

Supplemental Material

CBE—Life Sciences Education

Cary *et al.*

FIVE CORE CONCEPTS IN BIOLOGY

The core concepts listed below are major conceptual themes in biology, all of which overlap, interweave, and influence each other to form the principles that guide biological life. They are:

1. **Evolution (E)** - The diversity of life is a result of the processes of mutation, natural selection, and genetic change over time.
2. **Structure and function (SF)** – A structure of biological entities (molecules, genes, cells, tissues, organs, individuals, and ecosystems) is comprised of basic physical and chemical units that influence the interactions with other structures, thereby defining the function of all living things.
3. **Information flow, exchange, and storage (IFES)** – The growth and behavior of organisms are activated through the expression of genetic information in context. Information is transferred within cells, between cells, between organisms, and from one generation to the next.
4. **Pathways and transformations of energy and matter (PTEM)** – Energy and matter cannot be created nor destroyed, but can be changed from one form to another. Biological systems grow and change by processes based upon chemical transformation pathways and are governed by the laws of thermodynamics. Energy can be transformed within cells, between cells, or between the cell, the organism, and the environment.
5. **Systems (S)** – Biological entities (molecules, genes, cells, tissues, organs, individuals, and ecosystems) are interconnected and interact to form complex networks. This network is dynamic, and a change in one component of the network can affect many other components.

Antibiotic Resistance

Please read the narrative provided below. As you read, think about the core concepts in biology and how each one is represented in this example of antibiotic resistance.

To combat bacterial infections, humans are typically prescribed antibiotics. An antibiotic is a substance commonly produced by a microorganism that is harmful to the growth of a bacterium. The bacterium *Enterococcus faecium* is a common cause of urinary tract infections, diverticulitis, and meningitis in humans. *E. faecium* are damaging to human cells because they produce enzymes which break down cellular DNA and various cellular structural components, eventually leading to destruction of the cells.

One antibiotic used to treat *E. faecium* infections is vancomycin, a naturally occurring antibiotic made by a bacterial species found in soil. Vancomycin prevents the reinforcement of the bacterial cell wall. Bacterial cell walls are made up of a series of peptide chains that bind to one another (crosslink), to reinforce the cell wall during formation. The crosslinking occurs between the alanine residues found on the end of the bacterial peptide chains. The antibiotic vancomycin is effective because it can bind the alanine residues and prevent this crosslinking from occurring. Without the proper cross-linked reinforcements, the cell wall of the bacterium is compromised and the cell bursts and dies.

Unfortunately, within 50 years of its discovery, the antibiotic vancomycin was no longer effective against some *E. faecium* bacterial populations. These bacteria were considered “antibiotic resistant.” In these resistant populations, one of the residues on the peptide chain had changed from alanine to lactate through a series of random mutations. Despite the change in the residues, normal crosslinking could still occur to reinforce the cell wall. However, the change did mean the antibiotic could no longer bind and interfere with cell wall formation, and the bacterium was not affected by the antibiotic. This antibiotic-resistant bacterial population was then able to survive exposure to vancomycin, replicate quicker than its antibiotic-sensitive neighbors, and could propagate the antibiotic resistance gene throughout the bacterial population. Scientists are now looking for new antibiotics to treat *E. faecium* bacterial infections.

As an example, the core concept *Evolution* is represented in antibiotic resistance because the presence of antibiotics creates a selective pressure on bacteria. Bacteria that have antibiotic resistance have increased survival and are able to reproduce and pass on their genetic code, such that over time, the bacterial population becomes resistant to antibiotics.

AR.1 (5 pts) Another core concept represented in antibiotic resistance is *Information flow, exchange and storage (IFES)*. As was done with evolution above, briefly describe how *IFES* is represented in antibiotic resistance (1-2 sentences).

AR.2 (15 pts) True/False statements. Indicate whether each statement is true or false. Regardless of whether the statement is T or F, circle all of the core concept(s) represented in the statement: *Evolution (E)*, *Information flow, exchange, and storage (IFES)*, or *Both*.

Circle:		Circle one or both core concepts represented in the TF statement
T or F	Bacteria have a high replication rate, which may lead to increased mutations and an increased likelihood of an antibiotic resistant population occurring.	E IFES
T or F	The presence of antibiotics places a selective pressure on the bacterial population, such that bacteria with genes containing beneficial mutations are favored.	E IFES
T or F	The altered peptide residues produced by the bacteria store information that cause antibiotic resistance.	E IFES

T or F	Bacterial cells share signals with their neighbors instructing them how to switch peptide residues in order to develop antibiotic resistance and pass this trait onto their offspring.	E IFES
T or F	Bacterial populations purposefully adapt to escape damage by antibiotics.	E IFES

AR.3 (5 pts) Another core concept represented in antibiotic resistance is *Structure & Function*. As you did above for *Information flow, exchange and storage*, briefly describe how *Structure & Function* is represented in antibiotic resistance (1-2 sentences).

AR.4 (15 pts) True/False statements. Indicate whether each statement is true or false. Regardless of whether the statement is T or F, circle all of the core concept(s) represented in the statement: *Evolution (E)*, *Structure & Function (SF)*, or *Both*.

Circle:		Circle one or both core concepts represented in the TF statement
T or F	Even if the peptide chains cannot form cross-links, an antibiotic-resistant bacterium can successfully reproduce, passing along its resistance trait, if it has peptide chain structures that do not bind to the antibiotic.	E SF
T or F	The version of the gene that conferred resistance to vancomycin was already present in the bacterial population before the bacteria were exposed to vancomycin.	E SF
T or F	One way for a new antibiotic to be effective at killing the bacteria, would be to have a structure that binds to the peptide chain lactate residues.	E SF
T or F	The altered peptide residues are able to make cross-links that strengthen the cell wall, which confers greater survival and reproduction in the presence of the antibiotic.	E SF
T or F	Individual bacteria gradually develop altered peptides to evade the antibiotic in order to survive and reproduce.	E SF

AR.5 (5 pts) You have already provided descriptions above for how *Information Flow, Storage and Exchange (IFES)* and *Structure & Function* are independently represented in the antibiotic resistance scenario. Now, briefly describe the relationship between these two concepts (how are they connected?) in the antibiotic resistance scenario (1-2 sentences).

Antibiotic Resistance
ANSWER KEY & TABLE OF SPECIFICATIONS

AR.1 (5 pts) Another core concept represented in antibiotic resistance is *Information flow, exchange and storage (IFES)*. As was done with evolution above, briefly describe how *IFES* is represented in antibiotic resistance (1-2 sentences).

Use CE Framework to categorize and award points.

Criteria for Awarding Points	Total
2 pts – Identify one Conceptual Element	
1 pt – Identify a second Conceptual Element	5 pts
1 pt – Identify a third Conceptual Element	
1 pt – Quality of Response	

AR.2 (15 pts) True/False statements. Indicate whether each statement is true or false. Regardless of whether the statement is T or F, circle all of the core concept(s) represented in the statement: *Evolution (E)*, *Information flow, exchange, and storage (IFES)*, or *Both*.

Circle:		Circle one or both core concepts represented in the TF statement
<u>T</u> or F	Bacteria have a high replication rate, which may lead to increased mutations and an increased likelihood of an antibiotic resistant population occurring. (E3, IFES5)	<u>E</u> IFES
<u>T</u> or F	The presence of antibiotics places a selective pressure on the bacterial population, such that bacteria with genes containing beneficial mutations are favored. (E4, E5, IFES3)	<u>E</u> IFES
T or <u>F</u>	The altered peptide residues produced by the bacteria store information that cause antibiotic resistance. (IFES2)	E IFES
T or <u>F</u>	Bacterial cells share signals with their neighbors instructing them how to switch peptide residues in order to develop antibiotic resistance and pass this trait onto their offspring. (E2, E5, IFES1)	<u>E</u> IFES
T or <u>F</u>	Bacterial populations purposefully adapt to escape damage by antibiotics. (E6)	<u>E</u> IFES

AR.3 (5 pts) Another core concept represented in antibiotic resistance is *Structure & Function*. As you did above for *Information flow, exchange and storage*, briefly describe how *Structure & Function* is represented in antibiotic resistance (1-2 sentences).

Use CE Framework to categorize and award points.

Criteria for Awarding Points	Total
2 pts – Identify one Conceptual Element	
1 pt – Identify a second Conceptual Element	5 pts
1 pt – Identify a third Conceptual Element	
1 pt – Quality of Response	

AR.4 (15 pts) True/False statements. Indicate whether each statement is true or false. Regardless of whether the statement is T or F, circle all of the core concept(s) represented in the statement: *Evolution (E)*, *Structure & Function (SF)*, or *Both*.

Circle:		Circle one or both core concepts represented in the TF statement
T or <u>F</u>	Even if the peptide chains cannot form cross-links, an antibiotic-resistant bacterium can successfully reproduce, passing along its resistance trait, if it has peptide chain structures that do not bind to the antibiotic. (E5, SF1)	<u>E</u> SF
<u>I</u> or F	The version of the gene that conferred resistance to vancomycin was already present in the bacterial population before the bacteria were exposed to vancomycin. (E3)	<u>E</u> SF
<u>I</u> or F	One way for a new antibiotic to be effective at killing the bacteria, would be to have a structure that binds to the peptide chain lactate residues. (SF1)	E SF
<u>I</u> or F	The altered peptide residues are able to make cross-links that strengthen the cell wall, which confers greater survival and reproduction in the presence of the antibiotic. (E5, SF1)	<u>E</u> SF
T or <u>F</u>	Individual bacteria gradually develop altered peptides to evade the antibiotic in order to survive and reproduce. (E3, E4, E5, SF1)	<u>E</u> SF

AR.5 (5 pts) You have already provided descriptions above for how Information Flow, Storage and Exchange (IFES) and Structure & Function are independently represented in the antibiotic resistance scenario. Now, briefly describe the relationship between these two concepts (how are they connected?) in the antibiotic resistance scenario (1-2 sentences).

- | Criteria for Awarding Points | Total |
|---|-------|
| 1 pts – Make connection between CC2 & CC3 | |
| 1 pt – Describe CC2 | |
| 1 pt – Describe CC3 | 5 pts |
| 1 pt – Quality of Response | |

Antibiotic Resistance Table of Specifications	Open-ended questions		TF/I Questions
	Apply	Connect	Apply/Identify
Evolution (E)	given		
E2: The phenotypes of living organisms result from the gain and loss of traits along their lineage.			1
E3: Genetic variation within a population can be generated by mutation, which results in the generation of novel traits, and by sexual recombination, endosymbiosis and horizontal gene transfer.			3
E4: Phenotypes, based upon underlying genotypes and environmental factors, can be subject to selective pressure.			2
E5: Organisms have greater fitness if they have a phenotype that increases their ability to survive and reproduce in a particular environment.			4
E6: Populations are composed of individual organisms that vary in their fitness, leading to differential rates of survival and reproduction and therefore changes in allele frequency over time.			1
Information Flow, Exchange and Storage (IFES)	1	Connect	
IFES1: Information exists in many forms and is relayed within		IFES & SF	1

and across biological molecules, cells, tissues, organisms, populations and ecosystems.		1	
IFES2: Genetic information is stored in nucleic acids (DNA and RNA); epigenetic information is stored in proteins that associate with DNA and in reversible DNA modifications.			1
IFES3: The process of protein synthesis results from the flow of genetic information through various pathways.			1
IFES5: Organisms transmit genes and epigenetic information to their offspring.			1
Structure and Function (S&F)	1		
SF1: Biological structures from the molecular to the ecosystem scale and their interactions are determined by chemical and physical properties that both enable and constrain function.			4

FIVE CORE CONCEPTS IN BIOLOGY

The core concepts listed below are major conceptual themes in biology, all of which overlap, interweave, and influence each other to form the principles that guide biological life. They are:

1. **Evolution (E)** - The diversity of life is a result of the processes of mutation, natural selection, and genetic change over time.
2. **Structure and function (SF)** – A structure of biological entities (molecules, genes, cells, tissues, organs, individuals, and ecosystems) is comprised of basic physical and chemical units that influence the interactions with other structures, thereby defining the function of all living things.
3. **Information flow, exchange, and storage (IFES)** – The growth and behavior of organisms are activated through the expression of genetic information in context. Information is transferred within cells, between cells, between organisms, and from one generation to the next.
4. **Pathways and transformations of energy and matter (PTEM)** – Energy and matter cannot be created nor destroyed, but can be changed from one form to another. Biological systems grow and change by processes based upon chemical transformation pathways and are governed by the laws of thermodynamics. Energy can be transformed within cells, between cells, or between the cell, the organism, and the environment.
5. **Systems (S)** – Biological entities (molecules, genes, cells, tissues, organs, individuals, and ecosystems) are interconnected and interact to form complex networks. This network is dynamic, and a change in one component of the network can affect many other components.

Galápagos Finches

Please read the narrative provided below. As you read, think about the core concepts in biology and how each one is represented in this description of finches that live on the Galápagos Islands.

The ecologists Peter and Rosemary Grant have spent part of each year since 1973 on Daphne Major, a tiny, barren volcanic island in the Galápagos. They have caught, weighed, measured, and identified hundreds of the Galápagos finches on the island and recorded their diets of seeds in order to learn more about them. Galápagos finches are small song birds that have adaptations, which allow them to survive on these islands. Daphne Major, has a population of medium ground finches (*Geospiza fortis*) which vary in beak size among individuals. This variation ranges from large, strong beaks that are able to crack large, tough seeds to smaller, pointy beaks that are able to crack smaller, softer seeds. However, weather conditions can dramatically influence the population's average beak size. For example, when food is abundant, the average population beak size tends to be smaller as the birds thrive on smaller, softer seeds. But the drought of 1977 caused small seeds to become less abundant. The ground finches with larger, stronger beaks were able to consume the larger, tough seeds that were still available. Because of this, they survived and were able to reproduce passing along their genetic code so that their offspring also had large beaks. Fewer small-beaked ground finches survived because they could not feed on the large seeds, which resulted in fewer small-beaked ground finches able to reproduce and pass along their genetic code. Over a few generations, this resulted in a population of ground finches with average beak sizes 4% bigger than before the drought!

As an example, *Pathways and transformations of energy and matter* is represented in the Galápagos finch narrative, because the seeds are comprised of carbon-containing molecules that the birds use to make chemical energy needed to carry out life functions.

GF.1 (5 pts) Another core concept represented in the Galápagos finch narrative is *Evolution*. As was done with *Pathways and transformations of energy and matter* above, briefly describe how *Evolution* is represented in the Galápagos finch narrative (1-2 sentences).

GF.2 (15 pts) True/False statements. Indicate whether each statement is true or false. Regardless of whether the statement is T or F, circle all of the core concept(s) represented in the statement: *Pathways and Transformations of Energy and Matter (PTEM)* or *Evolution (E)* or *Both*.

Circle:		Circle one or both core concepts represented in the TF statement
T or F	Under the selective pressure of drought, finches that have larger, stronger beaks are able to reproduce when small seeds are limited compared to small-beaked finches.	PTEM E
T or F	Large seeds contain more nutrients than small seeds, so finches that can eat the large seeds will be better able to survive and reproduce than birds that eat small seeds regardless of drought conditions.	PTEM E
T or F	Genetic mutations allow finches to purposefully adapt to environmental conditions in order to metabolize their food resources.	PTEM E
T or F	In the presence of drought, individual finch adapted and gradually grew larger beaks in order to eat larger seeds and obtain more energy.	PTEM E
T or F	During times of drought, smaller beaked finches will spend more time looking for fewer seeds, resulting in a greater percentage of resources being used to obtain food.	PTEM E

GF.3 (5 pts) Another core concept represented in the Galápagos finch narrative is *Systems*. As you did above for *Evolution*, briefly describe how *Systems* is represented in the Galápagos finch narrative (1-2 sentences).

GF.4 (15 pts) True/False statements. Indicate whether each statement is true or false. Regardless of whether the statement is T or F, circle all of the core concept(s) represented in the statement: *Pathways and Transformations of Energy and Matter (PTEM)* or *Systems (S)* or *Both*.

Circle:		Circle one or both core concepts represented in the TF statement
T or F	Plants consume and store light energy. This light energy is then transformed in the finch to help the finch grow and reproduce.	PTEM S
T or F	Under non-drought conditions, the small beaked finch population increases to a relatively stable number of individuals.	PTEM S
T or F	With limited seeds, finches work together to find food and ensure that all finches are able to obtain nutrients for survival.	PTEM S
T or F	The amount of energy available per seed determines the total energy available to each finch.	PTEM S
T or F	Because these finches are seed eaters, if seeds become limited in abundance, individual finches must compete with each other to obtain enough energy to survive.	PTEM S

GF.5 (5 pts) You have already provided descriptions above for how *Evolution* and *Systems* are independently represented in the Galápagos Finch narrative. Now, briefly describe the relationship between these two concepts (how are they connected?) in the Galápagos Finch narrative (1-2 sentences).

Galápagos Finches
ANSWER KEY & TABLE OF SPECIFICATIONS

GF.1 (5 pts) Another core concept represented in the Galápagos finch narrative is *Evolution*. As was done with *Pathways and transformations of energy and matter* above, briefly describe how *Evolution* is represented in the Galápagos finch narrative (1-2 sentences).

Use CE Framework to categorize and award points.

Criteria for Awarding Points	Total
2 pts – Identify one Conceptual Element	
1 pt – Identify a second Conceptual Element	5 pts
1 pt – Identify a third Conceptual Element	
1 pt – Quality of Response	

GF.2 (15 pts) True/False statements. Indicate whether each statement is true or false. Regardless of whether the statement is T or F, circle all of the core concept(s) represented in the statement: *Pathways and Transformations of Energy and Matter (PTEM)* or *Evolution (E)* or *Both*.

Circle:		Circle one or both core concepts represented in the TF statement
<u>T</u> or F	Under the selective pressure of drought, finches that have larger, stronger beaks are able to reproduce when small seeds are limited compared to small-beaked finches. (E4, E5)	PTEM <u>E</u>
T or <u>E</u>	Large seeds contain more nutrients than small seeds, so finches that can eat the large seeds will be better able to survive and reproduce than birds that eat small seeds regardless of drought conditions. (PTEM2, E5)	<u>PTEM</u> <u>E</u>
T or <u>E</u>	Genetic mutations allow finches to purposefully adapt to environmental conditions in order to metabolize their food resources. (PTEM5, E3)	<u>PTEM</u> <u>E</u>
T or <u>E</u>	In the presence of drought, individual finch adapted and gradually grew larger beaks in order to eat larger seeds and obtain more energy. (PTEM2, E4, E5)	<u>PTEM</u> <u>E</u>
<u>T</u> or F	During times of drought, smaller beaked finches will spend more time looking for fewer seeds, resulting in a greater percentage of resources being used to obtain food. (PTEM5)	<u>PTEM</u> E

GF.3 (5 pts) Another core concept represented in the Galápagos finch narrative is *Systems*. As you did above for *Evolution*, briefly describe how *Systems* is represented in the Galápagos finch narrative (1-2 sentences).

Use CE Framework to categorize and award points.

Criteria for Awarding Points	Total
2 pts – Identify one Conceptual Element	
1 pt – Identify a second Conceptual Element	5 pts
1 pt – Identify a third Conceptual Element	
1 pt – Quality of Response	

GF.4 (15 pts) True/False statements. Indicate whether each statement is true or false. Regardless of whether the statement is T or F, circle all of the core concept(s) represented in the statement: *Pathways and Transformations of Energy and Matter (PTEM)* or *Systems (S)* or *Both*.

Circle:		Circle one or both core concepts represented in the TF statement
T or <u>F</u>	Plants consume and store light energy. This light energy is then transformed in the finch to help the finch grow and reproduce. (PTEM1, S1, S4)	PTEM S
<u>T</u> or F	Under non-drought conditions, the small beaked finch population increases to a relatively stable number of individuals. (S2, S4)	PTEM S
T or <u>F</u>	With limited seeds, finches work together to find food and ensure that all finches are able to obtain nutrients for survival. (PTEM2, S5)	PTEM S
T or <u>F</u>	The amount of energy available per seed determines the total energy available to each finch. (PTEM1, PTEM3)	PTEM S
<u>T</u> or F	Because these finches are seed eaters, if seeds become limited in abundance, individual finches must compete with each other to obtain enough energy to survive. (PTEM2, PTEM5, S2)	PTEM S

GF.5 (5 pts) You have already provided descriptions above for how *Evolution* and *Systems* are independently represented in the Galápagos Finch narrative. Now, briefly describe the relationship between these two concepts (how are they connected?) in the Galápagos Finch narrative (1-2 sentences).

Criteria for Awarding Points	Total
2 pts – Make connection between CC2 & CC3	
1 pt – Describe CC2	
1 pt – Describe CC3	5 pts
1 pt – Quality of Response	

Galápagos Finches Table of Specifications	Open-ended questions		TF/I questions
	Apply	Connect	Apply/Identify
Pathways and Transformations of Energy and Matter (PTEM)	given		
PTEM1: Energy is neither created nor destroyed, but can be transformed from one form to another to generate biological activity.			2
PTEM2: Input of energy, which can be from different sources, is needed to build and maintain biological entities, thereby lowering entropy in the system.			4
PTEM5: Biological entities regulate the synthesis, storage and mobilization of biological compounds to meet energy demands.			3
Evolution (E)	1		
E3: Genetic variation within a population can be generated by mutation, which results in the generation of novel traits, and by sexual recombination, endosymbiosis and horizontal gene transfer.		Connect E & S 1	1
E5: Organisms have greater fitness if they have a phenotype that increases their ability to survive and reproduce in a			3

particular environment.			
Systems (S)	1		
S1: Biological entities interact through chemical and physical signals that can be transient, depend on spatial organization, and are influenced by environmental factors.			1
S2: Changes in one component of a biological system can affect or be regulated by other components of the same system.			1
S4: Biological systems include and are affected by biotic and abiotic factors in the environment.			2
S5: Interactions between and among biological entities can generate new system properties.			1

FIVE CORE CONCEPTS IN BIOLOGY

The core concepts listed below are major conceptual themes in biology, all of which overlap, interweave, and influence each other to form the principles that guide biological life. They are:

1. **Evolution (E)** - The diversity of life is a result of the processes of mutation, natural selection, and genetic change over time.
2. **Structure and function (SF)** – A structure of biological entities (molecules, genes, cells, tissues, organs, individuals, and ecosystems) is comprised of basic physical and chemical units that influence the interactions with other structures, thereby defining the function of all living things.
3. **Information flow, exchange, and storage (IFES)** – The growth and behavior of organisms are activated through the expression of genetic information in context. Information is transferred within cells, between cells, between organisms, and from one generation to the next.
4. **Pathways and transformations of energy and matter (PTEM)** – Energy and matter cannot be created nor destroyed, but can be changed from one form to another. Biological systems grow and change by processes based upon chemical transformation pathways and are governed by the laws of thermodynamics. Energy can be transformed within cells, between cells, or between the cell, the organism, and the environment.
5. **Systems (S)** – Biological entities (molecules, genes, cells, tissues, organs, individuals, and ecosystems) are interconnected and interact to form complex networks. This network is dynamic, and a change in one component of the network can affect many other components.

Recombinant Humulin

Please read the narrative provided. As you look over the materials, think about the core concepts and how each one is represented in the recombinant production of humulin narrative.

In humans, glucose is the primary molecule broken down by cells to generate energy required for fueling cellular processes. Glucose is maintained at relatively constant levels in the blood by a group of hormones (chemical messengers that travel in the blood). One of these hormones, insulin, regulates the uptake of glucose into cells where it can be processed into energy. Consequently, insulin is essential for a cell to match energy production with the energy demands necessary for survival.

Insulin is a peptide hormone produced in the pancreas and is released into the blood when blood glucose levels increase, which typically occurs following meals when food is digested and glucose is released into the bloodstream. Because glucose is a large molecule that cannot readily cross the cell membrane, a transport protein is necessary to aid movement of glucose into the cell. Insulin regulates the uptake of glucose into cells by altering the concentration of glucose transport proteins located in the cell membrane. When insulin binds to an insulin receptor on the surface of the cell, it triggers recruitment of glucose transport proteins to the cell membrane. The increased concentration of transport proteins in the cell membrane increases glucose movement into the cell. Once inside the cell, glucose is metabolized via cellular respiration to generate energy (or is converted to glycogen for storage and use at a later time).

Loss of pancreatic beta cell function, and therefore insulin secretion, results in Type 1 diabetes. For many decades the only treatment for Type 1 diabetes was injections of insulin harvested from cow, pig or horse pancreas. Because those forms of insulin were not identical to human insulin some patients developed immune reactions, rendering the insulin less effective. Today, the standard treatment for Type 1 diabetes is humulin, a form of human insulin produced through the use of recombinant DNA technology. To produce humulin, human DNA that codes for insulin is inserted into a plasmid (a small circular piece of DNA) and the plasmid is inserted into a bacterial cell. The plasmid is replicated inside the bacterial cell and many copies of both the plasmid DNA and the inserted gene for insulin are produced. The bacteria generate insulin protein from the human genetic code using their own bacterial protein manufacturing machinery. Scientists then isolate the human insulin from the bacterial cultures, and purify the protein, which is now designated humulin and can be used for treatment of Type 1 diabetes.

As an example, *Structure and function* is represented in recombinant humulin because the structure of the nucleic acids in bacterial DNA are the same as that of human DNA. This similarity allows for bacteria to generate protein (i.e., insulin) from the human DNA.

RH.1 (5 pts) Another core concept represented in recombinant humulin production is *Information flow, exchange and storage (IFES)*. As was done with *Structure and function* above, in 1-2 sentences, describe how *IFES* is represented in humulin production.

RH.2 (15 pts) True/False statements: Determine whether each statement is true or false. Regardless of whether the statement is T or F, determine which core concept(s) is represented in each statement: *Structure and Function (SF)*, *Information Flow, exchange, and storage (IFES)*, or *Both*

Circle:		Circle one or both core concepts represented in the TF statement
T or F	DNA is the heritable material in both humans and bacteria, and the process of DNA replication for both species is initiated by proteins that recognize specific DNA sequences.	SF IFES
T or F	Glucose levels in the blood are relatively constant, indicating that insulin release from the pancreas is also constant.	SF IFES

T or F	If a human gene can produce a protein product in a bacterial cell; it must also be true that a bacterial gene inserted into human DNA code could produce a protein product in a human cell.	SF	IFES
T or F	To produce human insulin the cellular machinery for making human DNA into human protein must also be added to the bacteria.	SF	IFES
T or F	Humulin activates the insulin receptor in humans because its structure is the same as insulin produced in the human body.	SF	IFES

RH.3 (5 pts) Another core concept represented in recombinant humulin is *Pathways and Transformations of Energy and Matter (PTEM)*. As you did above for *IFES*, describe how *PTEM* is represented in the recombinant humulin narrative.

RH.4 (15 pts) True/False statements: Determine whether each statement is true or false. Regardless of whether the statement is T or F, determine which core concept(s) is represented in each statement: *Structure and Function (SF)*, *Pathways and Transformations of Energy and Matter (PTEM)*, or *Both*

Circle:		Circle one or both core concepts represented in each TF statement	
T or F	Following a meal, without insulin, glucose levels in the blood increase because glucose is unable to enter cells.	SF	PTEM
T or F	Because humulin has a different molecular structure than insulin, humulin binding to the insulin receptor results in a decreased rate of glucose metabolism in the cell.	SF	PTEM
T or F	When a cell breaks down glycogen to release glucose, the glucose is able to readily pass out of the cell.	SF	PTEM
T or F	Theoretically, if a person with Type 1 diabetes receives a transplant of healthy, insulin-secreting cells, they would no longer need to take humulin to regulate glucose uptake.	SF	PTEM
T or F	When organisms are not eating, cells cease metabolism to conserve energy.	SF	PTEM

RH.5 (5 pts) You have already provided descriptions above for how *Information Flow, Storage and Exchange (IFES)* and *Pathways and Transformations of Energy and Matter (PTEM)* are independently represented in the humulin production narrative. Now, briefly describe the relationship between these two concepts (how are they connected?) in the recombinant humulin production scenario (1-2 sentences).

Recombinant Humulin
ANSWER KEY & TABLE OF SPECIFICATIONS

RH.1 (5 Pts) Another core concept represented in recombinant humulin production is *Information flow, exchange and storage (IFES)*. As was done with *Structure and function* above, in 1-2 sentences, describe how *IFES* is represented in humulin production.

Use CE Framework to categorize and award points.

Criteria for Awarding Points	Total
2 pts – Identify one Conceptual Element	
1 pt – Identify a second Conceptual Element	
1 pt – Identify a third Conceptual Element	5 pts
1 pt – Quality of Response	

RH.2 (15 pts) True/False statements: Determine whether each statement is true or false. Regardless of whether the statement is T or F, determine which core concept(s) is represented in each statement: *Structure and Function (SF)*, *Information Flow, exchange, and storage (IFES)*, or *Both*

Circle:		Circle one or both core concepts represented in the TF statement
<u>I</u> or F	DNA is the heritable material in both humans and bacteria, and the process of DNA replication for both species is initiated by proteins that recognize specific DNA sequences. (SF1, IFES2)	<u>SF</u> <u>IFES</u>
T or <u>F</u>	Glucose levels in the blood are relatively constant, indicating that insulin release from the pancreas is also constant. (IFES1)	SF <u>IFES</u>
<u>I</u> or F	If a human gene can produce a protein product in a bacterial cell; it must also be true that a bacterial gene inserted into human DNA code could produce a protein product in a human cell. (SF1, IFES3)	<u>SF</u> <u>IFES</u>
T or <u>F</u>	To produce human insulin the cellular machinery for making human DNA into human protein must also be added to the bacteria. (SF1)	<u>SF</u> IFES
<u>I</u> or F	Humulin activates the insulin receptor in humans because its structure is the same as insulin produced in the human body. (SF1, IFES1)	<u>SF</u> <u>IFES</u>

RH.3 (5 pts) Another core concept represented in recombinant humulin is *Pathways and Transformations of Energy and Matter (PTEM)*. As you did above for *IFES*, describe how *PTEM* is represented in the recombinant humulin narrative.

Use CE Framework to categorize and award points.

Criteria for Awarding Points	Total
2 pts – Identify one Conceptual Element	
1 pt – Identify a second Conceptual Element	
1 pt – Identify a third Conceptual Element	5 pts
1 pt – Quality of Response	

RH.4 (15 pts) True/False statements: Determine whether each statement is true or false. Regardless of whether the statement is T or F, determine which core concept(s) is represented in each statement: *Structure and Function (SF)*, *Pathways and Transformations of Energy and Matter (PTEM)*, or *Both*

Circle:		Circle one or both core concepts represented in each TF statement	
<u>I</u> or F	Following a meal, without insulin, glucose levels in the blood increase because glucose is unable to enter cells. (SF1)	SF	PTEM
T or <u>F</u>	Because humulin has a different molecular structure than insulin, humulin binding to the insulin receptor results in a decreased rate of glucose metabolism in the cell. (SF1, PTEM5)	SF	PTEM
T or <u>F</u>	When a cell breaks down glycogen to release glucose, the glucose is able to readily pass out of the cell. (SF1, PTEM4)	SF	PTEM
<u>I</u> or F	Theoretically, if a person with Type 1 diabetes receives a transplant of healthy, insulin-secreting cells, they would no longer need to take humulin to regulate glucose uptake. (SF1, PTEM5)	SF	PTEM
T or <u>F</u>	When organisms are not eating, cells cease metabolism to conserve energy. (PTEM5)	SF	PTEM

RH.5 (5 pts) You have already provided descriptions above for how *Information Flow, Storage and Exchange (IFES)* and *Pathways and Transformations of Energy and Matter (PTEM)* are independently represented in the humulin production narrative. Now, briefly describe the relationship between these two concepts (how are they connected?) in the recombinant humulin production scenario (1-2 sentences).

Criteria for Awarding Points	Total
2 pts – Make connection between CC2 & CC3	
1 pt – Describe CC2	
1 pt – Describe CC3	
1 pt – Quality of Response	5 pts

Recombinant Humulin Table of Specifications	Open-ended questions		TF/I questions
	Apply	Connect	Apply/Identify
Structure and Function (S&F)			
SF1: Biological structures from the molecular to the ecosystem scale and their interactions are determined by chemical and physical properties that both enable and constrain function.	given		8
Information Flow, Exchange and Storage (IFES)			
IFES1: Information exists in many forms and is relayed within and across biological molecules, cells, tissues, organisms, populations and ecosystems.			2
IFES2: Genetic information is stored in nucleic acids (DNA and RNA); epigenetic information is stored in proteins that associate with DNA and in reversible DNA modifications.	1		1
IFES3: The process of protein synthesis results from the flow of genetic information through various pathways.		1	1
Pathways and Transformations of Energy and Matter (PTEM)			
PTEM4: Matter is recycled through the re-arrangement of chemical bonds in biological entities.	1		1
PTEM5: Biological entities regulate the synthesis, storage and mobilization of biological compounds to meet energy demands.			3

FIVE CORE CONCEPTS IN BIOLOGY

The core concepts listed below are major conceptual themes in biology, all of which overlap, interweave, and influence each other to form the principles that guide biological life. They are:

1. **Evolution (E)** - The diversity of life is a result of the processes of mutation, natural selection, and genetic change over time.
2. **Structure and function (SF)** – A structure of biological entities (molecules, genes, cells, tissues, organs, individuals, and ecosystems) is comprised of basic physical and chemical units that influence the interactions with other structures, thereby defining the function of all living things.
3. **Information flow, exchange, and storage (IFES)** – The growth and behavior of organisms are activated through the expression of genetic information in context. Information is transferred within cells, between cells, between organisms, and from one generation to the next.
4. **Pathways and transformations of energy and matter (PTEM)** – Energy and matter cannot be created nor destroyed, but can be changed from one form to another. Biological systems grow and change by processes based upon chemical transformation pathways and are governed by the laws of thermodynamics. Energy can be transformed within cells, between cells, or between the cell, the organism, and the environment.
5. **Systems (S)** – Biological entities (molecules, genes, cells, tissues, organs, individuals, and ecosystems) are interconnected and interact to form complex networks. This network is dynamic, and a change in one component of the network can affect many other components.

Sloth, Moth, Algae Symbiosis

Please read the narrative provided. As you read, think about the core concepts and how each one is represented by the symbiosis of sloths, moths and algae.

Three-toed sloths, mammals that spend their lives in the canopy of tropical forests, primarily eat leaves, a diet which provides few nutrients and is high in fiber. Typically, leaf-eating animals are large in size to accommodate a digestive tract long enough to process plant matter and obtain sufficient nutrients. However, to live in the forest canopy, sloths must be small and light weight. To compensate for their inability to have a long, heavy digestive tract, three-toed sloths digest leaves at a very slow rate. In spite of this, sloths still burn more calories than they gain from eating leaves. How can they survive with this caloric imbalance? Answers to this question are emerging from scientists who study the sloth's unique, inherited defecation behavior and the sloth's mutualistic symbiosis with two organisms, green algae and pyralid moths, which both live in the sloth's fur.

To defecate, sloths climb down from the canopy once a week, create a small hole in the ground, deposit their feces and cover it with leaves. Because descending from the canopy exposes sloths to dangerous predators and uses precious calories, scientists have been investigating whether there is a 'hidden' nutritional benefit of this behavior. It turns out that the pyralid moth larvae are coprophagous (feces-eating), and their eggs must be laid in feces for the larvae to survive. When the sloths descend from the trees each week, female moths living in the sloth fur lay eggs in the freshly deposited sloth feces. The moth eggs hatch in the feces, develop into larvae, and ultimately become adult moths that attach to sloth fur when a sloth defecates on the ground. When the adult moths die in the fur of their sloth hosts, their decaying bodies provide nutrients for green algae, which are growing in the water-trapping cracks of the sloth hairs. Studies of the digested food from sloth gastrointestinal tracts confirm that they eat the green algae, which is 3-5 times richer in lipids (fats) than plant leaves. Scientists now hypothesize that green algae not only provide camouflage for the sloth from aerial predators but also the "missing" calories in the three-toed sloth's diet. Therefore, this symbiotic relationship is a complex mutualism where all three organisms benefit from the intricate associations with one another.

As an example, *Pathways and Transformations of Energy and Matter* is represented in the sloth symbioses because the algae provide the extra calories three-toed sloths need to supplement their plant diet. Carbon trapped by the algae during photosynthesis is later incorporated into the sloth's biomass when the sloth eats the algae.

SMAS.1 (5 pts) Another core concept represented in sloth narrative is *Evolution*. As was done with *Pathways and Transformations of Energy and Transformations (PTEM)* above, in 1-2 sentences, describe how *Evolution (E)* is represented in the sloth symbiosis with moths and algae.

SMAS.2 (15 pts) True/False statements: Determine whether each statement is true or false. Regardless of whether the statement is T or F, determine which core concept(s) is represented in each statement: *Pathways and Transformations of Energy and Transformations (PTEM)*, *Evolution (E)*, or *Both*

Circle:		Circle one or both core concepts represented in the TF statement	
T or F	Moth larvae that incorporated nutrients from sloth feces into their own biomass incurred a survival (and therefore, as adults, a reproductive) advantage over larvae that did not.	PTEM	E
T or F	The sloth must gain more benefit from its defecation ritual than it loses from the energetic demands of descending the tree where it is vulnerable to predation.	PTEM	E
T or F	Green algae purposefully generate genetic mutations in order to adapt and survive on sloth hairs.	PTEM	E

T or F	Algae obtain and store light energy from the sun. When sloths consume the algae, they transform the light energy to chemical energy to support their growth and reproduction.	PTEM	E
T or F	An individual sloth adapts its defecation behavior to increase the moth and green algae colonies growing on its fur in order to maximize lipid intake.	PTEM	E

SMAS.3 (5 pts) Another core concept represented in the sloth narrative is *Systems*. As you did above for *Evolution*, describe in 1-2 sentences how *Systems (S)* is represented in the sloth symbiosis with moths and algae.

SMAS.4 (15 pts) True/False statements: Determine whether each statement is true or false. Regardless of whether the statement is T or F, determine which core concept(s) is represented in each statement: *Pathways and Transformations of Energy and Transformations (PTEM)*, *Systems (S)*, or *Both*

Circle:		Circle one or both core concepts represented in each TF statement	
T or F	When there are more moths there are more nutrients available to support algal growth.	PTEM	S
T or F	An elderly three-toed sloth that is no longer able to descend the tree to defecate, would be able to grow algae in its fur at the same rate as a young three-toed sloth that is able to descend the tree to defecate.	PTEM	S
T or F	Adult and larval pyralid moths occupy different, but equally necessary roles in the sloth-moth symbiotic relationship.	PTEM	S
T or F	A three-toed sloth that descends the tree to defecate many times per week would increase its energy reserves compared to sloths that only descend once per week.	PTEM	S
T or F	A sloth would increase its long-term survival if it ate its entire algae garden to obtain more lipids in a short amount of time.	PTEM	S

SMAS.5 (5 pts) You have already provided descriptions above for how *Evolution (E)* and *Systems (S)* are independently represented in the sloth narrative. Now, briefly describe the relationship between these two concepts (how are they connected?) in the sloth scenario (1-2 sentences).

Sloth, Moth, Algae Symbiosis
ANSWER KEY & TABLE OF SPECIFICATIONS

SMAS.1 (5 pts) Another core concept represented in sloth narrative is *Evolution*. As was done with *Pathways and Transformations of Energy and Transformations (PTEM)* above, in 1-2 sentences, describe how *Evolution (E)* is represented in the sloth symbiosis with moths and algae.

Use CE Framework to categorize and award points.

Criteria for Awarding Points	Total
2 pts – Identify one Conceptual Element	
1 pt – Identify a second Conceptual Element	
1 pt – Identify a third Conceptual Element	5 pts
1 pt – Quality of Response	

SMAS.2 (15 pts) True/False statements: Determine whether each statement is true or false. Regardless of whether the statement is T or F, determine which core concept(s) is represented in each statement: *Pathways and Transformations of Energy and Transformations (PTEM)*, *Evolution (E)*, or *Both*

Circle:		Circle one or both core concepts represented in the TF statement
<u>T</u> or F	Moth larvae that incorporated nutrients from sloth feces into their own biomass incurred a survival (and therefore, as adults, a reproductive) advantage over larvae that did not. (PTEM2, PTEM4, PTEM7, E5)	<u>PTEM</u> <u>E</u>
<u>T</u> or F	The sloth must gain more benefit from its defecation ritual than it loses from the energetic demands of descending the tree where it is vulnerable to predation. (PTEM3, E5, E6)	<u>PTEM</u> <u>E</u>
T or <u>F</u>	Green algae purposefully generate genetic mutations in order to adapt and survive on sloth hairs. (E3)	PTEM <u>E</u>
T or <u>F</u>	Algae obtain and store light energy from the sun. When sloths consume the algae, they transform the light energy to chemical energy to support their growth and reproduction. (PTEM1)	<u>PTEM</u> E
T or <u>F</u>	An individual sloth adapts its defecation behavior to increase the moth and green algae colonies growing on its fur in order to maximize lipid intake. (PTEM2, E5)	<u>PTEM</u> <u>E</u>

SMAS.3 (5 pts) Another core concept represented in the sloth narrative is *Systems*. As you did above for *Evolution*, describe in 1-2 sentences how *Systems (S)* is represented in the sloth symbiosis with moths and algae.

Use CE Framework to categorize and award points.

Criteria for Awarding Points	Total
2 pts – Identify one Conceptual Element	
1 pt – Identify a second Conceptual Element	
1 pt – Identify a third Conceptual Element	5 pts
1 pt – Quality of Response	

SMAS.4 (15 pts) True/False statements: Determine whether each statement is true or false. Regardless of whether the statement is T or F, determine which core concept(s) is represented in each statement: *Pathways and Transformations of Energy and Transformations (PTEM)*, *Systems (S)*, or *Both*

Circle:

Circle one or both core concepts represented in each TF statement

<u>I</u> or F	When there are more moths there are more nutrients available to support algal growth. (PTEM2, S2)	<u>P</u> TEM <u>S</u>
T or <u>F</u>	An elderly three-toed sloth that is no longer able to descend the tree to defecate, would be able to grow algae in its fur at the same rate as a young three-toed sloth that is able to descend the tree to defecate. (PTEM2, S1, S2)	<u>P</u> TEM <u>S</u>
<u>I</u> or F	Adult and larval pyralid moths occupy different, but equally necessary roles in the sloth-moth symbiotic relationship. (S5)	PTEM <u>S</u>
T or <u>F</u>	A three-toed sloth that descends the tree to defecate many times per week would increase its energy reserves compared to sloths that only descend once per week. (PTEM5)	<u>P</u> TEM S
T or <u>F</u>	A sloth would increase its long-term survival if it ate its entire algae garden to obtain more lipids in a short amount of time. (PTEM2, S1)	<u>P</u> TEM <u>S</u>

SMAS.5 (5 pts) You have already provided descriptions above for how Evolution (E) and Systems (S) are independently represented in the sloth narrative. Now, briefly describe the relationship between these two concepts (how are they connected?) in the sloth scenario (1-2 sentences).

Criteria for Awarding Points	Total
2 pts – Make connection between CC2 & CC3	
1 pt – Describe CC2	
1 pt – Describe CC3	5 pts
1 pt – Quality of Response	

Sloth, Moth, Algae Symbiosis Table of Specifications	Open-ended questions		TF/I Questions
	Apply	Connect	Apply/Identify
Pathways and Transformations of Energy and Matter (PTEM)	given		
PTEM1: Energy is neither created nor destroyed, but can be transformed from one form to another to generate biological activity.			1
PTEM2: Input of energy, which can be from different sources, is needed to build and maintain biological entities, thereby lowering entropy in the system.			5
PTEM4: Matter is recycled through the re-arrangement of chemical bonds in biological entities.			1
PTEM5: Biological entities regulate the synthesis, storage and mobilization of biological compounds to meet energy demands.			1
PTEM7: Matter can transfer between the abiotic and biotic components of biological systems.			1
Evolution (E)	1		
E3: Genetic variation within a population can be generated by mutation, which results in the generation of novel traits, and by sexual recombination, endosymbiosis and horizontal gene transfer.		Connect E & S 1	1
E5: Organisms have greater fitness if they have a phenotype that increases their ability to survive and reproduce in a particular environment.			3
E6: Populations are composed of individual organisms that vary in their fitness, leading to differential rates of survival and			1

reproduction and therefore changes in allele frequency over time.			
Systems (S)	1		
S1: Biological entities interact through chemical and physical signals that can be transient, depend on spatial organization, and are influenced by environmental factors.			2
S2: Changes in one component of a biological system can affect or be regulated by other components of the same system.			2
S5: Interactions between and among biological entities can generate new system properties.			1