	Trait				
Species	1	2	3	4	5
V	+	+	+	-	-
W	+	+	-	-	-
X	+	-	-	-	-
Y	-	-	-	-	-
Z	+	-	-	-	+

Which of the following cladograms provides the simplest and most accurate representation of the data in the table?

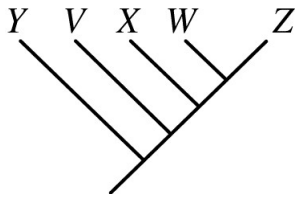
a.



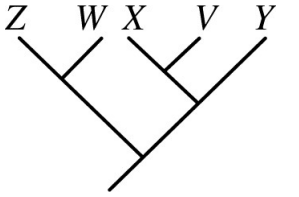
b.



c.



d.



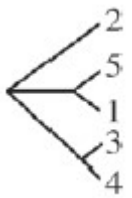
11. Five new species of bacteria were discovered in Antarctic ice core samples. The nucleotide (base) sequences of rRNA subunits were determined for the new species. The table below shows the number of nucleotide differences between the species.

NUCLEOTIDE DIFFERENCES

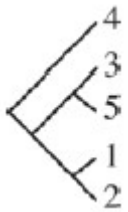
Species	1	2	3	4	5
1	–	3	19	18	27
2		–	19	18	26
3			–	1	27
4				–	27
5					–

Which of the following phylogenetic trees is most consistent with the data?

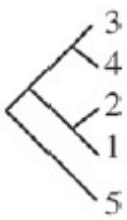
a.



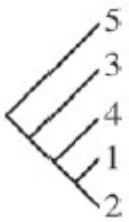
b.



c.



d.



12. The apple maggot fly, *Rhagoletis pomonella*, is native to North America and originally fed on fruit of the wild hawthorn. Since the mid-1800s, a population of flies has emerged that instead feed on domesticated apples. Apple maggot flies typically mate on or near the fruit of their host plants. Many varieties of apples ripen three to four weeks before the hawthorn fruits do.

    The different fruit preferences of the two fly populations will most likely have which of the following effects?
    a. The flies that eat hawthorn fruit will increase in number, while the flies that eat apples will decrease in number because of the use of insecticides on apple trees.
    b. The single fly species will evolve into two distinct species because of the lack of gene flow between the two populations.
    c. The ability to survive on a diet of two different fruits will help the flies learn to eat many more types of fruit.
    d. The flies that eat hawthorn fruit will lay some of their eggs on the earlier ripening apples to minimize competition among the larvae.

Use the following information to answer questions 13 – 15:

Rhagoletis pomonella is a parasitic fly native to North America that infests fruit trees. The female fly lays her eggs in the fruit. The larvae hatch and burrow through the developing fruit. The next year, the adult flies emerge.

Prior to the European colonization of North America, the major host of *Rhagoletis* was a native species of hawthorn, *Crataegus marshallii.* The domestic apple tree, *Malus domestica*, is not native to North America, but was imported by European settlers in the late 1700s and early 1800s.

When apple trees were first imported into North America, there was no evidence that Rhagoletis could use them as hosts. Apples set fruit earlier in the season and develop faster, where hawthorns set later and develop more slowly.

Recent analysis of *Rhagoletis* populations has shown that two distinct populations of flies have evolved from the original ancestral population of flies that were parasitic on hawthorns. One population infests only apple trees, and the other infests only hawthorns. The life cycles of both fly populations are coordinated with those of their host trees. The flies of each population apparently can distinguish and select mates with similar host preferences and reject mates from the population specific to the other host tree. There is very little hybridization (only about 5 percent) between the two groups.

13. The divergence between the two populations of Rhagoletis must have occurred very rapidly because
    a. the apple tree was imported into North America with European settlement approximately 200 years ago
    b. flies were imported into North America with European settlement approximately 200 years ago
    c. long-distance rail transport of fruit increased only after the American Civil War (1861–1865)
    d. heavy use of gunpowder during the American Civil War (1861–1865) led to increased mutation rates in many natural populations of plants and animals

14. Initially, which of the following isolating mechanisms is likely to have been the most important in preventing gene flow between the two populations of *Rhagoletis*?
    a. Gamete incompatibility
    b. Temporal isolation
    c. Mechanical isolation
    d. Reduced hybrid viability

15. Matings between individuals from the two populations of *Rhagoletis* produce hybrid flies that appear to be healthy and have normal life spans. The eggs laid by these hybrid flies, however, hatch less often than those of flies from either of the two populations. What isolating mechanism seems to be important in this hybrid population?
    a. Prezygotic isolation
    b. Mechanical isolation
    c. Reduced hybrid fertility
    d. Habitat isolation

16. A group of students summarized information on five great extinction events.

Mass Extinction	Time of Extinction	Organisms Greatly Reduced or Made Extinct
End of the Ordovician period	443 million years ago	Trilobites, brachiopods, echinoderms, and corals
End of the Devonian period	354 million years ago	Marine families on tropical reefs, corals, brachiopods, and bivalves
End of the Permian period	248 million years ago	Trilobites, mollusks, brachiopods, and many vertebrates
End of the Triassic period	206 million years ago	Mollusks, sponges, marine vertebrates, and large amphibians
End of the Cretaceous period	65 million years ago	Ammonites, dinosaurs, brachiopods, bivalves, and echinoderms

The students are sampling a site in search of fossils from the Devonian period. Based on the chart, which of the following would be the most reasonable plan for the students to follow?
    a. Searching horizontal rock layers in any class of rock and try to find those that contain the greatest number of fossils
    b. Collecting fossils from rock layers deposited prior to the Permian period that contain some early vertebrate bones
    c. Looking in sedimentary layers next to bodies of water in order to find marine fossils of bivalves and trilobites
    d. Using relative dating techniques to determine the geological ages of the fossils found so they can calculate the rate of speciation of early organisms

17. By discharging electric sparks into a laboratory chamber atmosphere that consisted of water vapor, hydrogen gas, methane, and ammonia, Stanley Miller obtained data that showed that a number of organic molecules, including many amino acids, could be synthesized. Miller was attempting to model early Earth conditions as understood in the 1950s. The results of Miller's experiments best support which of the following hypotheses?
    a. The molecules essential to life today did not exist at the time Earth was first formed.
    b. The molecules essential to life today could not have been carried to the primordial Earth by a comet or meteorite.
    c. The molecules essential to life today could have formed under early Earth conditions.
    d. The molecules essential to life today were initially self-replicating proteins that were synthesized approximately four billion years ago.

18. Which of the following best explains the process of natural selection?
    a. individuals with less favorable phenotypes are more likely to survive and produce less offspring, thus modifying traits for subsequent generations
    b. individuals with more favorable phenotypes are more likely to survive and produce less offspring, thus modifying traits for subsequent generations
    c. individuals with more favorable phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations
    d. individuals with less favorable phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations

19. Natural selection acts on
    a. phenotype
    b. genotype
    c. gene expression
    d. reproduction

20. Which of the following best explains convergent evolution?
    a. different selective pressures result in similar phenotypic adaptations in different populations or species
    b. similar selective pressures result in similar phenotypic adaptations in different populations or species
    c. similar selective pressures result in different phenotypic adaptations in a population or species
    d. different selective pressures result in similar phenotypic adaptations in a populations or species

21. Which of the following is the cause of genetic variation?
    a. crossing over
    b. independent assortment
    c. random fertilization
    d. mutations

22. Which of the following describes why bottleneck effect is harmful to genetic diversity?
    a. the reduction in population size could lead to fixation of an allele
    b. the reduction in population size could result in a change in allele frequency
    c. the reduction in population size could cause a change in genotype frequency
    d. the reduction in population size could inhibit reproductive events

23. Which of the following describes why the founder's effect results in an increase of differences between populations of the same species?
    a. presence of genetic drift
    b. absence of gene flow
    c. addition of harmful alleles
    d. removal of reproductive barriers

24. Which of the following is a condition that must be met for a population to be in Hardy-Weinberg equilibrium?
    a. small population size
    b. nonrandom mating
    c. absence of selection
    d. presence of migration

25. If the recessive allele frequency is 0.4, what is the genotypic frequency of the heterozygous individual?
    a. 0.16
    b. 0.24
    c. 0.36
    d. 0.48

26. Which of the following describes a population most susceptible to random environmental impact?
    a. small populations
    b. large populations

27. Which of the following is NOT a method to date fossils?
    a. DNA sequencing
    b. age of rocks where a fossil is found
    c. rate of decay of isotopes including carbon-14
    d. geographical data

28. Which of the following does provides evidence for evolution and common ancestry?
    a. analogous structures
    b. homologous structures

29. Which of the following does NOT indicate common ancestry of all eukaryotes?
    a. membrane-bound organelles
    b. linear chromosomes
    c. genes that contain introns
    d. presence of chloroplasts

30. Which of the following describes why single HIV drugs are ineffective over time?
    a. Reverse transcriptase binds to HIV drugs inhibiting drug effectiveness
    b. Mutations in the HIV genome leads to reproductive success
    c. HIV engulfs drugs through phagocytosis and digests them in the lysosome
    d. Drugs decompose prior to inhibit HIV genome from replication

31. Which of the following best represents the outgroup in a cladogram?
    a. least closely related to the remainder of the organisms in the cladogram
    b. most closely related to the remainder of the organisms in the cladogram
    c. organism found on the farthest branch point from the common ancestor
    d. organism found on the closest branch point to the organism of interest

32. Which type of data provides the most accurate and reliable evidence to construct phylogenetic trees or cladograms?
    a. morphological
    b. molecular
    c. biogeographical
    d. temporal

33. Which of the following describes the biological species concept?
    a. group capable of interbreeding and exchanging genetic information to produce feeble, fertile offspring
    b. group capable of interbreeding and exchanging genetic information to produce feeble, sterile offspring
    c. group capable of interbreeding and exchanging genetic information to produce viable, fertile offspring
    d. group capable of interbreeding and exchanging genetic information to produce viable, sterile offspring

34. Which of the following contrasts punctuated equilibrium and gradualism?
    a. punctuated equilibrium occurs slowly over hundreds of thousands of years while gradualism results in rapid evolution after long period of stasis
    b. punctuated equilibrium results from allopatric speciation while gradualism results from sympatric speciation
    c. punctuated equilibrium results from sympatric speciation while gradualism results from allopatric speciation
    d. punctuated equilibrium results in rapid evolution after long period of stasis while gradualism occurs slowly over hundreds of thousands of years

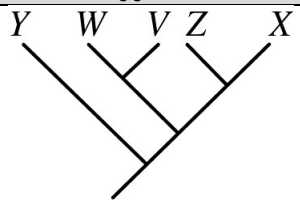
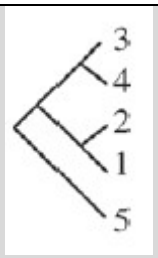
35. Which of the following types of reproductive barriers involves inhibiting reproduction due to a different mating season?
    a. behavioral
    b. temporal
    c. gametic
    d. ecological

36. Which of the following describes ways that the amount of diversity in an ecosystem can be determined?
    a. rate of speciation and rate of extinction
    b. rate of reproductive and rate of speciation
    c. rate of extinction and rate of immigration
    d. rate of reproduction and rate of immigration

37. Which of the following provides a viable option as to the origin of organic molecules?
    a. biotic synthesis
    b. transported to Earth by meteorite
    c. hydrolysis of inorganic molecules
    d. Earth colliding with other planets

38. Which of the following was the earliest genetic material?
    a. DNA
    b. RNA
    c. Proteins
    d. Carbohydrates

Multiple Choice Key

Question	Correct Answer	Unit/Topic	Source
1	D. The coloration in the population shifted toward more darker-colored beetles, as in diagram IV. The lighter- colored beetles were found more easily by the predators than were the darker-colored beetles.	7.1	2012 CED #21
2	B. The field was composed primarily of light-colored soil and little vegetation, affording gray mice protection from predators.	7.1	2012 #23
3	B. II	7.2	2013 #51
4	B. The reduced population will likely have allelic frequencies that are different from the initial population.	7.4	2013 #4
5	<table><tr><th>Letter Choice</th><th>Populations</th><th>Tasters</th><th>Non-tasters</th><th>Size of Population</th></tr><tr><td>C</td><td>3</td><td>215</td><td>500</td><td>715</td></tr></table>	7.5	2013 #40
6	D. The frequency of the Ellis-van Creveld allele is 0.0447 in the isolated population and 0.0026 in the general population, which suggests that genetic drift has occurred in the isolated population.	7.5	2013 #53
7	D. Because all of the organisms contain chlorophyll a, the organisms share a common ancestor.	7.6	2020 CED #9
8	B. Glycolysis is a universal energy-releasing process and therefore suggests a common ancestor for all forms of life.	7.7	2012 CED #29
9	C. The common ancestor of reptiles, birds, and mammals produced amniotic eggs.	7.9	2013 #32
10	 A.	7.9	2013 #18
11	 C.	7.9	2012 CED #18
12	B. The single fly species will evolve into two distinct species because of the lack of gene flow between the two populations.	7.10	2020 CED #13
13	A. the apple tree was imported into North America with European settlement approximately 200 years ago	7.10	2013 #20
14	B. Temporal isolation	7.10	2013 #21
15	C. Reduced hybrid fertility	7.10	2013 #22
16	B. Collecting fossils from rock layers deposited prior to the Permian period that contain some early vertebrate bones	7.11	2012 CED #37
17	C. The molecules essential to life today could have formed under early Earth conditions.	7.13	2012 CED #1

18	C. individuals with more favorable phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations		Self
19	A. phenotype		Self
20	B. similar selective pressures result in similar phenotypic adaptations in different populations or species		Self
21	D. mutations		Self
22	A. the reduction in population size could lead to fixation of an allele		Self
23	B. absence of gene flow		Self
24	C. absence of selection		Self
25	D. 0.48		Self
26	A. small populations		Self
27	A. DNA sequencing		Self
28	B. homologous structures		Self
29	D. presence of chloroplasts		Self
30	B. Mutations in the HIV genome leads to reproductive success		Self
31	A. least closely related to the remainder of the organisms in the cladogram		Self
32	B. molecular		Self
33	C. group capable of interbreeding and exchanging genetic information to produce viable, fertile offspring		Self
34	D. punctuated equilibrium results in rapid evolution after long period of stasis while gradualism occurs slowly over hundreds of thousands of years		Self
35	B. temporal		Self
36	A. behavioral		Self
37	A. rate of speciation and rate of extinction		Self
38	B. transported to Earth by meteorite		Self
39	B. RNA		Self

Free Response Practice

2019 #1

This question is in Unit 8.

2019 #2

This question is in Unit 8.

2019 #5

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

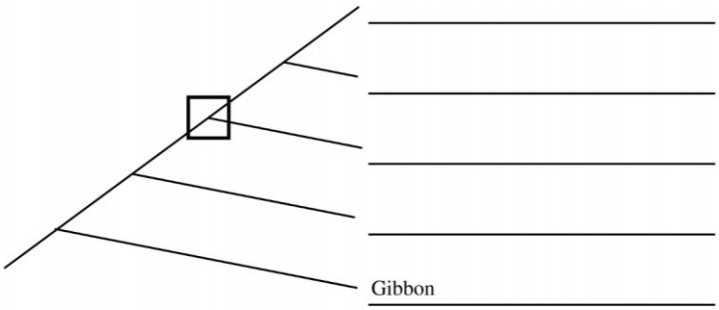
	Human	Gorilla	Orangutan	Gibbon	Chimpanzee
Human	-	10.3	16.1	18.1	8.8
Gorilla		-	16.7	18.9	10.6
Orangutan			-	18.9	17.2
Gibbon				-	18.9
Chimpanzee					-

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.

(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.

(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.



2018 #1

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).

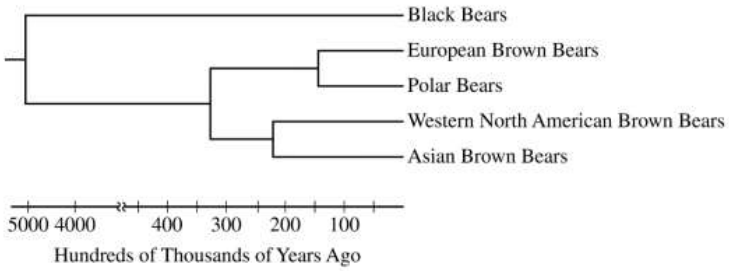


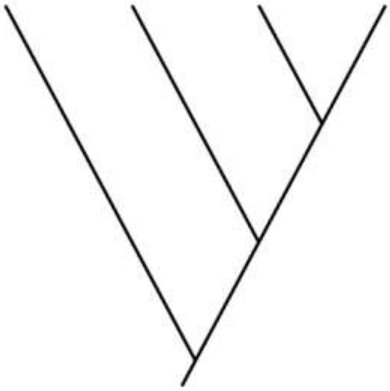
Figure 1. Phylogenetic tree representing the evolutionary relatedness among bear populations based on mitochondrial DNA sequence comparisons

A researcher studying adaptations in bears sequenced the nuclear gene encoding a lysosomal trafficking protein (LYST) in polar bears, brown 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	–

(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 cladogram.



(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.

(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.

(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.

(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 the fur color, **predict** the percent of white offspring produced by a mating between a polar bear and a brown bear.

2016 #1

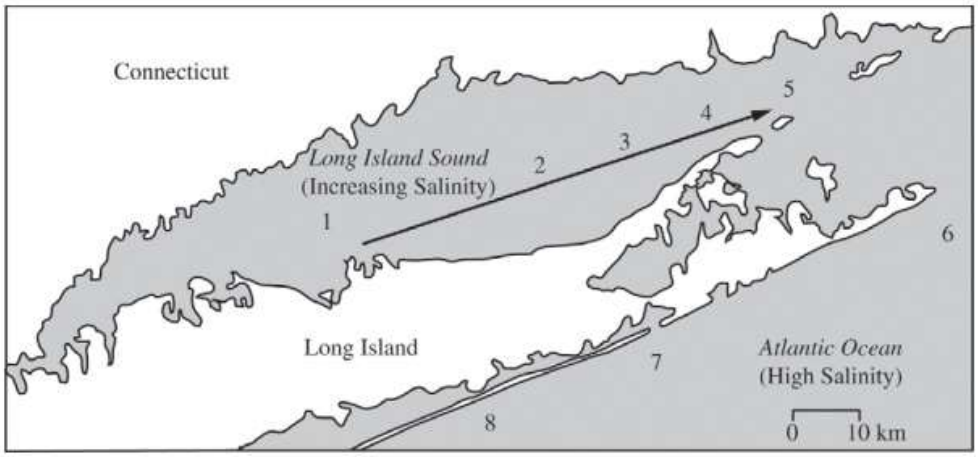


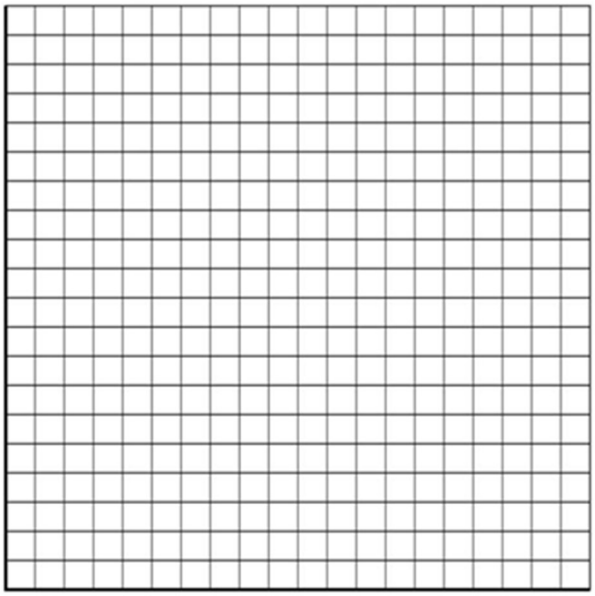
Figure 1. Sampling sites of marine mussels at various locations (1–8) in Long Island Sound and the Atlantic Ocean

TABLE 1. PERCENT OF INDIVIDUALS POSSESSING *lap*^{94} ALLELE

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

Leucine aminopeptidase (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).

(a) On the axes provided, **construct** an appropriately labeled bar graph to illustrate the observed frequencies of the lap^{94} allele in the study population.



(b) Based on the data, **describe** the most likely effect of salinity on the frequency of the lap^{94} allele in the marine mussel population 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.

(c) **Describe** the most likely effect of LAP^{94} activity on the osmolarity of the cytosol. **Describe** the function of LAP^{94} in maintaining water balance in mussels living in the Atlantic Ocean.

(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 of distribution of mussels in Long Island Sound if the lap^{94} allele was found in all the mussels in the population. **Justify** your prediction.

2016 #3
This question is in Unit 8.

2015 #1
This question is in Unit 8.

2015 #2

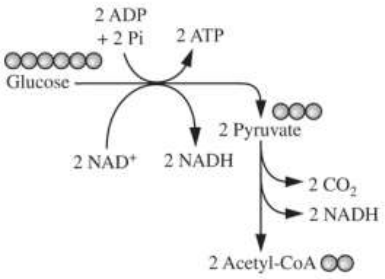


Figure 1. Glycolysis and pyruvate oxidation

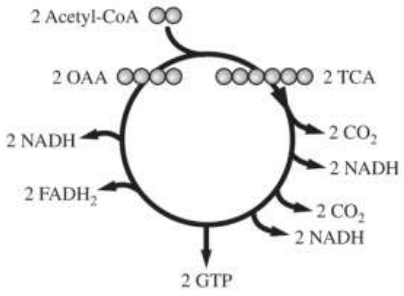


Figure 2. Krebs cycle

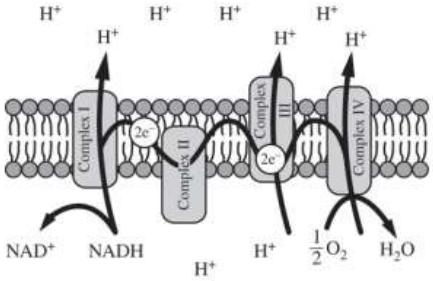


Figure 3. Electron transport chain

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

(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.

(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.

(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.

2015 #3

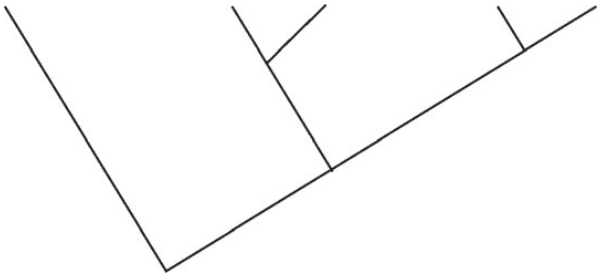
The amino acid sequence of cytochrome c was determined for five different species of vertebrates. The table below shows the number of differences in the sequences between each pair of species.

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

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

(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.



2014 #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	?	+	+	?	+

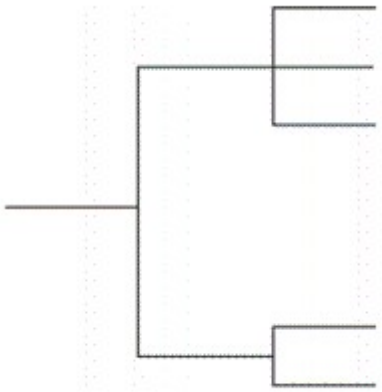
? indicates the absence of the character
+ indicates the presence of the character

(a) 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.

Note: part b & c are out of scope

(b) **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.

(c) **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 expose three months earlier. **Justify** your prediction.



2014 #4

This question is in Unit 8.

2014 #5

This question is in Unit 8.

2014 #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.

(a) **Provide** ONE piece of evidence that would indicate new genetic variation has occurred in the engineered flies.

(b) **Describe** ONE mechanism that could lead to genetic variation in the engineered strain of flies.

(c) **Describe** how genetic variation in a population contributes to the process of evolution in the population.

2013 #3

Fossils of lobe-finned fishes, which are ancestors of amphibians, are found in rocks that are at least 380 million years old. Fossils of the oldest amphibian-like vertebrate animals with true legs and lungs are found in rocks that are approximately 363 million years old.

Three samples of rocks are available that might contain fossils of a transitional species between lobe-finned fishes and amphibians: one rock sample that is 350 million years old, one that is 370 million years old, and one that is 390 million years old.

(a) **Select** the most appropriate sample of rocks in which to search for a transitional species between lobe-finned fishes and amphibians. **Justify** your selection.

(b) **Describe** TWO pieces of evidence provided by fossils of a transitional species that would support a hypothesis that amphibians evolved from lobe-finned fishes.

Free Response Scoring Guidelines

2019 #5		
Part	Scoring Guidelines	Topic
(a)	**Calculation (1 point)** • 1.25 OR 1.26	7.6
(b)	**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).	7.9
(c)	**Circle (1 point)** • Circle species 1, 2, and 3, as numbered from the top.	7.9

2018 #1		
Part	Scoring Guidelines	Topic
(a)	**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)	7.9
(b)	**Construction (1 point)** • Correctly illustrated evolutionary relationship among the four species **Circling (1 point)** • Correctly circled out-group based on orientation of cladogram	7.9
(c)	**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.	6.7
(d)	**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.	6.7
(e)	**Description (1 point)** • Natural selection for the white fur phenotype **Prediction (1 point)** • 0%	5.3 7.1

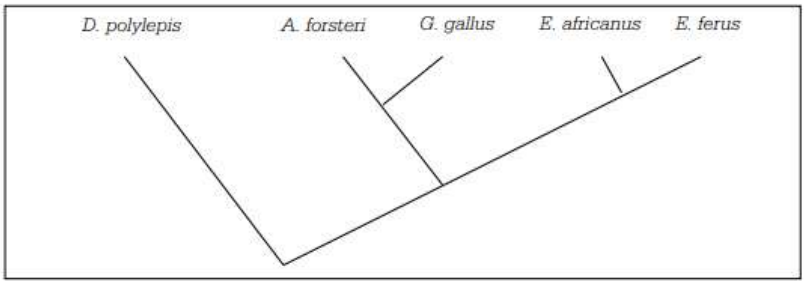
2016 #1

Part	Scoring Guidelines	Topic
(a)	**Construct graph (3 points)** • Correctly plotted bar graph that accurately represents the trend • Correct axis labeling • Correct scale and units	7.12
(b)	**Description (1 point)** • As salinity increases *lap*^{94} frequency increases • As salinity decreases *lap*^{94} frequency decreases **Prediction (1 point)** Between 13 and 16 percent (or a selected value between 13 and 16 percent)	7.12
(c)	**Describe effect of LAP^{94} activity (1 point)** • LAP^{94} increases osmolarity/solute concentration of the cytosol • LAP^{94} decreases water potential of the cytosol **Describe function of LAP^{94} in maintaining water balance (1 point)** Prevents water loss to the environment	2.8
(d)	**Explanation (1 point)** • Mussels with *lap*^{94} allele are more likely to survive in high salinity/less likely to survive in low salinity. • Mussels without *lap*^{94} allele are less likely to survive in high salinity/more likely to survive in low salinity. **Prediction (1 point)** • Mussel population will increase in high salinity. • Mussel population will decline in low salinity. **Justification (1 point)** • Mussels in high salinity with *lap*^{94} allele will osmoregulate. • Mussels in low salinity with *lap*^{94} allele will not osmoregulate.	7.12

2015 #2

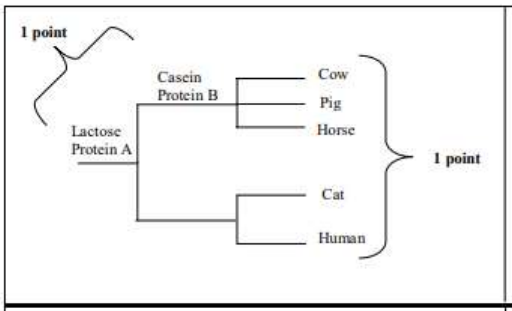
Part	Scoring Guidelines	Topic
(a)	Process: Catabolism of glucose in glycolysis and pyruvate oxidation **Description (1 point each box; 3 points maximum)** • Produces NADH for use in ETC • Produces acetyl-CoA for entry into Krebs cycle • Provides energy for (substrate level) phosphorylation of ADP Process: 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 Process: 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	3.6
(b)	Observation: Nearly all existing organisms perform glycolysis **Justification (1 point each box; 3 points maximum)** • Trait/gene/process originated early and was inherited/passed down/highly conserved • Glycolysis provided a selective advantage that was passed on to descendants Observation: Glycolysis occurs under anaerobic conditions Origin of glycolysis pre-dates free atmospheric oxygen/photosynthesis Observation: Glycolysis occurs only in the cytosol Origin of glycolysis pre-dates cell types with membrane-bound organelles/eukaryotes/endosymbiosis	3.6
(c)	**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	3.6

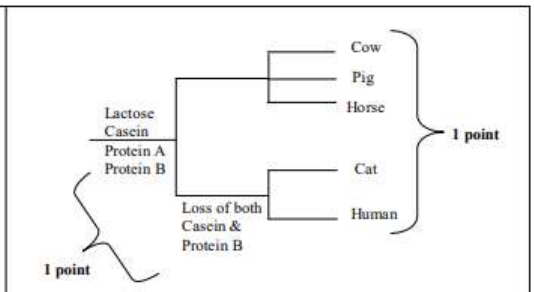
(d)	**Question (1 point)** • A valid scientific question related to evolution of eukaryotes (e.g., Since the Krebs cycle occurs in the "cytoplasm" of the mitochondria (matrix), does it suggest that mitochondria were once prokaryotes?)	7.6

2015 #3		
Part	**Scoring Guidelines**	**Topic**
(a)	**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).	7.9
(b)	**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).	7.9

2014 #2

Part	Scoring Guidelines	Topic
(a)	NOTE: Points are earned in one column only.	7.9





Justification (**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.	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.

(b) N/A

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

(c) N/A

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 *in utero*/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

2014 #8		
Part	Scoring Guidelines	Topic
(a)	Piece of evidence • New phenotypes • Different DNA sequence • New genotypes • Chromosomal differences • Different mRNA sequence • Protein with different amino acid sequence	5.2 6.7 6.8
(b)	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	5.2 6.7
(c)	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	7.1 7.6

2013 #3		
Part	Scoring Guidelines	Topic
(a)	• Selection: Rocks from 370 MYA sample. • Justification: Transitional fossils are found between 380 MYA (when lobe-finned fishes lived) and 363 MYA (when amphibians appeared) OR between different strata/layers in the correct order.	7.6
(b)	Descriptions include but are not limited to the following: • Bones OR specific skeletal structures legs /limbs/digits vertebrae flat skulls (interlocking) ribs flexible neck • Scales • Teeth • Other homologous structures • Has traits of both the lobe-finned fish and the amphibian • Finding the transitional fossils in the same area/same environment as either the lobe-finned fish or the amphibian • Molecular (DNA) evidence	7.6

Unit 8: Ecology

Topic	Learning Objective(s)
8.1 Responses to the Environment	**ENE-3.D** Explain how the behavioral and/or physiological response of an organism is related to changes in internal or external environment.
	IST-5.A Explain how the behavioral responses of organisms affect their overall fitness and may contribute to the success of the population.
8.2 Energy Flow Through Ecosystems	**ENE-1.M** Describe the strategies organisms use to acquire and use energy
	ENE-1.N Explain how changes in energy availability affect populations and ecosystems
	ENE-1.O Explain how the activities of autotrophs and heterotrophs enable the flow of energy within an ecosystem.
8.3 Population Ecology	**SYI-1.G** Describe factors that influence growth dynamics of populations.
8.4 Effect of Density of Populations	**SYI-1.H** Explain how the density of a population affects and is determined by resource availability in the environment.
8.5 Community Ecology	**ENE-4.A** Describe the structure of a community according to its species composition and diversity
	ENE-4.B Explain how interactions within and among populations influence community structure.
	ENE-4.C Explain how community structure is related to energy availability in the environment.
8.6 Biodiversity	**SYI-3.F** Describe the relationship between ecosystem diversity and its resilience to changes in the environment.
	SYI-3.G Explain how the addition or removal of any component of an ecosystem will affect its overall short-term and long-term structure.
8.7 Disruptions to Ecosystems	**EVO-1.O** Explain the interaction between the environment and random or preexisting variations in populations.
	SYI-2.A Explain how invasive species affect ecosystem dynamics.
	SYI-2.B Describe human activities that lead to changes in ecosystem structure and/ or dynamics.
	SYI-2.C Explain how geological and meteorological activity leads to changes in ecosystem structure and/or dynamics

Topic 8.1: Responses to the Environment

Learning Objective	**ENE-3.D** Explain how the behavioral and/or physiological response of an organism is related to changes in internal or external environment.
I can…	☐ I can explain ways the behavioral response of an organisms is related to changes in internal or external environment. ☐ I can explain ways the physiological response of an organism is related to changes in internal or external environment. ☐ I can explain ways organisms exchange information with one another in response to internal changes. ☐ I can explain ways organisms exchange information with one another in response to external cues. ☐ I can explain ways organism's behaviors changes due to internal cues. ☐ I can explain ways organism's behaviors changes due to external cues.

1. Identify two behavioral changes in an organism due to an internal cue.
2. Identify two behavioral changes in an organism due to an external cue.
3. Identify two physiological changes in an organism due to an internal cue.
4. Identify two physiological changes in an organism due to an external cue.
5. How does an organism's responses to internal changes or external cues change their behavior?

Learning Objective	IST-5.A Explain how the behavioral responses of organisms affect their overall fitness and may contribute to the success of the population.
I can…	☐ I can explain ways the behavioral responses of organisms affect their overall fitness ☐ I can explain ways the behavioral responses of organisms affects the success of the population ☐ I can describe that individuals act on information ☐ I can describe that individuals communicate with others. ☐ I can describe signaling behavior that result in differential reproductive success ☐ I can describe ways animals communicate ☐ I can describe functions of animal communication ☐ I can describe innate behaviors ☐ I can describe learned behaviors ☐ I can describe ways cooperative behaviors increase the fitness of the individual ☐ I can describe ways cooperative behaviors increase the fitness of the population

6. What is differential reproductive success?
7. How does communication result in differential reproductive success?
8. What are the five types of signals individuals use to communicate with others?
    a. Describe the environment where each type is favorable.
9. What is the function of animal communication?
10. What is an innate behavior?
11. What is a learned behavior?
12. What type of behaviors does natural selection favor?
13. What is cooperative behavior?
14. How does cooperative behavior increase the fitness of an individual and the survival of the population?
15. What is altruism?
16. How does altruism increase the population's reproductive fitness?

Topic 8.2: Energy Flow Through Ecosystems

Learning Objective	ENE-1.M Describe the strategies organisms use to acquire and use energy
I can…	☐ I can describe the strategies organisms use to acquire and use energy. ☐ I can describe ways organisms use energy to regulate body temperature. ☐ I can describe endothermic. ☐ I can describe ways endotherms regulate their body temperature. ☐ I can describe ectothermic. ☐ I can describe ways ectotherms regulate their body temperature. ☐ I can describe ways organisms use energy for reproductive strategies. ☐ I can describe the relationship between metabolic rate per unit body mass and size of multicellular organisms. ☐ I can describe the result of a net gain in energy on growth of an organism. ☐ I can describe the result of a net gain in energy on energy storage. ☐ I can describe the result of a net loss of energy on mass of organisms. ☐ I can describe the result of a net loss of energy on survival of an organism.

1. What is an endotherm?
2. How do endotherms regulate their body temperature?
3. What is an ectotherm?
4. How do ectotherms regulate their body temperature?
5. Which organism requires more food consumption in a cooler environment? ENDOTHERM or ECTOTHERM
6. How would temperature effect oxygen consumption in an endotherm?
7. What is the relationship between metabolic rate per unit body mass and the size of multicellular organisms?
8. What does a net gain in energy result in for an organism?
9. What does a net loss in energy result in for an organism?

Learning Objective	ENE-1.N Explain how changes in energy availability affect populations and ecosystems
I can…	☐ I can explain ways changes in energy availability affect populations and ecosystems. ☐ I can explain the result of a change in energy availability on population size. ☐ I can explain the result of a change in energy availability on ecosystem. ☐ I can explain the effect of a change in sunlight on number and size of trophic levels. ☐ I can explain the effect of a change in the producer level on number and size of other trophic levels.

10. How does a change in energy available affect population size?
11. How does a decrease in sunlight affect the number and sizes of each trophic level?
12. How does an increase in sunlight affect the number and sizes of each trophic level?
13. How does a decrease in producers affect the number and size of other trophic levels?
14. How does an increase in producers affect the number and size of other trophic levels?

Learning Objective	**ENE-1.0** Explain how the activities of autotrophs and heterotrophs enable the flow of energy within an ecosystem.
I can…	☐ I can explain ways the activities of autotroph and heterotroph enable the flow of energy within an ecosystem. ☐ I can describe the function of autotrophs in capturing energy. ☐ I can describe ways photosynthetic organisms capture energy. ☐ I can describe ways chemosynthetic organisms capture energy. ☐ I can describe the function of heterotrophs in capturing energy. ☐ I can identify a heterotrophs sources of energy by hydrolysis.

15. What is an autotroph?
16. What is the function of an autotroph in capturing energy?
17. How do photosynthetic organisms capture energy?
    a. Identify one example of a photosynthetic organism.
18. How do chemosynthetic organisms capture energy?
    a. Identify one example of a photosynthetic organism.
19. True or False: Oxygen is required for the photosynthetic and chemosynthetic organism to capture energy.
20. What is a heterotroph?
21. What macromolecules can a heterotroph use for sources of energy?

Topic 8.3: Population Ecology

Learning Objective	SYI-1.G Describe factors that influence growth dynamics of populations.
I can…	☐ I can describe factors that influence growth dynamics of populations. ☐ I can describe ways populations interact with one another. ☐ I can describe ways populations interact with the environment. ☐ I can describe adaptations for obtaining energy and matter in the environment. ☐ I can describe adaptations for using energy and matter in the environment. ☐ I can describe factors that population growth dynamics depend on. ☐ I can calculate population growth. ☐ I can calculate birth rate (per capita). ☐ I can calculate death rate (per capita). ☐ I can describe exponential growth of a population. ☐ I can describe factors that allow for exponential growth of a population. ☐ I can calculate exponential growth rate. ☐ I can calculate per capita growth rate of a population.
Formula Sheet	**RELEVANT EQUATION** Population Growth— $\frac{dN}{dt} = B - D$ where: dt = chage in time B = birth rate D = death rate N = population size **RELEVANT EQUATION** Exponential Growth— $\frac{dN}{dt} = r_{max}N$ where: dt = change in time N = population size r_{max} = maximum per capita growth rate of population

1. What makes up a population?
2. How do populations interact with one another?
3. How do populations interact with the environment?
4. Identify two adaptations for obtaining energy and matter in the environment.
5. Identify two adaptations for using energy and matter in the environment.
6. Identify two factors that population growth dynamics depend on.
7. What is population growth?
8. How do you solve for B?
9. How do you solve for D?
10. If a population has 300 individuals, then 20 new individuals are born and 40 individuals die. What is the population growth of this population?
    a. Solve for B b. Solve for D c. Solve for dN/dt.
11. What is exponential growth?
12. What allows for a population to undergo exponential growth?
13. How do you solve for r?
14. If a population has 300 individuals, then 40 new individuals are born and 20 individuals die. What is the population size after 3 generations?
    a. Solve for r b. Solve for dN/dt

Topic 8.4: Effect of Density of Populations

Learning Objective	**SYI-1.H** Explain how the density of a population affects and is determined by resource availability in the environment.
I can…	☐ I can explain ways the density of a population affects resource availability in the environment. ☐ I can explain ways the density of a population is determined by resource availability in the environment. ☐ I can identify density-dependent factors. ☐ I can identify density-independent factors. ☐ I can describe the effect of density-dependent factors on a population's growth. ☐ I can describe the effect of density-independent factors on a population's growth. ☐ I can calculate logistic growth rate of a population. ☐ I can describe carrying capacity. ☐ I can describe population growth rate as the population size approaches the carrying capacity.
Formula Sheet	**RELEVANT EQUATION** $\frac{dN}{dt} = r_{max} N\left(\frac{K-N}{K}\right)$ where: dt = change in time N = population size r_{max} = maximum per capita growth rate of population K = carrying capacity

1. What is density?
2. What is carrying capacity?
3. What are density-dependent factors?
    a. Identify three density-dependent factors.
    b. How do density-dependent factors affect a population's growth?
4. What are density-independent factors?
    a. Identify three density-independent factors.
    b. How do density-independent factors affect a population's growth?
5. If a population has 300 individuals and the environment can support 400 individuals, then 50 new individuals are born and 10 individuals die. What is the logistic growth rate of this population?
6. What happens to the growth rate as the population size approaches the carrying capacity?

Topic 8.5: Community Ecology

Learning Objective	ENE-4.A Describe the structure of a community according to its species composition and diversity
I can…	☐ I can describe the structure of a community according to its species composition and diversity. ☐ I can describe ways the structure of a community is measured. ☐ I can describe ways the structure of a communication is described in terms of species composition and species diversity. ☐ I can apply Simpson's Diversity Index to a population. ☐ I can describe properties of a diverse population.
Formula Sheet	**RELEVANT EQUATION** Simpson's Diversity Index— $\text{Diversity Index} = 1 - \Sigma\left(\frac{n}{N}\right)^2$ n = the total number of organisms of a particular species N = total number of organisms of all species

1. How is the structure of a community measured?
2. What is a species?
3. What is species composition?
4. What is species diversity?
5. Identify two properties of a diverse population.
6. Complete the Practice Problem for Simpson's Index (from http://www.countrysideinfo.co.uk/simpsons.htm):
   Calculate the Simpson's Index of a sample from the woods:

Species	Number (n)
Woodrush	2
Holly (seedlings)	8
Bramble	1
Yorkshire Fog	1
Sedge	3
Total (N)	15

Learning Objective	ENE-4.B Explain how interactions within and among populations influence community structure.
I can…	☐ I can explain ways interactions within and among populations influence community structure. ☐ I can explain ways communities change over time depending on interactions between populations. ☐ I can explain ways interactions among populations determine how they access energy and matter within a community. ☐ I can describe positive interactions between populations. ☐ I can describe negative interactions between populations. ☐ I can describe predator/prey interactions. ☐ I can describe trophic cascades. ☐ I can describe niche partitioning. ☐ I can explain ways competition drives population dynamics. ☐ I can explain ways predation drives population dynamics. ☐ I can explain ways symbioses drives population dynamics. ☐ I can explain ways parasitism drives population dynamics. ☐ I can explain ways mutualism drives population dynamics. ☐ I can explain ways commensalism drives population dynamics.

7. How do interactions among populations affect their ability to access energy and matter within a community?
8. What are positive interactions between populations?
9. What are negative interactions between populations?
10. What are trophic cascades?
11. What is niche partitioning?
12. Identify the following as positive or negative interactions?
    a. Predation/prey interactions
    b. Trophic cascades
    c. Niche partitioning
13. What is competition?
    a. How does competition drive population dynamics?
14. What is predation?
    a. How does predation drive population dynamics?
15. Identify the three types of symbiosis.
16. What is parasitism?
    a. How does parasitism drive population dynamics?
17. What is mutualism?
    a. How does mutualism drive population dynamics?
18. What is commensalism?
    a. How does commensalism drive population dynamics?

Learning Objective	ENE-4.C Explain how community structure is related to energy availability in the environment.
I can…	☐ I can explain ways communication structure is related to energy availability in the environment. ☐ I can explain ways cooperation between organisms can result in enhanced movement of/access to matter and energy. ☐ I can explain ways cooperation between populations can result in enhanced movement of/access to matter and energy. ☐ I can explain ways cooperation between species can result in enhanced movement of/access to matter and energy.

19. What is cooperation?
20. How does cooperation affect access to matter and energy?

Topic 8.6: Biodiversity

Learning Objective	SYI-3.F Describe the relationship between ecosystem diversity and its resilience to changes in the environment.
I can…	☐ I can describe the relationship between ecosystem diversity and its resilience to changes in the environment. ☐ I can describe the effect of fewer components and little diversity among the parts. ☐ I can describe keystone species. ☐ I can describe producers. ☐ I can describe essential abiotic factors. ☐ I can describe essential biotic factors. ☐ I can describe ways keystone species, producers, and essential abiotic/biotic factors maintain diversity of an ecosystem.

1. In terms of component parts and diversity, what type of ecosystem is more resilient to changes in the environment?
2. What are keystone species?
    a. How do they maintain diversity in an ecosystem?
3. What are producers?
    a. How do they maintain diversity in an ecosystem?
4. What are abiotic factors?
    a. What abiotic factors are essential in maintaining the diversity in an ecosystem?
5. What are biotic factors?
    a. What biotic factors are essential in maintaining the diversity in an ecosystem?

Learning Objective	SYI-3.G Explain how the addition or removal of any component of an ecosystem will affect its overall short-term and long-term structure.
I can…	☐ I can explain ways the addition of any component of an ecosystem will affect its overall short term structures. ☐ I can explain ways the removal of any component of an ecosystem will affect its overall short term structures. ☐ I can explain ways the addition of any component of an ecosystem will affects its long-term structure. ☐ I can explain ways the removal of any component of an ecosystem will affect its long-term structure. ☐ I can describe ways the diversity can influence the organization of ecosystem. ☐ I can describe the effects of keystone species on the ecosystem.

6. How does the diversity of a species within an ecosystem influence the organization of the ecosystem?
7. Identify an example of an addition to an ecosystem and its effect…
    a. Short-term structure
    b. Long-term structure
8. Identify an example of a removal from an ecosystem and its effect on…
    a. Short-term structure
    b. Long-term structure
9. Identify a keystone species.
    a. What would occur if this keystone species was removed from the ecosystem?

Topic 8.7: Disruptions to Ecosystems

Learning Objective	EVO-1.0 Explain the interaction between the environment and random or preexisting variations in populations.
I can…	☐ I can explain the interaction between the environment and random variation in the populations. ☐ I can explain the interaction between the environment and preexisting variations in populations. ☐ I can explain adaptations. ☐ I can explain ways that adaptations are selected in a population. ☐ I can explain where mutations come from. ☐ I can explain that mutations are random with no direction for selective pressures.

1. What is an adaptation?
2. How do adaptations get introduced?
3. How are adaptations selected for in a population?
4. What is a mutation?
5. Where do mutations come from?

Learning Objective	SYI-2.A Explain how invasive species affect ecosystem dynamics.
I can…	☐ I can explain ways invasive species affect ecosystem dynamics. ☐ I can describe ways invasive species enter an area. ☐ I can describe ways invasive species are able to exploit an area. ☐ I can describe the population growth rate of an invasive species.

6. What is an invasive species?
7. How are invasive species able to exploit an area?
8. What does the population growth rate curve look like?
9. How do invasive species affect ecosystem dynamics?

Learning Objective	SYI-2.B Describe human activities that lead to changes in ecosystem structure and/ or dynamics.
I can…	☐ I can describe human activities that lead to changes in ecosystem structure. ☐ I can describe human activities that lead to changes in ecosystem dynamics. ☐ I can describe the distribution of global ecosystems. ☐ I can describe the effect of disease introduction. ☐ I can describe the effect of human activities on habitats.

10. What is a local ecosystem?
11. What is a global ecosystem?
12. How does the distribution of an ecosystem change over time?

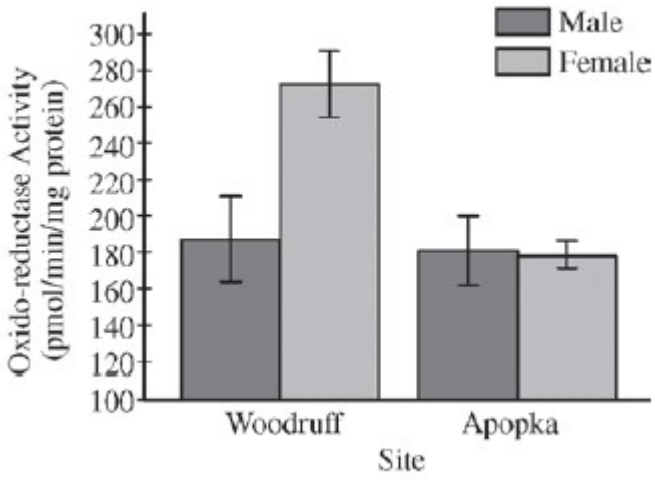
13. What happens to an ecosystem when a new disease is introduced?
14. What happens to an ecosystem due to human activity?

Learning Objective	SYI-2.C Explain how geological and meteorological activity leads to changes in ecosystem structure and/or dynamics
I can…	☐ I can explain ways geological activity leads to changes in ecosystem structure. ☐ I can explain ways meteorological activity leads to changes in ecosystem structure. ☐ I can explain ways geological activity leads to changes in ecosystem dynamics. ☐ I can explain ways meteorological activity leads to changes in ecosystem dynamics.

15. How do geological events affect habitat change and ecosystem distribution?
16. What is biogeography?
17. How did the habitats and ecosystems change when Pangaea split apart?

Multiple Choice Practice

1. Testosterone oxido-reductase is a liver enzyme that regulates testosterone levels in alligators. One study compared testosterone oxido-reductase activity between male and female alligators from Lake Woodruff, a relatively pristine environment, and from Lake Apopka, an area that has suffered severe contamination. The graph above depicts the findings of that study.



The data in the graph best support which of the following claims?

a. Environmental contamination elevates total testosterone oxido-reductase activity in females.
b. Environmental contamination reduces total testosterone oxido-reductase activity in females.
c. Environmental contamination elevates total testosterone oxido-reductase activity in males.
d. Environmental contamination reduces total testosterone oxido-reductase activity in males.

Use the following information to answer question 2.

A student placed 20 tobacco seeds of the same species on moist paper towels in each of two petri dishes. Dish A was wrapped completely in an opaque cover to exclude all light. Dish B was not wrapped. The dishes were placed equidistant from a light source set to a cycle of 14 hours of light and 10 hours of dark. All other conditions were the same for both dishes. The dishes were examined after 7 days and the opaque cover was permanently removed from dish A. Both dishes were returned to the light and examined again at 14 days. The following data were obtained.

	Dish A		Dish B	
	Day 7 Covered	Day 14 Uncovered	Day 7 Uncovered	Day 14 Uncovered
Germinated seeds	12	20	20	20
Green-leaved seedlings	0	14	15	15
Yellow-leaved seedlings	12	6	5	5
Mean stem length below first set of leaves	8 mm	9 mm	3 mm	3 mm

2. The most probable cause for the difference in mean stem length between plants in dish A and plants in dish B is which of the following?
    a. Shortening of cells in the stem in response to the lack of light
    b. Elongation of seedlings in response to the lack of light
    c. Enhancement of stem elongation by light
    d. Genetic differences between the seeds

3. Which of the following statements most directly supports the claim that different species of organisms use different metabolic strategies to meet their energy requirements for growth, reproduction, and homeostasis?
    a. During cold periods pond-dwelling animals can increase the number of unsaturated fatty acids in their cell membranes while some plants make antifreeze proteins to prevent ice crystal formation in tissues.
    b. Bacteria lack introns while many eukaryotic genes contain many of these intervening sequences.
    c. Carnivores have more teeth that are specialized for ripping food while herbivores have more teeth that are specialized for grinding food.
    d. Plants generally use starch molecules for storage while animals use glycogen and fats for storage.

4. Figure I shows the growth of an algal species in a flask of sterilized pond water. If phosphate is added as indicated, the growth curve changes as shown in Figure II.

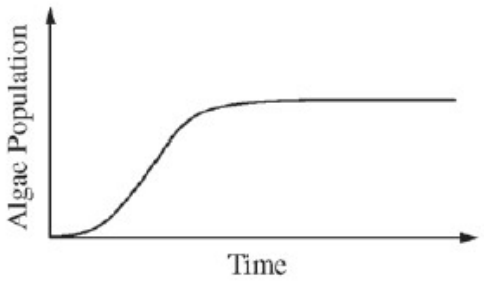


Figure I

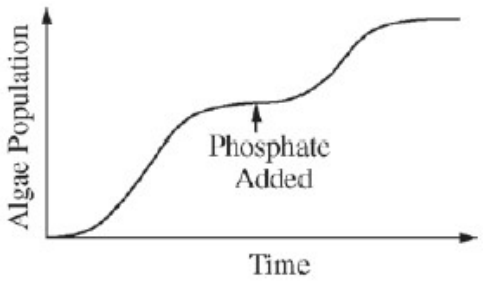
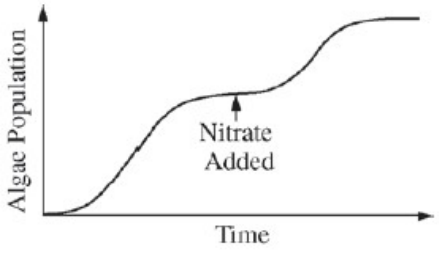
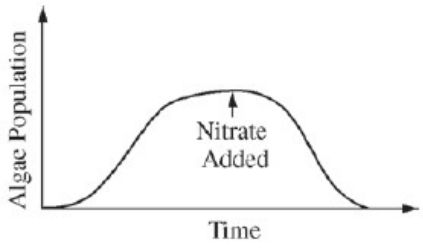


Figure II

Which of the following is the best prediction of the algal growth if nitrate is added instead of phosphate?

a.


b.


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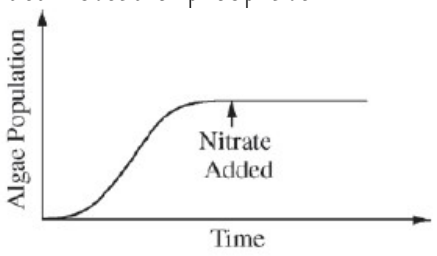
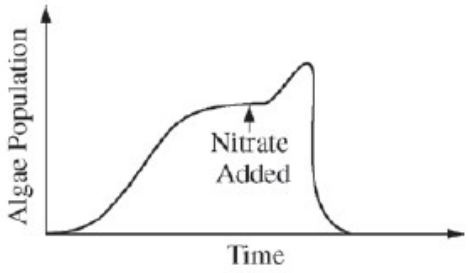
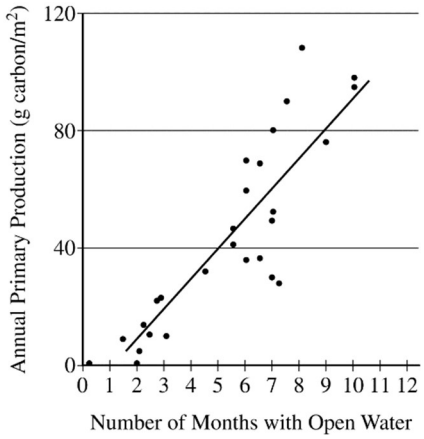


d.




5. In the Arctic Ocean, the predominant primary producers are phytoplankton. Phytoplankton are consumed by zooplankton, which in turn are eaten by codfish. In years when there is more open water (less ice coverage), there are more zooplankton and fish than in years with less open water (more ice coverage). Based on the graph above, the difference is most likely because

   a. when there is less open water, light is blocked from the zooplankton, so they cannot produce as much food for the fish
   b. when there is more open water, the temperature is warmer, so the zooplankton and fish populations increase in size
   c. the ice blocks the light, so in years with more ice coverage, there is less photosynthesis by the phytoplankton
   d. the ice increases the light available for photosynthesis, so primary production increases and zooplankton populations increase in size

Use the following information to answer question 6.

An experiment to measure the rate of respiration in crickets and mice at 10°C and 25°C was performed using a respirometer, an apparatus that measures changes in gas volume. Respiration was measured in mL of O_2 consumed per gram of organism over several five-minute trials and the following data were obtained.

Organism	Temperature (°C)	Average respiration (mL O_2/g/min)
Mouse	10	0.0518
Mouse	25	0.0321
Cricket	10	0.0013
Cricket	25	0.0038

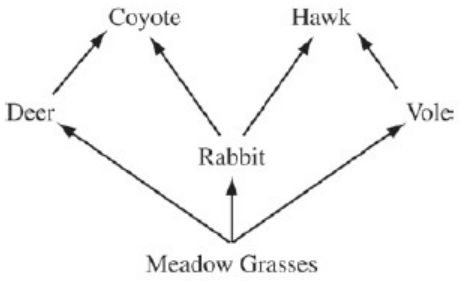
6. According to the data, the crickets at 25°C have greater oxygen consumption per gram of tissue than do the crickets at 10°C. This trend in oxygen consumption is the opposite of that in the mice. The difference in trends in oxygen consumption among crickets and mice is due to their

   a. relative size
   b. mode of nutrition
   c. mode of internal temperature regulation
   d. mode of ATP production

7. Beaked whales feed at various depths, but they defecate at the ocean's surface. Nitrogen-rich whale feces deposited in surface waters supply nutrients for algae that are eaten by surface dwelling fish. Which of the following best predicts what would happen if the whale population decreased?

   a. There would be a reduction in surface nitrogen concentration, which would cause an algal bloom.
   b. The surface fish populations would decline due to reduced populations of algae.
   c. The remaining whales would accumulate mutations at a faster rate.
   d. The remaining whales would be forced to forage in the deepest parts of the ocean.

8. The following is a food web for a meadow habitat that occupies 25.6 km^2. The primary producers' biomass is uniformly distributed throughout the habitat and totals 1,500 kg/km^2.

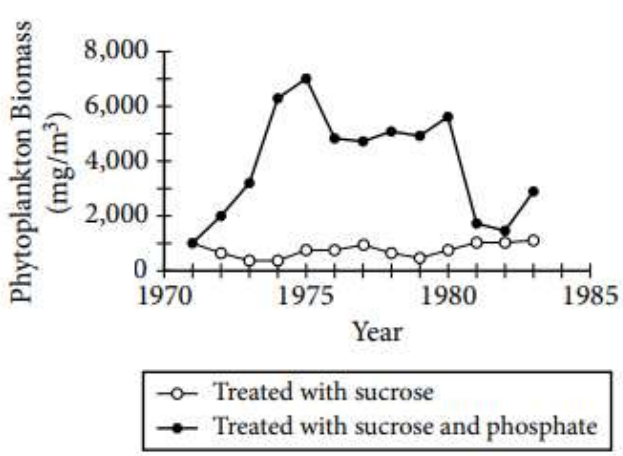


Developers have approved a project that will permanently reduce the primary producers' biomass by 50 percent and remove all rabbits and deer.

Which of the following is the most likely result at the completion of the project?

a. The biomass of coyotes will be 6 kg, and the biomass of hawks will be 0.5 kg.
b. The biomass of coyotes will be dramatically reduced.
c. The coyotes will switch prey preferences and outcompete the hawks.
d. There will be 50 percent fewer voles and 90 percent fewer hawks.

Use the following information to answer questions 9-12.



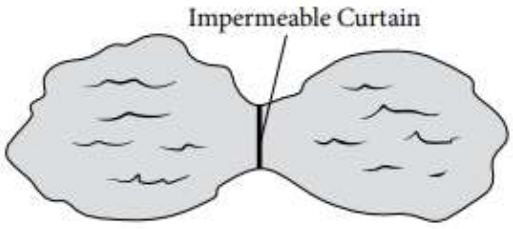


Figure 1. Phytoplankton biomass in two sides of a small lake that is divided by an impermeable curtain

In the early 1970s, researchers hypothesized that carbon was the limiting nutrient in many aquatic ecosystems. To test this hypothesis, the researchers divided a small lake in two roughly equal halves with an impermeable curtain that was fastened and sealed to the bedrock of the lake. Beginning in 1971 the researchers treated one side of the lake with sucrose and the other side with both sucrose and phosphate. From 1971 to 1983 the researchers monitored the phytoplankton biomass in both parts of the lake. The results are shown in Figure 1.

9. Which of the following claims is best supported by the data?
    a. Carbon was a limiting factor for phytoplankton in the lake.
    b. Phosphate was a limiting factor for phytoplankton in the lake.
    c. Both carbon and phosphate were limiting factors for phytoplankton in the lake.
    d. Neither carbon nor phosphate was a limiting factor for phytoplankton in the lake

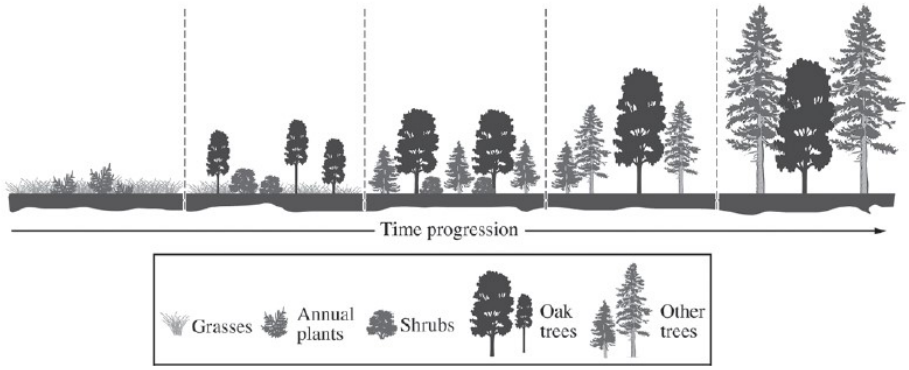
10. The average growth rate of the phytoplankton population from 1971 to 1975 in the side of the lake treated with sucrose and phosphate is closest to which of the following?
    a. 125 (mg/m^3)/year
    b. 1,000 (mg/m^3)/year
    c. 1,500 (mg/m^3)/year
    d. 6,000 (mg/m^3)/year

11. Which of the following treatments would have been the best control treatment for the experiment?
    a. An untreated section of the lake
    b. A section of the lake that was treated with phosphate but not sucrose
    c. A different lake that was treated with sucrose and phosphate
    d. A small pool of the lake water maintained in a controlled laboratory environment

12. Which of the following was most likely a direct consequence of the addition of phosphate to the lake?
    a. The amount of biomass in the first trophic level decreased.
    b. The amount of biomass in the second trophic level decreased.
    c. The amount of energy available to producers in the lake increased.
    d. The amount of energy available to consumers in the lake increased

13. Thrips are insects that feed on rose pollen. Scientists noted that the thrips population increased in the spring and decreased dramatically during the summer. The researchers hypothesized that food abundance was the limiting factor for the population. Which of the following types of data would be most useful for the scientists to collect at regular intervals on a designated test plot of rose plants?
    a. Amount of sunlight (hours/day)
    b. Mean temperature (°C)
    c. Density of rose pollen produced (g/m^2)
    d. Amount of pollen produced by each flower (g/flower)

14. The diagram below shows the progression of ecological events after a fire in a particular ecosystem. Based on the diagram, which of the following best explains why the oak trees are later replaced by other trees?



a. Eventually the other trees grow taller than the oak trees and form a dense canopy that shades the understory.
b. Oak trees alter the pH of the soil, making the forest better suited for shrubs and other trees.
c. Roots of shrubs proliferate in the soil of the forest and prevent the oak trees from obtaining water.
d. Oak trees succumb to environmental pollutants more readily than do either the shrubs or the other trees.

Use the following information to answer questions 15-17.

The figures below show the changes in populations of two species of flour beetles, Tribolium confusum (Figure I) and Tribolium castaneum (Figure II), in cultures without parasites (o) and in cultures infected with a parasite (•). Each data point represents the mean population size from ten culture dishes of equal size and food content.

FIGURE I: NUMBER OF *TRIBOLIUM CONFUSUM* OVER TIME

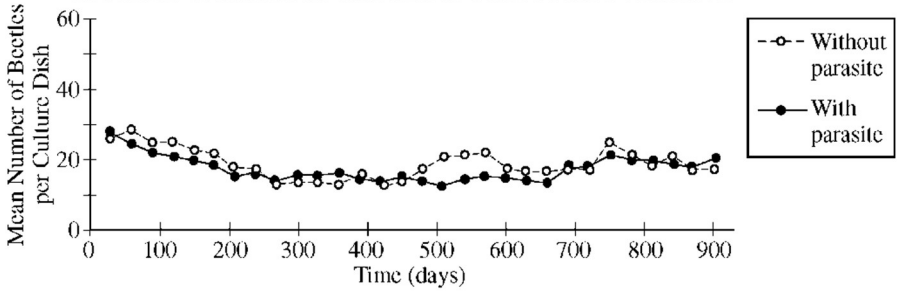
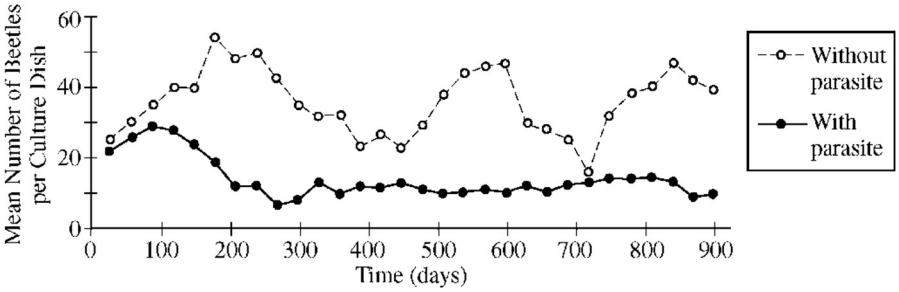


FIGURE II: NUMBER OF *TRIBOLIUM CASTANEUM* OVER TIME



15. Under which of the following conditions is the observed number of beetles per culture dish the greatest?
    a. *T. confusum* with parasite at 500 days
    b. *T. confusum* without parasite at 300 days
    c. *T. castaneum* with parasite at 100 days
    d. *T. castaneum* with parasite at 600 days

16. The data over the duration of the experiment provide the strongest support for which of the following conclusions regarding the effect of the parasite on *Tribolium* populations?
    a. *T. confusum* is adversely affected by the parasite, while *T. castaneum* is not.
    b. *T. castaneum* is adversely affected by the parasite, while *T. confusum* is not.
    c. Both *T. confusum* and *T. castaneum* are adversely affected by the parasite.
    d. Both *T. confusum* and *T. castaneum* show increased fitness in the presence of the parasite.

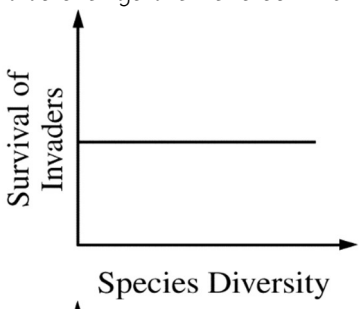
17. In Figure I, the difference between the two curves can best be attributed to which of the following?
    a. The difference between controlled laboratory conditions and the natural environment
    b. The effect of the host on its parasite
    c. The influence of competition for limited resources
    d. The natural variation among populations

18. If the experiment was continued for an additional 500 days, the population density of *T. castaneum* with the parasite would most likely stabilize at a value closest to which of the following?
    a. 5 beetles/culture dish
    b. 10 beetles/culture dish
    c. 20 beetles/culture dish
    d. 25 beetles/culture dish

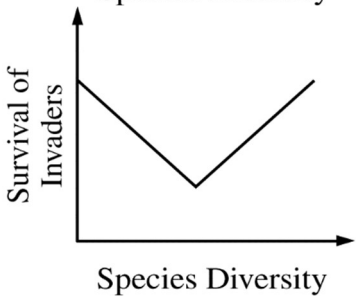
19. A researcher is investigating the relationship between the existing species diversity in a community and the ability of an introduced nonnative species to destabilize the community.

    Which of the following graphs is most consistent with the claim that communities with high diversity are more resistant to change than are communities with low diversity?

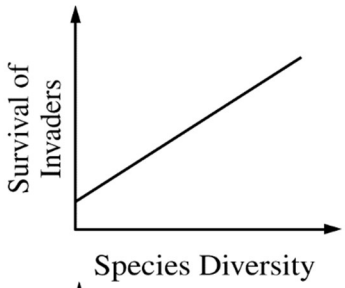
a.



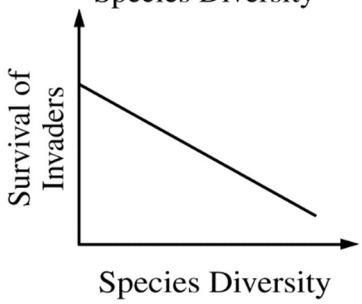
b.



c.



d.



20. Scientists have found that the existing populations of a certain species of amphibian are small in number, lacking in genetic diversity, and separated from each other by wide areas of dry land. Which of the following human actions is most likely to improve the long-term survival of the amphibians?
    a. Cloning the largest individuals to counteract the effects of aggressive predation
    b. Reducing the population size by one-fifth to decrease competition for limited resources
    c. Constructing a dam and irrigation system to control flooding
    d. Building ponds in the areas of dry land to promote interbreeding between the separated populations

21. Which of the following best describes altruistic behaviors?
    a. a defensive behavior in which organisms huddle all together
    b. a selfless behavior to save the population but risk yourself
    c. a protective behavior describing how organisms migrate
    d. a reproductive behavior for attracting a mate through a ritual

22. A fruit fly vibrates its wings to serenade a potential mate. Which of the following describes the type of behavior?
    a. audible
    b. tactile
    c. electrical
    d. chemical

23. A cheetah urinates on a tree. Which of the following types of signals is the cheetah using?
    a. visual
    b. audible
    c. tactile
    d. chemical

24. A cheetah urinates on a tree. Which of the following describes the purpose of this signal?
    a. indicate dominance
    b. establish territory
    c. find food
    d. ensure reproductive success

25. Which of the following best describes the body temperature regulation for an alligator?
    a. ectotherm that maintains body temperature through metabolism
    b. ectotherm that maintains body temperature through behaviors
    c. endotherm that maintains body temperature through metabolism
    d. endotherm that maintains body temperature through behaviors

26. Which of the following best describes the relationship between metabolic rate per unit body mass and the size of multicellular organisms?
    a. the smaller the organism, the higher the metabolic rate
    b. the larger the organism, the higher the metabolic rate
    c. the higher the surface area to volume ratio of the cells, the higher the metabolic rate
    d. the lower the surface area to volume ratio of the cells, the higher the metabolic rate

27. Which of the following best describes the changes to the trophic structure with a decrease in plant population?
    a. increase in primary and secondary consumers
    b. decrease in primary and secondary consumers
    c. decrease in secondary consumer, increase in primary consumer
    d. increase in secondary consumer, decrease in primary consumer

28. Which of the following describes the energy resource used by chemosynthetic organisms?
    a. small inorganic molecules preset in their environment
    b. organic molecules broken down by the mitochondria
    c. photons absorbed by chlorophyll in the chloroplast
    d. air movement turns hairs on organismal surface

29. Which of the following is a material that heterotrophs are unable to metabolize?
    a. carbohydrates
    b. nucleic acids
    c. lipids
    d. proteins

30. In a population of 100 individuals, 20 individuals are born and there are 5 deaths. What is the r value?
    Recall: r = per capita growth rate of population
    a. .05
    b. .15
    c. .20
    d. .25

31. If the population size is 100 individuals and there is a r value of 0.3, what is dN/dt?
    Recall: dN/dt = rN
    a. 10
    b. 15
    c. 30
    d. 60

32. As the population size approaches carrying capacity, dN/dt...
    a. increases steadily
    b. increases slowly
    c. decreases slowly
    d. decreases steadily

33. Which of the following describes the relationship of the mistletoe that gains resources and harms the mesquite tree that it grows on?
    a. parasitism
    b. commensalism
    c. mutualism
    d. predator/prey

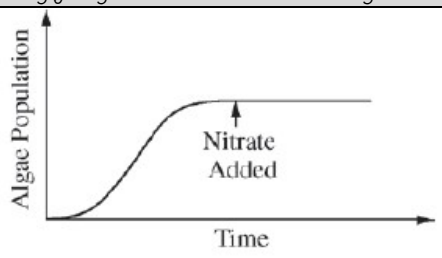
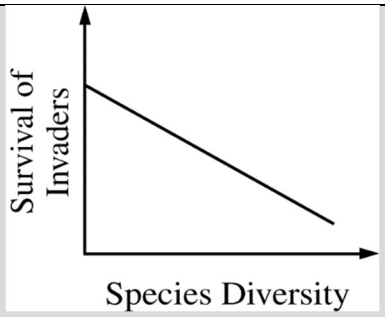
34. Which of the following describes the disadvantage of little species diversity in a community?
    a. less likely to have immigration
    b. more likely to be consumed by predators
    c. more likely to have mutations
    d. less resilient to changes in the environment

35. Which of the following is an organism that is disproportionate relative to their abundance and when removed from the ecosystem causes it to collapse?
    a. dominant species
    b. invasive species
    c. keystone species
    d. primary consumer

36. A group of bacteria are resistant to antibiotics. Which of the following describes HOW the bacteria became resistant?
    a. the bacterial population got changed by the antibiotic in the environment
    b. the bacterial population had random mutations making them favorable in the presence of the antibiotic
    c. the bacterial population consumed the antibiotic providing a food source
    d. the bacterial population uses the antibiotic for reproduction

37. Which of the following is NOT a reason for exponential growth of an invasive species?
    a. outcompete other organisms
    b. free of predators
    c. free of competition
    d. free of prey

Multiple Choice Key

Question	Correct Answer	Unit/Topic	Source
1	B. Environmental contamination reduces total testosterone oxido-reductase activity in females.	8.1	2012 CED #22
2	B. Elongation of seedlings in response to the lack of light	8.1	2012 CED #14
3	D. Plants generally use starch molecules for storage while animals use glycogen and fats for storage.	8.1	2012 CED #11
4	C. 	8.1	2012 CED #40
5	C. the ice blocks the light, so in years with more ice coverage, there is less photosynthesis by the phytoplankton	8.2	2013 #37
6	C. mode of internal temperature regulation	8.2	2012 CED #10
7	B. The surface fish populations would decline due to reduced populations of algae.	8.2	2013 #14
8	B. The biomass of coyotes will be dramatically reduced.	8.2	2012 CED #4
9	B. Phosphate was a limiting factor for phytoplankton in the lake.	8.3	2020 CED #4
10	C. 1,500 (mg/m^3)/year	8.3	2020 CED #5
11	A. An untreated section of the lake	8.3	2020 CED #6
12	D. The amount of energy available to consumers in the lake increased	8.2	2020 CED #7
13	C. Density of rose pollen produced (g/m^2)	8.5	2012 #2
14	A. Eventually the other trees grow taller than the oak trees and form a dense canopy that shades the understory.	8.5	2012 CED #6
15	C. *T. castaneum* with parasite at 100 days	8.5	2013 #10
16	B. *T. castaneum* is adversely affected by the parasite, while *T. confusum* is not.	8.5	2013 #11
17	D. The natural variation among populations	8.5	2013 #12
18	B. 10 beetles/culture dish	8.3	2013 #13
19	D. 	8.6	2013 #8

20	D. Building ponds in the areas of dry land to promote interbreeding between the separated populations	8.7	2013 #24
21	B. a selfless behavior to save the population but risk yourself	8.1	Self
22	A. audible	8.1	Self
23	D. chemical	8.1	Self
24	B. establish territory	8.1	Self
25	B. ectotherm that maintains body temperature through behaviors	8.2	Self
26	A. the smaller the organism, the higher the metabolic rate	8.2	Self
27	B. decrease in primary and secondary consumers	8.2	Self
28	A. small inorganic molecules preset in their environment	8.2	Self
29	B. nucleic acids	8.2	Self
30	B. 0.15	8.3	Self
31	C. 30	8.3	Self
32	B. increases slowly	8.4	Self
33	A. parasitism	8.5	Self
34	D. less resilient to changes in the environment	8.6	Self
35	C. keystone species	8.6	Self
36	B. the bacterial population had random mutations making them favorable in the presence of the antibiotic	8.7	Self
37	D. free of prey	8.7	Self

Free Response Practice

2019 #1

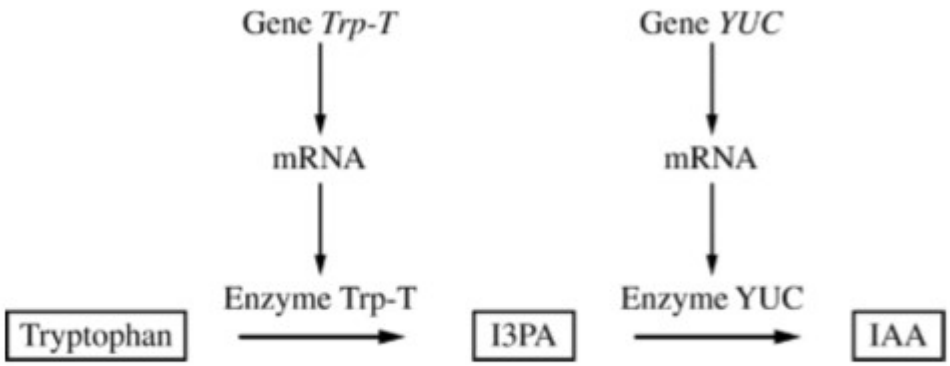


Figure 1. Model of two-step enzymatic plant pathway for synthesis of IAA from tryptophan

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.

(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.

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

(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.

(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 non-cheater 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.

2019 #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

	Group I. Grown Separately		Group II. Grown Together	
Time (h)	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

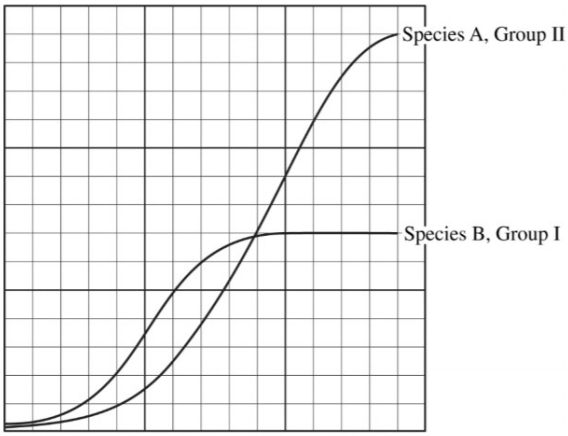
(a) The growth curves for species B in group I and for species A in group II (shaded columns) have been plotted on the template. Use the template to **complete** an appropriately labeled line graph to illustrate the growth of species A in treatment group I and species B in treatment group II (unshaded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

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

(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.

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

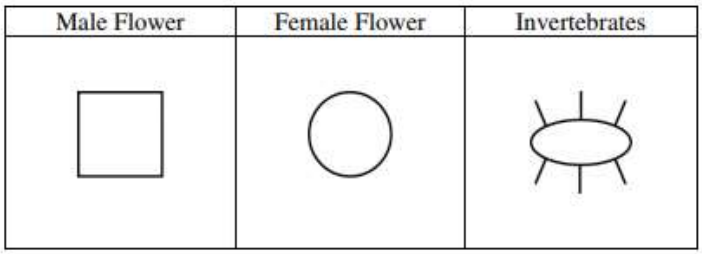
(e) Many protists contain an organelle called a contractile vacuole that pumps water out of the cell. The student repeated the experiment using a growth medium with a lower solute concentration. **Predict** how the activity of the contractile vacuole will change under the new experimental conditions.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



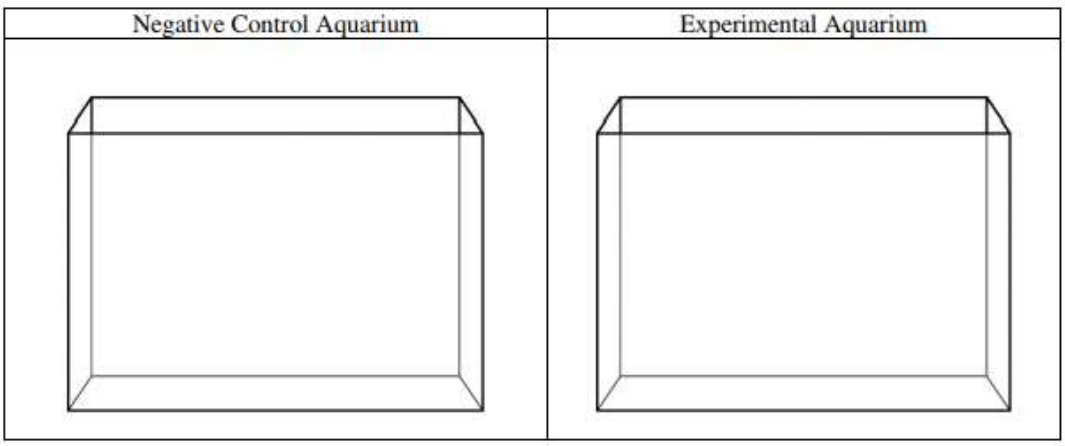
2018 #3

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 interaction 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 an symbol more than once in the same aquarium.



(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.



2018 #5

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 nest 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 from a nest containing warblers and cuckoos (group 2).

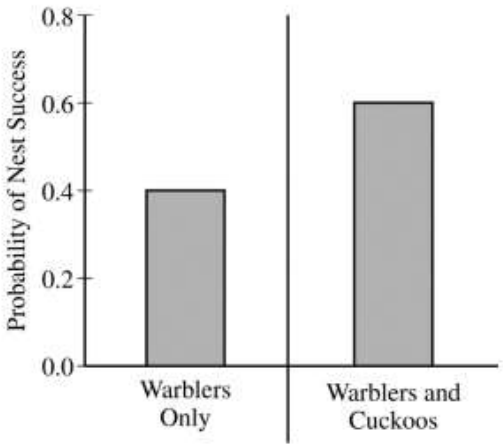


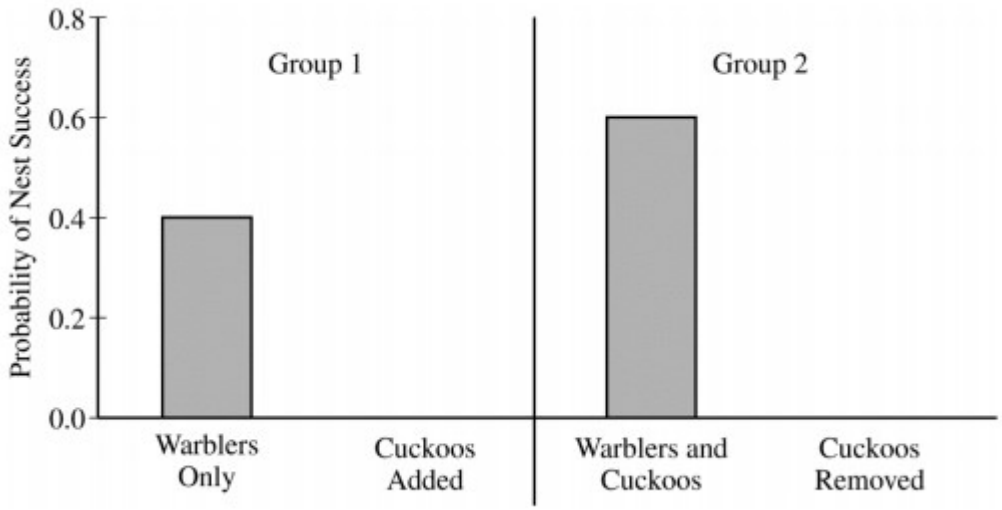
Figure 1. Probability of nest success in an environment with predators

(a) **Describe** the symbiotic relationship that exists between the cuckoo and warbler in an environment predators.

(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 <u>added</u> to the nest containing only warblers (group 1)
* the cuckoos were removed from the nest containing warblers and cuckoos (group 2)

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



2018 #7

In the tongue sole fish (*Cynoglossis 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 F_1 offspring of the cross shown in the Punnett square if the offspring are raised at 22°C.

(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.

2017 #1

In flowering plants, pollination is a process that leads to the fertilization of an egg and the production of seeds. Some flowers attract pollinators, such as bees, using visual and chemical cues. When a bee visits a flower, in addition to transferring pollen, the bee can take nectar from the flower and use it to make honey for the colony.

Nectar contains sugar, but certain plants also produce caffeine in the nectar. Caffeine is a bitter-tasting compound that can be toxic to insects at high concentrations. To investigate the role of caffeine in nectar, a group of researchers studied the effect of 0.1 mM caffeine on bee behavior. The results of an experiment to test the effect of caffeine on bees' memory of a nectar source are shown in Table 1.

TABLE 1. EFFECT OF 0.1 mM CAFFEINE ON MEMORY IN BEES

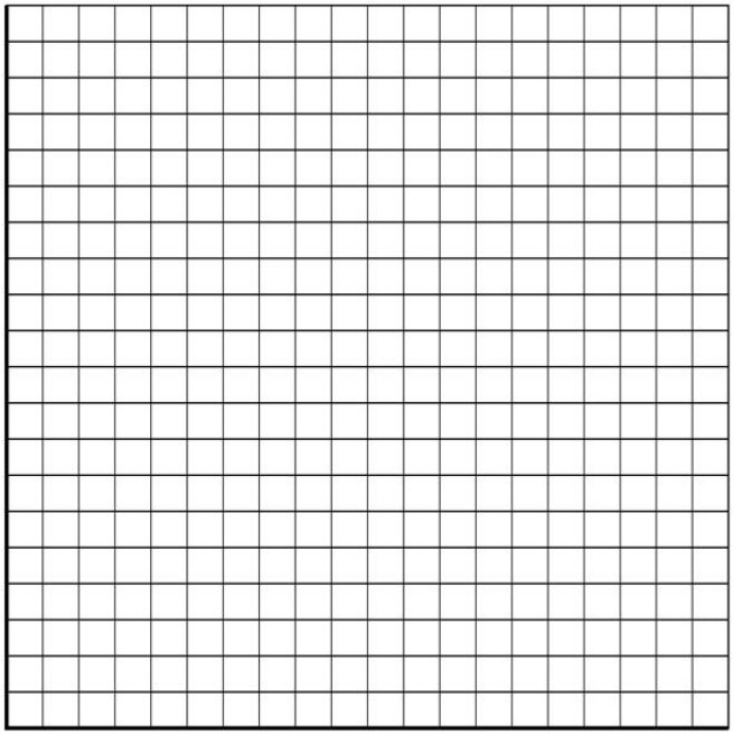
Treatment	Memory (average probability of revisiting a nectar source $\pm 2SE_{\bar{x}}$)	
	10 Minutes	24 Hours
Control	0.72 ± 0.09	0.41 ± 0.07
Caffeine	0.83 ± 0.07	0.78 ± 0.08

(a) On the axes provided, **construct** an appropriately labeled graph to illustrate the effect of caffeine on the probability of bees revisiting a nectar source (memory).

(b) Based on the results, **describe** the effect of caffeine on each of the following:
(i) Short-term (10 minute) memory of a nectar source
(ii) Long-term (24 hour) memory of a nectar source

(c) **Design an experiment** using artificial flowers to investigate potential negative effects of increasing caffeine concentrations in nectar on the number of floral visits by bees. **Identify** the null hypothesis, an appropriate control treatment, and the predicted results that could be used to reject the null hypothesis.

(d) Researchers found that nectar with caffeine tends to have a lower sugar content than nectar without caffeine. Plants use less energy to produce the caffeine in nectar than they do to produce the sugar in nectar. **Propose ONE benefit** to plants that produce nectar with caffeine and a lower sugar content. **Propose ONE cost** to bees that visit the flowers of plants that produce nectar with caffeine and a lower sugar content.



2017 #2

Fires frequently occur in some ecosystems and can destroy all above-ground vegetation. Many species of plants in these ecosystems respond to compounds in smoke that regulate seed germination after a major fire. Karrikins (KAR) and trimethylbutenolides (TMB) are water-soluble compounds found in smoke that are deposited in the soil as a result of a fire. KAR and TMB bind to receptor proteins in a seed. In a study on the effects of smoke on seeds, researchers recorded the timing and percent of seed germination in the presence of various combinations of KAR and TMB. The results are shown in Figure 1.

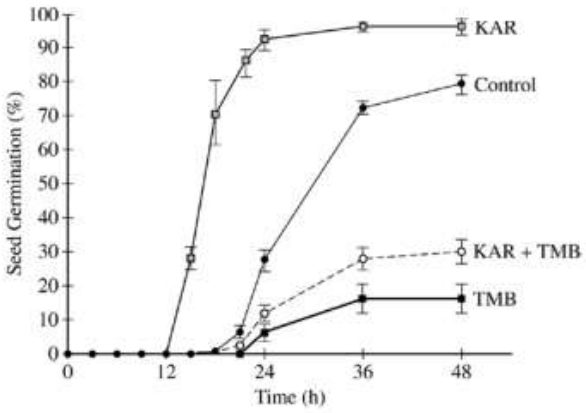


Figure 1. The effect of karrikins (KAR) and trimethylbutenolides (TMB) on seed germination in *Lactuca* plants. Error bars represent $\pm 2SE_{\bar{x}}$.

In a second investigation into the effect of available water on seed germination after a fire, researchers treated seeds with KAR or TMB. The treated seeds were then divided into two treatment groups. One group received a water rinse and the other group received no water rinse. The seeds were then incubated along with a group of control seeds that were not treated. The results are shown in the table.

EFFECT OF CHEMICAL TREATMENT AND WATER RINSE ON GERMINATION

Treatment Group	Chemical Treatment		Water	Germination Result
	KAR	TMB		
1 (control)	–	–	–	Control result
2	+	–	–	Different from control
3	–	+	–	Different from control
4 (control)	–	–	+	Control result
5	+	–	+	Different from control
6	–	+	+	Same as control

(a) The researchers made the following claims about the effect of KAR and the effect of TMB on seed germination relative to the control treatment.

- KAR alone affects the timing of seed germination
- KAR alone affects the percentage of seeds that germinate
- TMB alone affects the timing of seed germination
- TMB alone affects the percentage of seeds that germinate

Provide support using data from Figure 1 for each of the researchers' claims.

(b) **Make a claim** about the effect of rinsing on the binding of KAR to the receptor in the seed and about the effect of rinsing on the binding of TMB to the receptor in the seed. Identify the appropriate treatment groups and results from the table that, when compared with the controls, **provide support** for each claim.

(c) There is intense competition by plants to successfully colonize areas that have been recently cleared by a fire. **Describe** ONE advantage of KAR regulation and ONE advantage of TMB regulation to plants that live in an ecosystem with regular fires.

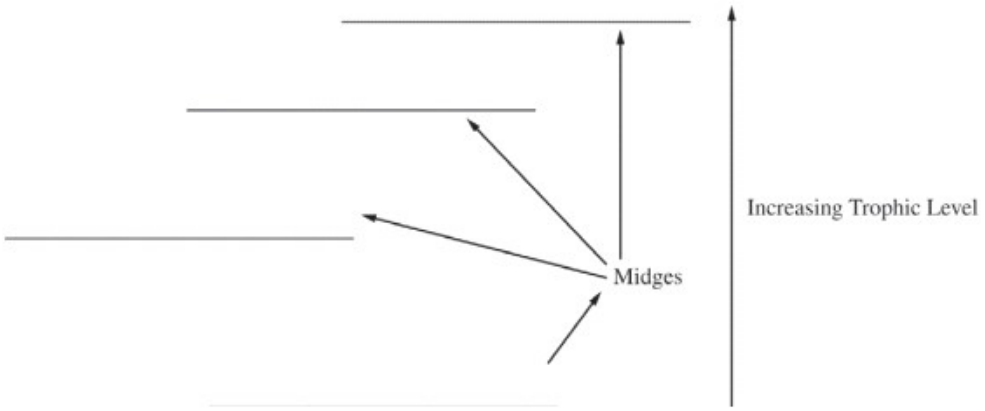
2017 #4

The table below shows how much each organism in an aquatic ecosystem relies on various food sources. The rows represent the organisms in the ecosystem, and the columns represent the food source. The percentages indicate the proportional dietary composition of each organism. High percentages indicate strong dependence of an organism on a food source.

DIETARY COMPOSITION OF ORGANISMS IN AN AQUATIC ECOSYSTEM

Organism	Food Source (% of diet)				
	Algae	Stoneflies	Midges	Hellgrammites	Caddisflies
Algae					
Stoneflies			90		10
Midges	100				
Hellgrammites		20	10		70
Caddisflies	70		30		

(a) Based on the food sources indicated in the data table, **construct** a food web in the template below. Write the organism names on the appropriate lines AND draw the arrows necessary to indicate the energy flow between organisms in the ecosystem.



(b) In an effort to control the number of midges, an area within the ecosystem was sprayed with the fungus *Metarhizium anisopliae*, which significantly decreased the midge population. Based on the data in the table, **predict** whether the spraying of fungus will have the greatest short-term impact on the population of the stoneflies, the caddisflies, or the hellgrammites. **Justify** your prediction.

2016 #2

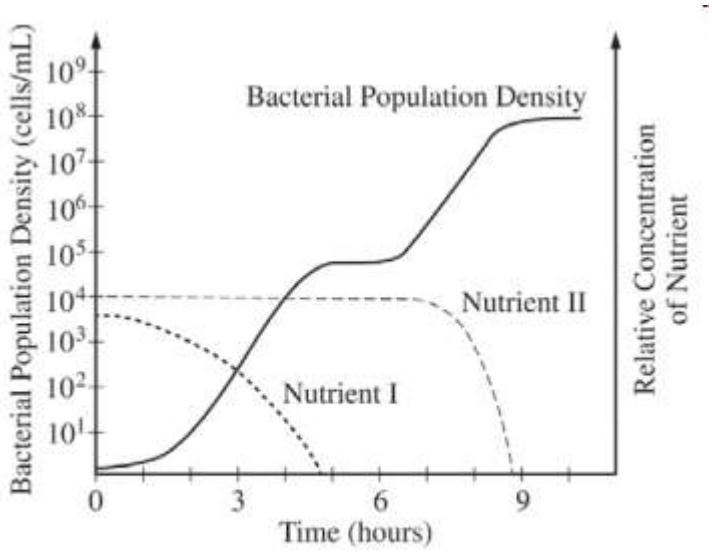


Figure 1. Bacterial population growth in the presence of two nutrients (nutrient I and nutrient II)

Bacteria can be cultured in media with a 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 $\frac{cells}{mL}$ for the culture. Using the data, **describe** what prevents further growth of the bacterial population in the culture.

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

(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.
(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.

2016 #3

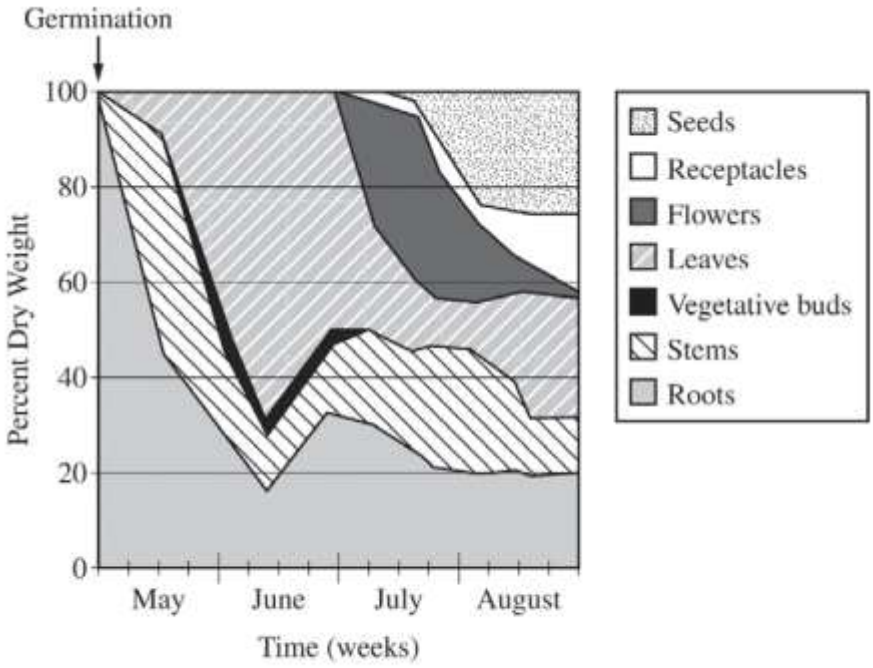


Figure 1. Percent dry weight of different plant structures during the growing season for an annual plant

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).

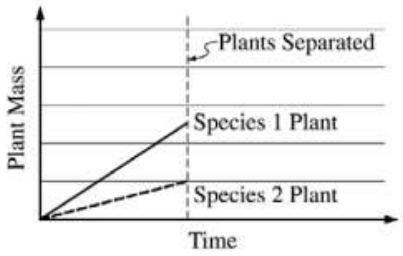
(a) **Identify** the direct source of energy used for plant growth during the first week of May, and **identify** the part of the plant that grew the most during the same period.

(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.

(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.

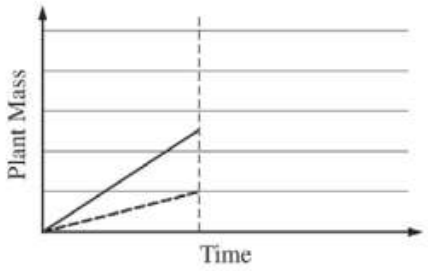
2016 #5

The graph below 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.

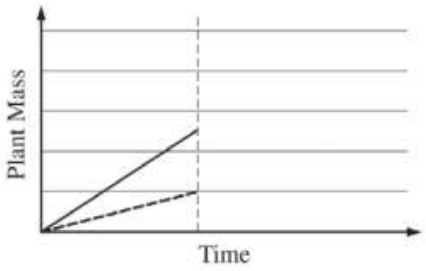


Using template 1, **graph** the predicted shape of the plant-mass lines after separation of the two plants if the plants were in an obligate mutualistic relationship. On template 2, **graph** the predicted shape of the plant-mass lines if the species 2 plant was a parasite of the species 1 plant. **Justify**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

TEMPLATE 1: OBLIGATE MUTUALISM



TEMPLATE 2: PARASITISM



2016 #8

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.

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

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

2015 #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.

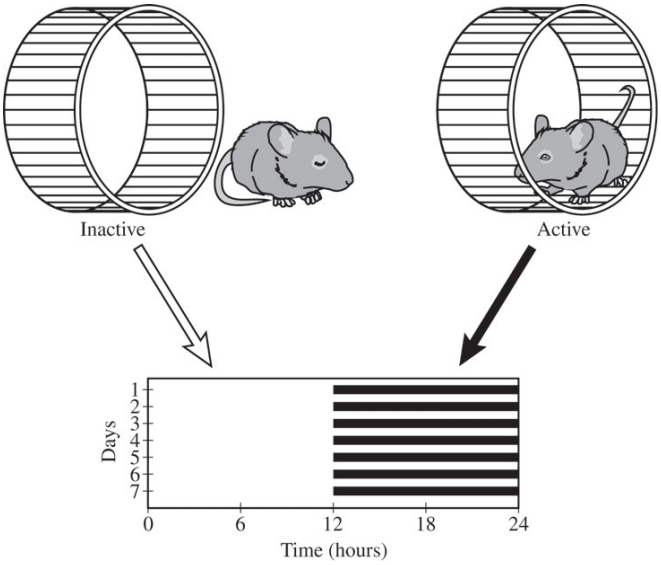


Figure 1. Strategy for recording mouse activity data. When a mouse is active on the running wheel, the activity is recorded as a dark horizontal line on an actogram. When the mouse is inactive, no dark line is recorded.

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.

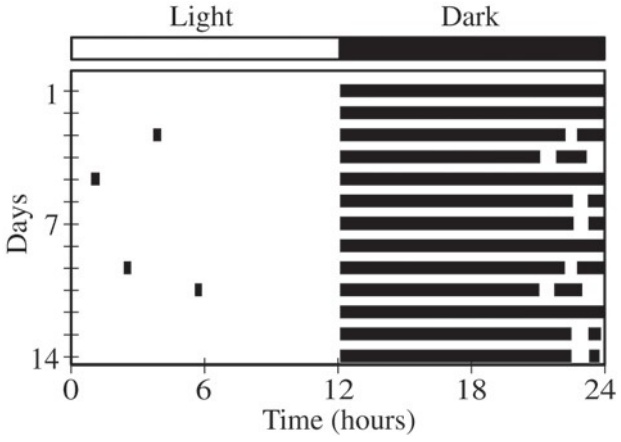


Figure 2. Actogram of mouse activity under L12:D12 conditions. Each row represents a 24-hour period, and the dark horizontal lines represent activity on the running wheel.

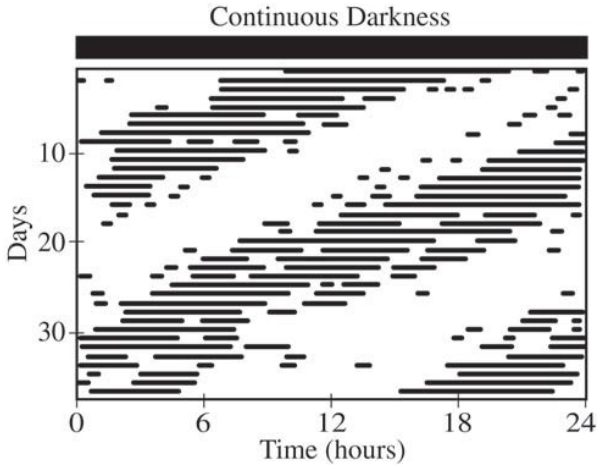


Figure 3. Actogram of mouse activity under DD conditions. Each row represents a 24-hour period, and the dark horizontal lines represent activity on the running wheel.

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.

NOTE: Part (a) IS OUT OF SCOPE FOR THE EXAM

(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

(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.

(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.

(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.

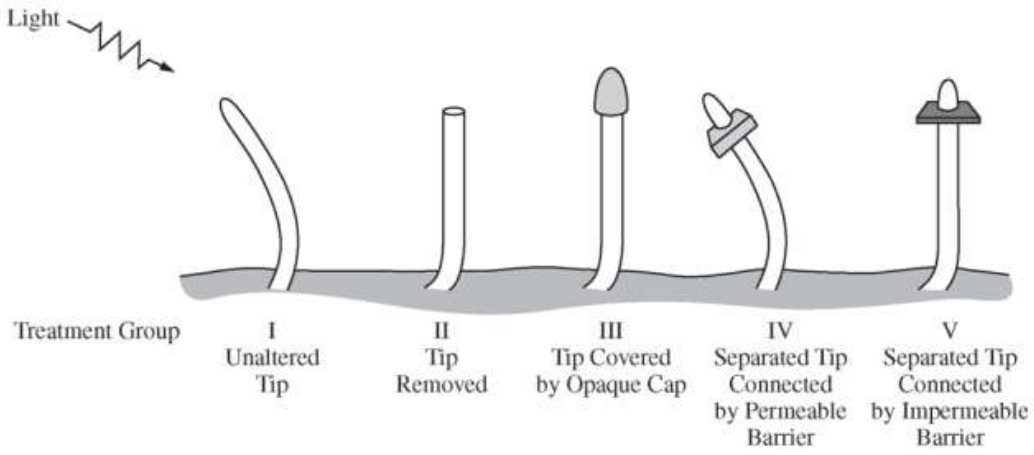
(e) In nature, mice are potential prey for some predatory birds that hunt during the day. **Describe** TWO features of a model that represents how the predator-prey relationship between the birds and the mice may have resulted in the evolution of the observed activity pattern of the mice.

2015 #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 below.

(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.

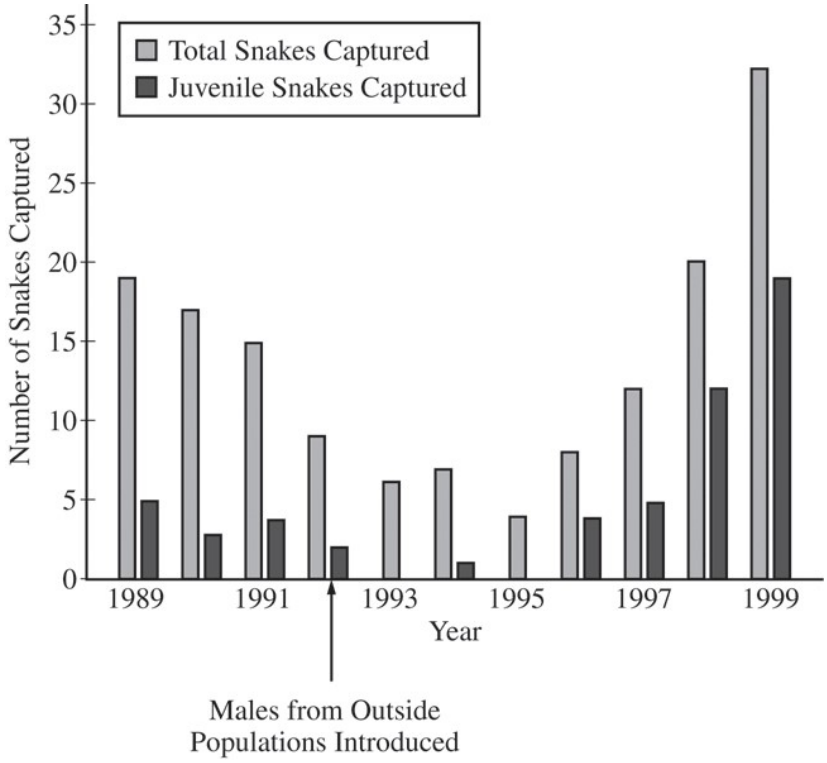
(b) In treatment groups IV and V, the tips of the plants are removed and placed back onto the shoot on either a permeable or impermeable barrier. Using the results from treatment groups IV and V, **describe** TWO additional characteristics of the phototropism response.



2015 #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 indicate 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.

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

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

2014 #3

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

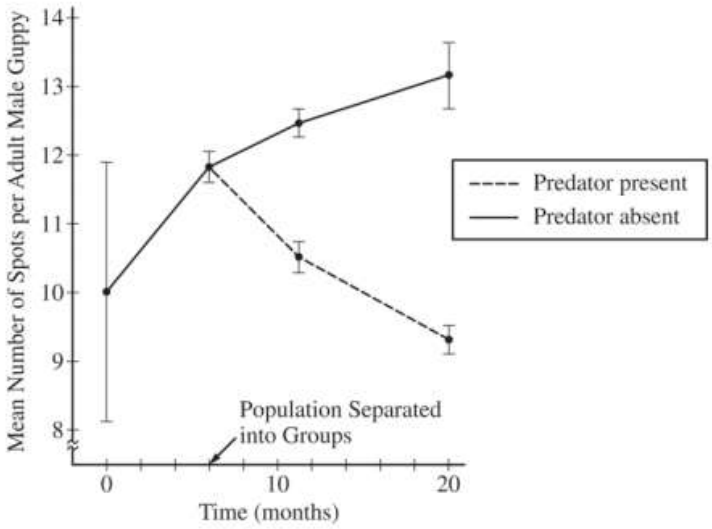
(a) **Predict** ONE ecological consequence on the local plant community that is likely to result during the site preparation and construction of the sports complex. **Justify** your predication.

(b) 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.

2014 #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 population 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 artifical 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.

(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.

(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.

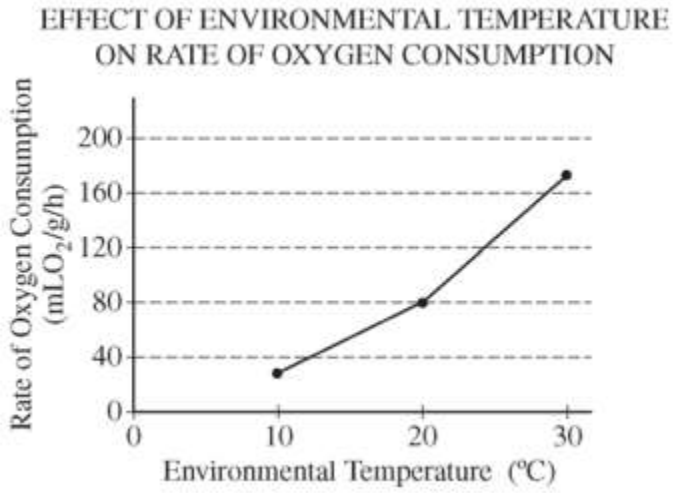
2014 #5

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

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

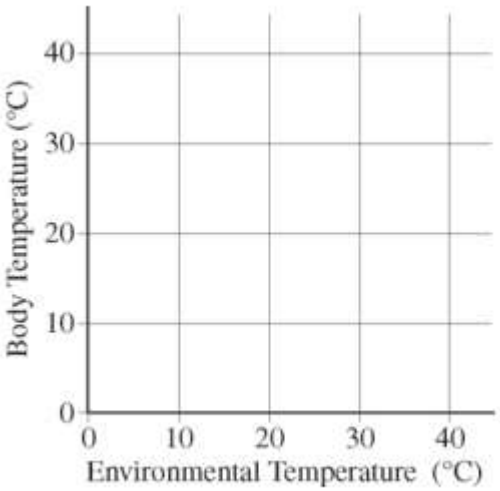
(b) For each of the risks you described in part (a), **propose** a practical approach for reducing the risk.

2014 #7

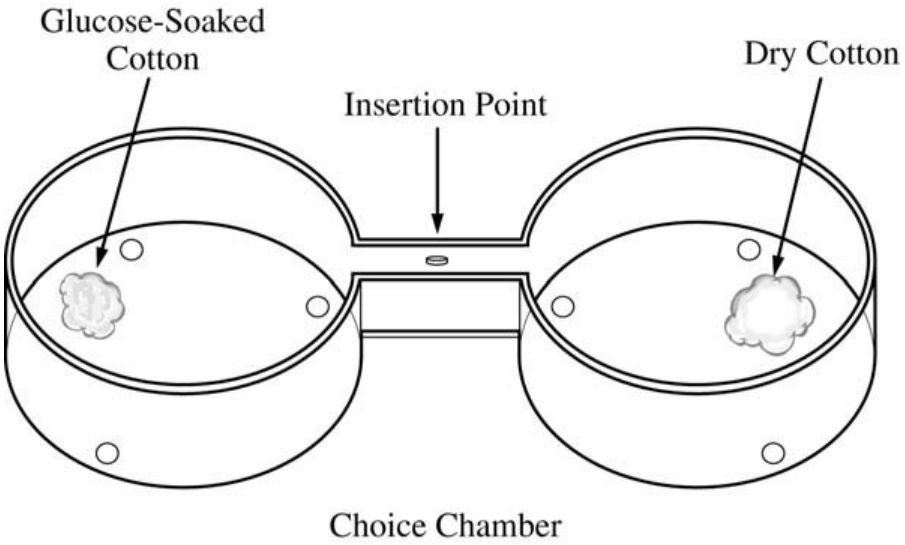


(a) Based on the graph, **describe** a specific method of thermoregulation used by the species of animal. **Provide** support for your answer using the data.

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



2013 #1



Choice Chamber

In an investigation of fruit-fly behavior, a covered choice chamber is used to test whether the spatial distribution of flies is affected by the presence of a substance placed at one end of the chamber. To test the flies' preference for glucose, 60 flies are introduced into the middle of the choice chamber at the insertion point indicated by the arrow in the figure above. A cotton ball soaked with a 10% glucose solution is placed at one end of the chamber, and a dry cotton ball with no solution is placed at the other end. The positions of flies are observed and recorded every minute for 10 minutes.

(a) **Predict** the distribution of flies in the chamber after 10 minutes and **justify** your prediction.

(b) **Propose** ONE specific improvement to each of the following parts of the experimental design and **explain** how the modification will affect the experiment.

- Experimental control
- Environmental factors

(c) The experiment described above is repeated with ripe bananas at one end and unripe bananas at the other end. Once again the positions of the flies are observed and recorded every minute for 10 minutes. The positions of flies after 1 minute and after 10 minutes are shown in the table below.

DISTRIBUTION OF FLIES IN CHOICE CHAMBER

Time (minutes)	Position in Chamber		
	End with Ripe Banana	Middle	End with Unripe Banana
1	21	18	21
10	45	3	12

Perform a chi-square test on the data for the 10-minute time point in the banana experiment. Specify the null hypothesis that you are testing and **enter** the values from your calculations in the table below.

(d) **Explain** whether your hypothesis is supported by the chi-square test and **justify** your explanation.

(e) Briefly **propose** a model that describes how environmental cues affect the behavior of the flies in the choice chamber.

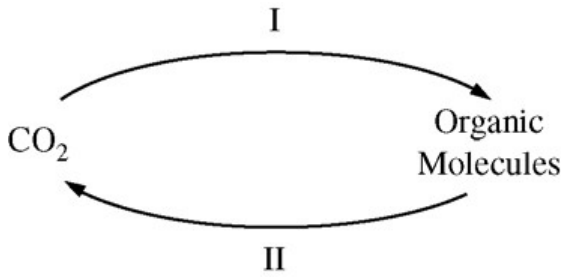
PART (C): CHI-SQUARE CALCULATIONS

Null Hypothesis:

	Observed (o)	Expected (e)	$(o-e)^2/e$
End with ripe banana			
Middle			
End with unripe banana			
Total			

2013 #4

Matter continuously cycles through an ecosystem. A simplified carbon cycle is depicted below.



(a) **Identify** the key metabolic process for step I and the key metabolic process for step II, and briefly **explain** how each process promotes movement of carbon through the cycle. For each process, your explanation should focus on the role of energy in the movement of carbon.

(b) **Identify** an organism that carries out both processes.

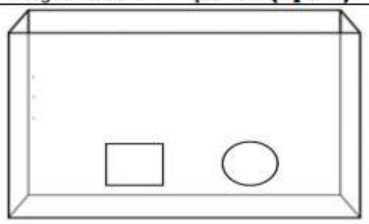
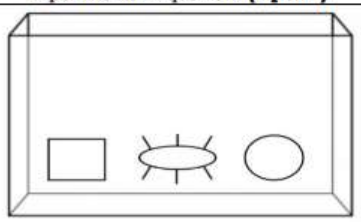
Free Response Scoring Guidelines

2019 #1		
Part	Scoring Guidelines	Topic
(a)	**Circle (1 point)** • Circle around either arrow pointing from a gene (*Trp-T* or *YUC*) to mRNA **Identification (1 point)** • IAA	6.3
(b)	**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.	6.3
(c)	**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.	6.3
(d)	**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).	8.5
(e)	**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)	7.2

2019 #2		
Part	Scoring Guidelines	Topic
(a)	**Completion (3 points)** • Correctly plotted lines for remaining two treatments • Correctly labeled axes including units • Correctly labeled data lines	
(b)	**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.	8.3

(c)	**Evidence (1 point per row; 2 points max.)** <table><tr><th>Comparison of Groups</th><th>Evidence</th></tr><tr><td>I-A to II-A</td><td>• Growth rate is faster in I/slower in II</td></tr><tr><td>I-A to II-A</td><td>• Grows to a higher population density in I/lower population density in II</td></tr><tr><td>I-B to II-B</td><td>• Growth rate is faster in I/slower in II</td></tr><tr><td>I-B to II-B</td><td>• Grows to a higher population density in I/lower population density in II/ II dies out/II goes to zero</td></tr></table>	8.4
(d)	**Prediction (2 points)** Acceptable factors include: • Food • Space • Metabolic waste • Dissolved oxygen	8.5
(e)	**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.	2.8

2018 #3

Part	Scoring Guidelines	Topic
(a)	**Drawing (2 points)** <table><tr><th>Negative Control Aquarium **(1 point)**</th><th>Experimental Aquarium **(1 point)**</th></tr><tr><td>  </td><td>  </td></tr></table>	8.6
(b)	<table><tr><th>**Identification (1 point maximum)**</th><th>**Prediction (1 point maximum)**</th></tr><tr><td>Number/presence of pollen grains on female flowers OR pollination</td><td>More pollen grains transferred/pollination seen in experimental aquarium</td></tr><tr><td>Number/presence of fertilized plants/flowers OR fertilization</td><td>More fertilized plants/flowers/fertilization seen in experimental aquarium</td></tr><tr><td>Number/presence of seed/fruit/offspring produced OR reproduction</td><td>More seeds/fruits/offspring produced/reproduction in experimental aquarium</td></tr></table>	8.6

2018 #5

Part	Scoring Guidelines	Topic
(a)	**Description (1 point)** • Cuckoos are parasites (of the warbler). • The cuckoo benefits from the relationship, and the warbler is harmed by the relationship.	8.5

(b)	**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.	8.5
(c)	**Identification (1 point)** • Mutualism • Both organisms benefit	8.5

2018 #7		
Part	Scoring Guidelines	Topic
(a)	**Prediction (1 point)** 75%	5.4
(b)	**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.	8.1

2017 #1		
Part	Scoring Guidelines	Topic
(a)	**Construct graph (3 points)** • Correctly plotted means on a bar graph/modified bar graph • Appropriate labels, units, and scaling • Correctly plotted error bars	8.1
(b)	**Description (2 points)** Short-term: Caffeine does not affect short-term memory/memory at 10 minutes. Long-term: Caffeine improves/increases the long-term memory/memory at 24 hours.	8.1
(c)	**Identification (3 points; 1 point per row)** Null hypothesis: Increasing caffeine concentration has no effect (on the number of floral visits by bees). Control: (Nectar/flowers with) no caffeine Predicted results: • The number of floral visits by bees is different at increasing caffeine concentrations. • The number of floral visits by bees is different than the control.	8.1
(d)	**Proposed plant benefit (1 point)** • More pollen is transferred/more visits by pollinators. • Plants store energy/have more energy available for other uses. **Proposed bee cost (1 point)** • (Individual) bees visit more flowers. • (Individual) bees use more energy. • The colony/bees may produce less honey • The colony/bees may produce lower quality honey/honey that provides less energy.	8.1

2017 #2

Part	Scoring Guidelines	Topic
(a)	**Provide support** using data from Figure 1 for each of the researchers' claims. **(4 points)**	3.7
(b)		005
(c)		8.5

Provide support using data from Figure 1 for each of the researchers' claims. **(4 points)**

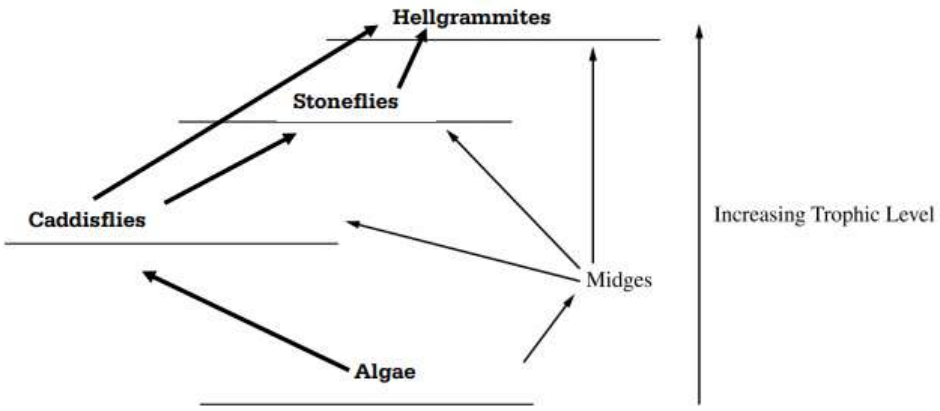
Claim	Support (1 point each row; 4 points maximum)
KAR affects timing	• germination starts earlier/sooner/faster/quicker
KAR affects percentage	• higher percentage of seeds germinate in the presence of only KAR
TMB affects timing	• germination starts later/slower
TMB affects percentage	• lower percentage of seeds germinate in presence of only TMB

Claim (2 points maximum; 1 point for KAR; 1 for TMB)	Support (2 points maximum; 1 point for KAR; 1 for TMB)				
• KAR remains (bound after rinsing) • Rinsing does not affect KAR (binding)	KAR with no rinse	KAR with rinse	different than	Controls	
	Group 2	Group 5		Group 1	Group 4
• TMB does not remain (bound) • Rinsing affects TMB (binding)	TMB with no rinse		different than	Control	
	Group 3			Group 1	
	TMB with rinse		same as	Control	
	Group 6			Group 4	

Description (1 point per row; 2 points maximum)	
Advantage of KAR regulation	• Germination occurs at times of increased resources availability. • Plants with KAR regulation can outcompete other plants (without KAR regulation). • Germination occurs when fewer competitors are present/land is barren.
Advantage of TMB regulation	• Plants with TMB regulation do not germinate/can maintain seed dormancy until (enough) water is available. • Plants with TMB regulation do not germinate in a dry environment.

2017 #4

Part	Scoring Guidelines	Topic
(a)	**Construction of food web (2 points maximum)** • All four organisms placed on the appropriate lines • All four arrows correctly drawn between organisms	8.2 8.5



(b)	**Prediction (1 point)** • Stoneflies **Justification (1 point)** • Stoneflies have a higher dependence on the midges than do the hellgrammites and caddisflies. • Midges are 90 percent of the stonefly diet, while 30 percent of the caddisfly and 10 percent of the hellgrammite diet are midges.	8.6

2016 #2		
Part	Scoring Guidelines	Topic
(a)	**Estimate (1 point)** • 10^8 **Description (1 point)** • When both nutrients are depleted	8.3
(b)	**Calculation (1 point)** • 4,995	8.3
(c)	**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.	8.3
(d)	**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.	8.1

2016 #3		
Part	Scoring Guidelines	Topic
(a)	**Identify direct source of energy (1 point)** • Seed • Stored organic nutrients/carbohydrates **Identify plant part (1 point)** • Roots	3.7
(b)	**Identification (1 point)** • Any value between 45-55 percent	3.7
(c)	**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.	7.1 8.2

2016 #5

Part	Scoring Guidelines	Topic
		8.5

	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.

2016 #8

Part	Scoring Guidelines	Topic
(a)	**Justification (1 point)** • Attribute changes in the concentration of blood prolactin to exercise only • Rule out normal fluctuations in prolactin release/levels	8.1
(b)	**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 $\pm 2SE_{\bar{x}}$.	8.1

2015 #1

Part	Scoring Guidelines	Topic
(a)		005

	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)	**Description (1 point)** • Active during dark phase AND inactive during light phase • Active ONLY during the dark period • Inactive ONLY during the light period	8.1
(c)	**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)	<table><tr><th>Conditions</th><th>**Predicted Activity Pattern (1 point per box; 2 points maximum)**</th></tr><tr><td>Mutant under L12:D12</td><td>Normal rhythm/rhythm similar to wild-type mouse under L12:D12 (Figure 2)</td></tr><tr><td>Mutant under DD</td><td>• Random activity throughout the 24 hour period • No pattern/rhythm • Constantly active/constantly inactive</td></tr></table>	
(e)	<table><tr><th></th><th>**Description (1 point per box; 2 points maximum)**</th></tr><tr><td>Selective Advantage</td><td>• 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</td></tr><tr><td>Reproductive Success</td><td>• Mice selected for produce more offspring • Mice selected against produce fewer offspring</td></tr></table>	7.1

2015 #5		
Part	**Scoring Guidelines**	**Topic**
(a)	**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.	8.1
(b)	**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	8.1

2015 #6		
Part	**Scoring Guidelines**	**Topic**
(a)	**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	8.3
(b)	**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	8.3 8.7
(c)	**Description (1 point)** • Population can/does grow • If resources are limited population would not grow	8.4

2014 #3

Part	Scoring Guidelines	Topic
(a)	See table below	8.6 8.7
(b)	See table below	8.6 8.7

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

Predicted consequence on animal community **(1 point)**	Justification of prediction **(1 point)**
Harm / Death 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 #4

Part	Scoring Guidelines	Topic
(a)	See table below	7.1
(b)	• Sexual selection for individuals with more spots • Random mating behavior resulted in increased number of spots by chance	8.1
(c)	• 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	7.5

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

2014 #5

Part	Scoring Guidelines	Topic
		6.8 7.3 8.7

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.

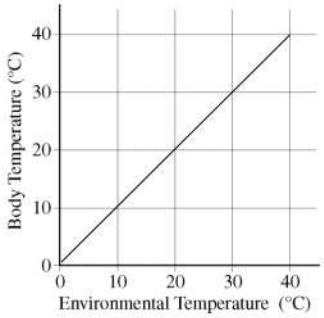
+Mitigation must be practical for the risk given.

2014 #7

Part	Scoring Guidelines	Topic
(a)		8.1

Describe method (**1 point**)	Support (**1 point**)
This species is an ectotherm/incapable of endoregulation	• Increased metabolic rate/O_2 consumption rate/respiration rate with increased temperature • Decreased metabolic rate/O_2 consumption rate/respiration rate with decreased temperature • If the animal were endothermic, O_2 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/O_2 consumption rate/respiration rate with increased temperature • Decreased metabolic rate/O_2 consumption rate/respiration rate with decreased temperature • This species is ectothermic/incapable of endoregulation

(b) 8.1



- Line/curve with positive slope

2013 #1

(a)

- 1 point for predicting the location of the flies in the choice chamber
- 1 point for justifying the prediction

Topic: 8.1

(b)

	Proposed Improvement (includes but not limited to) **(1 point maximum)**	Explanation **(1 point maximum)**
Experimental control	Replace the dry cotton ball with a water-soaked cotton ball.	Ensures that glucose is the attractant
	Constant light or temperature or duration of experiment or time of day, etc.	Other variables must be held constant

	Proposed Improvement (includes but not limited to) **(1 point maximum)**	Explanation **(1 point maximum)**
Environmental factors	• Use different concentrations of glucose • Use different temperature(s) • Use different light levels • Use a different choice chamber (size/shape) • Vary duration of the experiment • Vary time of day when experiment is performed	Attributes movement of flies only to glucose preference

Topic: 8.1

(c)

PART (c): CHI-SQUARE CALCULATION

Null Hypothesis: **(1 point)**
The flies will be evenly distributed across the three different parts of the choice chamber.

	Observed (o)	Expected (e)* **(1 point)**	$(o - e)^2/e$
End with ripe banana	45	20	31.25
Middle	3	20	14.45
End with unripe banana	12	20	3.2
Total	60	60	48.9

*Expected values must be those predicted by the null hypothesis provided in the student response, add up to 60, and include no cells equal to 0.

Topic: 8.1

(d)

- Correct explanation with justification of why the stated null hypothesis is rejected or not rejected. Response must clarify each of the following:
  - degrees of freedom (df) = 2 and p = 0.05 (critical value = 5.99)
    OR
    degrees of freedom (df) = 2 and p = 0.01 (critical value = 9.21)
  - how the calculated test statistic compares to the selected critical value
  - whether the null hypothesis should be rejected

Topic: 8.1

(e)

- Stimulus → Response
- Input →(possible integration) →Output

Topic: 8.1

2013 #4

<table>
<tr><th>Part</th><th>Scoring Guidelines</th><th>Topic</th></tr>
<tr><td>(a)</td><td>
Identification: 1 point maximum
I = photosynthesis / Calvin cycle
AND
II = (cellular) respiration / citric acid cycle / Krebs cycle

Explanation: 1 point each row; 2 points maximum
<table>
<tr><td>Process</td><td>Carbon Input</td><td>Role of Energy in the Movement of Carbon</td><td>Carbon Output</td></tr>
<tr><td>Photosynthesis</td><td>CO_2 is fixed</td><td>Uses (light) energy OR ATP from light reactions</td><td>Organic molecules</td></tr>
<tr><td>(Cellular) Respiration</td><td>Organic molecules are hydrolyzed / broken down</td><td>Uses energy for cellular processes such as growth and /or ATP production</td><td>CO_2</td></tr>
</table>
</td><td>3.5
3.6</td></tr>
<tr><td>(b)</td><td>
• Plant
• Algae
• Photosynthetic protist (e.g., Euglena)
• Cyanobacterium
• CO_2 fixing bacterium
• Lichen (not fungus)
</td><td>8.2</td></tr>
</table>