Supplemental Material

CBE—Life Sciences Education

Couch *et al.*

GenBio-MAPS: A programmatic assessment to measure student understanding of Vision and Change core concepts across general biology programs

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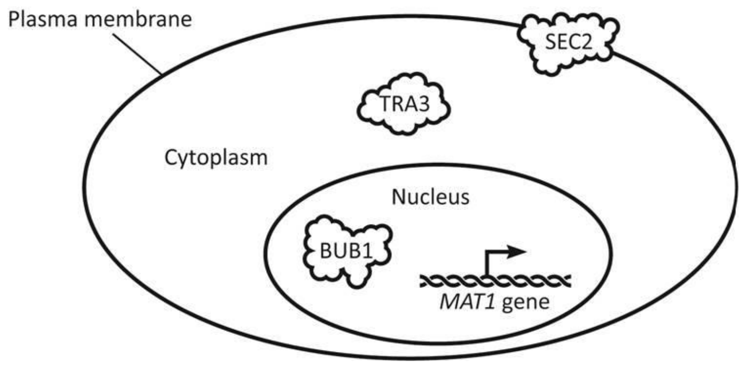
Supplementary Materials 1. GenBio-MAPS questions and knowledge statements.

GBM-01

A signal transduction pathway in yeast activates expression of the *MAT1* gene. This pathway is activated when a neighboring cell secretes a large, hydrophilic growth factor called Alpha. Three cellular proteins, SEC2, TRA3, and BUB1, are essential components of the *MAT1* signaling pathway activated by Alpha. The subcellular locations of these proteins in the absence of Alpha are shown below. The bent arrow indicates the start site of transcription.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F The TRA3 protein could function as a receptor for Alpha.
b) T/F In a cell treated with Alpha, the TRA3 protein could move into the nucleus.
c) T/F In a cell treated with Alpha, the entire SEC2 protein could move into the nucleus to activate the *MAT1* gene.
d) T/F In the absence of Alpha, the gene that codes for the TRA3 protein is located in the nucleus.
e) T/F A mutation in the *SEC2* gene could disrupt expression of the *MAT1* gene.

Knowledge statements:

a) Large, hydrophilic proteins do not readily cross through the plasma membrane.
b) Cytosolic proteins can translocate into the nucleus in response to external signals.
c) Intact transmembrane proteins are not readily released from the membrane.
d) The genes for nearly all cellular factors are located in the nucleus, even for proteins not located in the nucleus.
e) A mutation in one gene in a signaling pathway can affect the expression of another gene.

GBM-02

A bacterium uses ammonia, NH_3, as its only food source. This bacterium has an enzyme called ammonia monooxygenase that catalyzes the reaction shown below, which is energetically favorable under the conditions found in this bacterium.

$$\underset{\text{ammonia}}{NH_3} + O_2 + 2H^+ \xrightleftharpoons{\text{ammonia monooxygenase}} \underset{\text{hydroxylamine}}{NH_2OH} + H_2O$$

Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F Energy released during the conversion of ammonia to hydroxylamine could be used by the bacterium to drive ATP synthesis.
b) T/F Enzymes, such as ammonia monooxygenase, are often inhibited by the products of the reactions that they catalyze.
c) T/F Ammonia monooxygenase likely raises the activation energy of the reaction.
d) T/F A mutation in the ammonia monooxygenase gene could increase the fitness of this bacterium.

Knowledge statements:

a) Energy released during energetically favorable reactions can be coupled to drive energetically unfavorable reactions.
b) The enzymes that catalyze catabolic pathways are often inhibited by the end products of the pathway.
c) Enzymes catalyze chemical reactions by lowering the activation energy of the reaction.
d) Mutations can increase the fitness of an organism.

GBM-03

Human immune-deficiency virus, HIV, is a virus that infects human cells. When HIV infects a cell, the cell synthesizes a viral protein called HIV protease. The function of HIV protease is to bind and cut another viral protein called Gag-Pol to create two separate proteins, Gag and Pol. A newly discovered strain of HIV makes an altered form of the HIV protease that differs by a single amino acid substitution from the normal protease.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F This altered protease is the result of a mutation within the viral genome.
b) T/F This altered protease could be more efficient at cutting Gag-Pol than the normal protease.
c) T/F This altered protease could bind less tightly to the Gag-pol protein.
d) T/F The HIV strain that makes this altered protease could be resistant to drugs designed to block the function of the normal protease.
e) T/F This altered protease will likely be shorter than the normal protease.

Knowledge statements:

a) Viruses carry their own genomes that become expressed within cellular hosts. A mutation within the viral genome can lead to changes in the products expressed from the viral genome.
b) A single amino acid change in a protein can change the structure of a protein causing that protein to function more efficiently.
c) A single amino acid change in a protein can change the structure of a protein causing that protein to function less efficiently.
d) Mutations can confer viral drug resistance by changing the ability of a drug to bind its viral target.
e) A mutation that causes a single amino acid substitution in a protein will not likely change the overall length of the polypeptide.

GBM-04

During the course of normal human development, the muscle myosin protein becomes expressed in muscle cells but not in non-muscle cells, such as liver cells.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F This expression pattern could result from the muscle myosin gene being present in muscle cells but not in liver cells.
b) T/F This expression pattern could result from the regulatory sequence of the muscle myosin gene being different in muscle cells compared to liver cells.
c) T/F This expression pattern could result from epigenetic modifications, such as DNA methylation, being present on the myosin gene in liver cells but not in muscle cells.
d) T/F This expression pattern could result from a transcription factor that activates expression of the muscle myosin gene being present in muscle cells but not in liver cells.

Knowledge statements:

a) Different cell types have the same genetic composition. With some exceptions, cell-type specific gene expression patterns are not caused by the programmed loss of genes during development.
b) Different cell types have the same genetic composition. While single cells may develop mutations, cell-type specific gene expression patterns are not the result of programmed mutations during development.
c) Different chemical modifications to DNA and associated histone proteins can occur in different cell types, leading to changes in gene expression.
d) Different transcription factor proteins are selectively expressed in different cell types, contributing to differences in gene expression between these cell types.

GBM-07

The *EOT1* gene is required to promote toe development in normal mice. A mutation in this gene results in a paw with two extra toes.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F The mutation could be located in a regulatory region of the *EOT1* gene where an inhibitor protein normally binds.
b) T/F The two extra toes could result from a mutation in the *EOT1* gene that causes the EOT1 protein to be nonfunctional.
c) T/F The mutation could result in the mouse having lower than average fitness.
d) T/F If the extra toes result in the mouse having increased fitness, the mutation could increase in frequency in a population of mice over time.
e) T/F If the extra toes do not cause any change in the fitness of the mouse, the mutation could increase in frequency in a population of mice over time.

Knowledge statements:

a) Gene expression can be regulated by the binding of inhibitor proteins to gene regulatory regions. A mutation that promotes a biological process could be due to disruption of an inhibitor protein that normally inhibits that process.
b) If a gene normally promotes a biological process, a mutation that renders this gene nonfunctional would cause a decrease in the corresponding biological process.
c) A mutation that causes a change in body morphology can negatively affect the fitness of an organism.
d) Mutations that confer a reproductive advantage will tend to increase in frequency in a population.
e) Mutations that do not confer a reproductive advantage can increase in frequency in a population, for example if they are located near a beneficial allele in the genome or as a result of genetic drift.

GBM-08

A single species of bacteria only spreads by physical contact between living birds of the same species. The bacteria infect the birds' eyes and can cause inflammation leading to blindness and death.

Over the past 15 years, the way this bacterial species infects and kills birds has shifted: an Eastern Canadian strain now causes severe infection and rapid death, while strains of the same species of bacteria that spread to Western Canada do not cause severe infection or death. Although birds in Western Canada do not experience severe infection and do not die, the Western bacterial strain still lives in these birds. Both strains of bacteria divide every 20 minutes, while birds take approximately 3 years to reach reproductive age.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

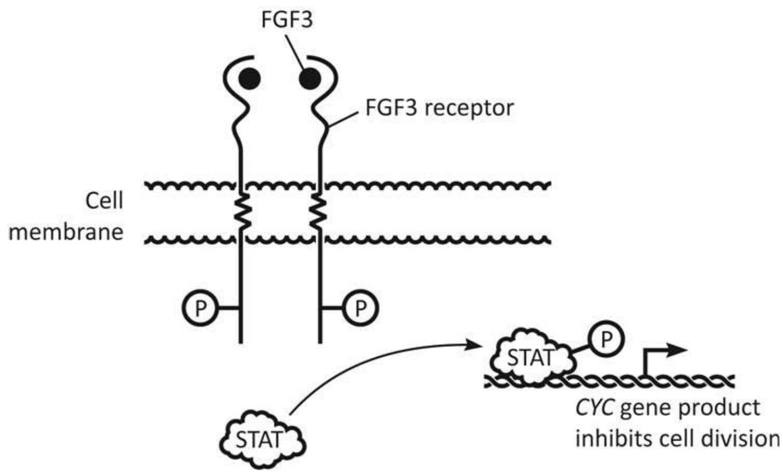
a) T/F During this 15 year period, both bacterial strains have the capacity to accumulate genetic changes more rapidly than birds.
b) T/F The Eastern Canadian bacterial strain is still evolving, but Eastern Canadian birds are no longer evolving.
c) T/F In Western Canada, a bird that survives bacterial infection due to the bird's specific genetic makeup is likely to have offspring who survive infection by the same strain of bacteria.
d) T/F The difference in the severity of infection in Eastern and Western Canada could be due to genetic differences in Eastern and Western bird hosts.

Knowledge Statements

a) Species that reproduce more rapidly or have higher mutation rates have the capacity to accumulate genetic changes more rapidly than those with slower reproduction rates.
b) All species continue to evolve.
c) If an organism has a genetically based fitness advantage, then this organism's offspring are also likely to have this fitness advantage.
d) A pathogen can have different effects in different subgroups of a species due to underlying genetic differences between the subgroups. Genetic differences in subgroups can also drive the divergent evolution of a pathogen.

GBM-12

One way that dwarfism occurs is from the premature inhibition of cell division in bone precursor cells, controlled by the signaling pathway shown in the diagram below. Fibroblast Growth Factor 3 (FGF3) binds to the FGF3 receptor, triggering the phosphorylation of the STAT transcription activator. Phosphorylated STAT then binds to the regulatory region of the *CYC* gene and activates transcription of the *CYC* gene. The *CYC* gene product inhibits cell division. The bent arrow indicates the start site of transcription.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

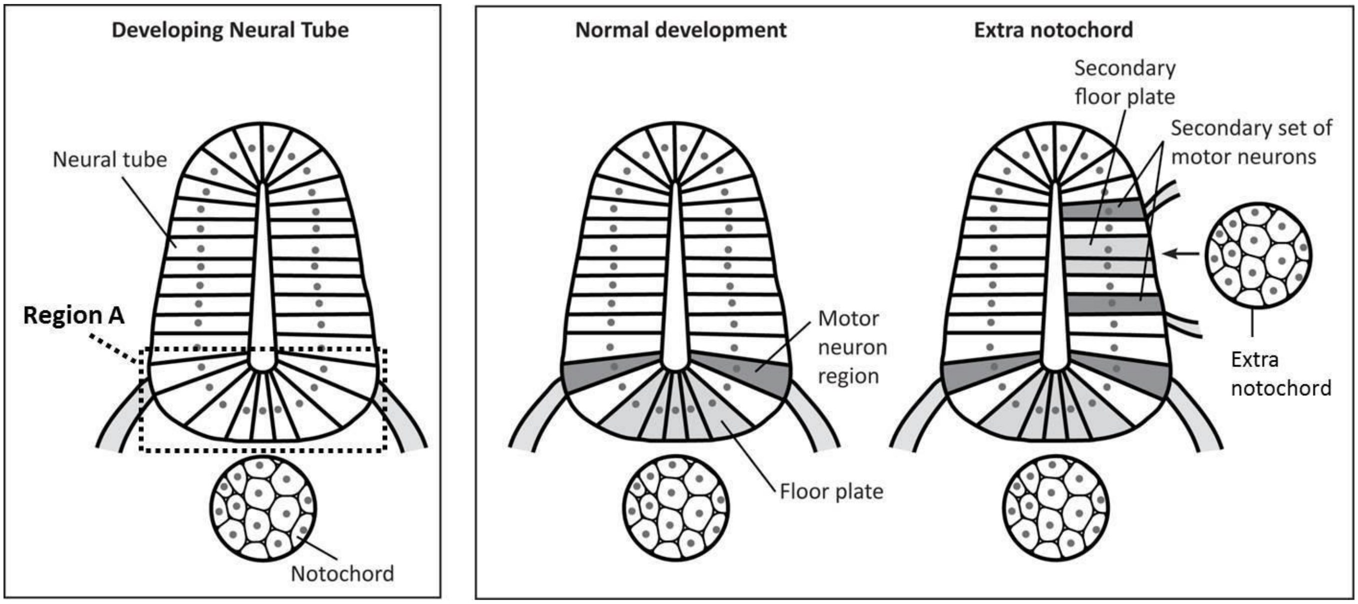
a) T/F Other signaling pathways could also regulate expression of the *CYC* gene.
b) T/F Dwarfism could be caused by a loss of function of the STAT protein.
c) T/F If FGF3 binds to the same FGF3 receptors on a different cell type, the FGF3 receptors on those cells could activate different downstream signaling pathways.
d) T/F Phosphorylation of the STAT protein changes its shape in a way that allows it to bind to the *CYC* gene regulatory sequence.
e) T/F The phosphorylated STAT protein can bind as well as dissociate from the *CYC* regulatory sequence.

Knowledge statements

a) Most genes are regulated by a complex array of signaling pathways.
b) Inactivation of a transcription activator will lead to decreased expression of the genes regulated by that activator, resulting in decreased activity of the resulting gene products.
c) Similar signals can elicit different downstream responses in different cell types, due to differences in the signaling factors present in each cell type.
d) Phosphorylation activates proteins by causing a structural change that alters their biochemical properties.
e) Binding between two macromolecules is a reversible interaction whose frequency and duration is determined by the biochemical properties of the macromolecules and local environmental conditions.

GBM-13

There are several kinds of motor neurons in the adult spinal cord, all of which extend axons to different kinds of muscles. The left side of the figure below shows a normally developing neural tube and notochord. The notochord interacts with the neural tube, secreting a signaling molecule that influences the development of the neural tube. The right side of the figure shows the results of an experiment in which a developing neural tube is exposed to an extra set of notochord cells.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

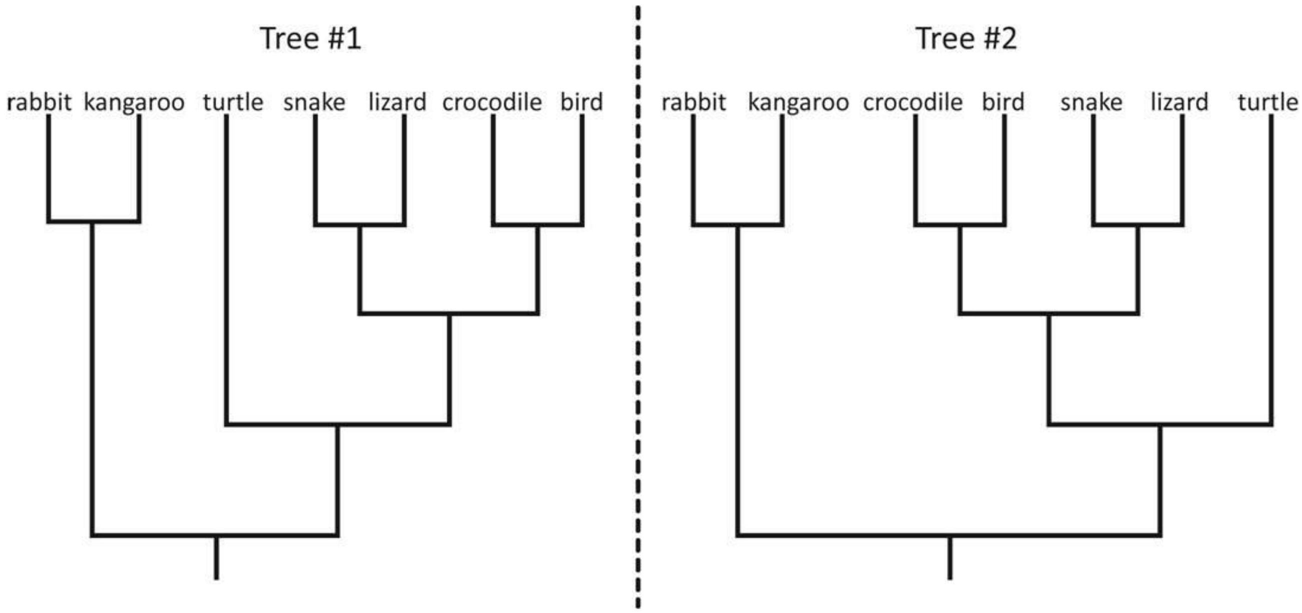
a) T/F The relative concentration of the signaling molecule secreted by the notochord can determine the identity of different kinds of cells in the neural tube.
b) T/F Prior to notochord signaling, only cells in Region A have the potential to develop into motor neurons.
c) T/F The cells of the neural tube have a receptor that allows them to respond to the signal from the notochord.
d) T/F Motor neurons move from the spinal cord through the blood to signal to the muscle cells.

Knowledge statements

a) The concentration of a signaling molecule can determine cell fate. Cells more distant from the source of a signaling molecule will be exposed to a lower concentration of the signal.
b) Undifferentiated cells can assume different fates depending on the signals to which they are exposed.
c) Signaling molecules activate signal transduction pathways by initially binding to a receptor.
d) Motor neurons communicate to muscle cells by transmitting electrical signals along cellular processes called axons. Motor neurons do not communicate by physically moving their entire cell bodies through the blood to contact the target cell.

GBM-14

The phylogenetic trees below are based on DNA sequence data.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F In Tree #1, turtles share a more recent common ancestor with snakes than with birds.
b) T/F Tree #1 shows that lizards evolved from snakes.
c) T/F Based on these phylogenies, it is most likely that legs were lost only in the lineage that gave rise to snakes.
d) T/F The evolutionary relationships shown in Tree #1 are the same as the evolutionary relationships shown in Tree #2.

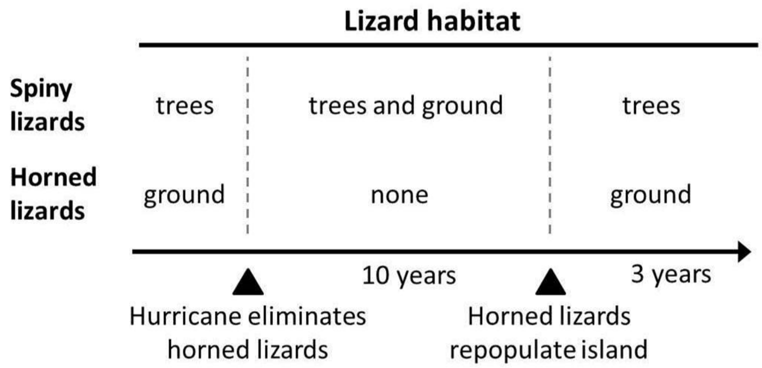
Knowledge statements

a) Within a phylogenetic tree, each branch point represents a common ancestor that ultimately gave rise to all the organisms stemming from the branch point (node). The most recent common ancestor between two species is the most recent branch point that is shared by both species.
b) Branch points represent common ancestors, but these ancestors are not the same as the descendant groups, which have evolved into something different (i.e., the common ancestor of today's snakes and lizards wasn't a snake and wasn't a lizard).
c) All the species sharing an initial common ancestor are expected to have common features based on their shared inheritance. In cases where one species is lacking a particular trait and this lineage shares common ancestors with other lineages that have the trait, it is likely that the trait was lost in the individual lineage, rather than being gained in all the other lineages.
d) The orientation of each branch point can be rotated without altering the representation of underlying evolutionary relationships.

GBM-15

An island had two small populations of lizard species: the spiny lizard occupied the trees and the horned lizard occupied the ground as shown below. A hurricane caused a tidal surge, killing all of the horned lizards.

Immediately after the hurricane, individual spiny lizards could be found moving between the trees and the ground. Ten years later, a small number of horned lizards naturally repopulated the island, and it took three additional years for their population size to stabilize. During these three years, as the horned lizard population increased on the ground, the spiny lizard population decreased on the ground. Neither lizard species preys upon the other lizard species.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

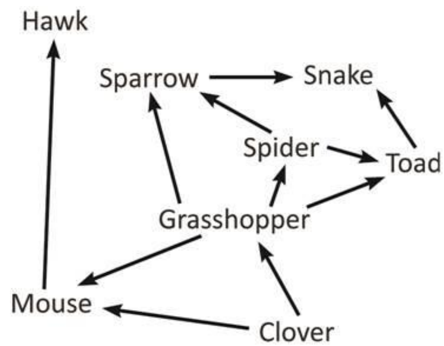
a) T/F Before the hurricane, the spiny lizard was capable of surviving and reproducing on the ground in the absence of the horned lizard.
b) T/F For several years before the hurricane, allele frequencies likely remained the same in the spiny lizard population.
c) T/F Horned lizards likely outcompete spiny lizards on the ground.
d) T/F During the ten years when individual spiny lizards could be found moving between the trees and the ground, the spiny lizards likely diverged into two different species.

Knowledge statements

a) Species may be able to exist in several different habitats (fundamental niche), but their actual distribution may be limited by competition with other species (realized niche).
b) Allele frequencies within a population fluctuate over time due to genetic drift, which is particularly pronounced in smaller populations.
c) In cases where the fundamental niches of two species overlap, one species may outcompete, and as a result exclude, the other species. In this scenario, the realized niche of spiny lizards seems to be restricted by the presence of horned lizards on the ground. When horned lizard repopulate the island, the population of spiny lizards on the ground decreases as the horned lizard population increases, suggesting that horned lizards are outcompeting spiny lizards on the ground.
d) Species that are not physically separated are unlikely to diverge into different species within a short time span. The development of species takes place over long periods of time as lineages diverge due to physical and/or reproductive barriers.

GBM-16

In the diagram below, the arrowheads point to consumers. For example, toads are eaten by snakes. Biomass refers to the total mass of living biological material, excluding water. For this question, assume that no other outside organisms affect the biomass or population sizes of the organisms shown.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F Assuming there is an abundance of clover, the mouse population size would likely increase if most of the hawks were eliminated from this environment.
b) T/F If more toads were added to this ecosystem, the number of grasshoppers and spiders would likely decrease before the number of sparrows decreases.
c) T/F If a field of clover is sprayed with a chemical that cannot be broken down, over time grasshoppers will likely accumulate a higher concentration of this chemical than hawks.
d) T/F Over the course of one year, the amount of grasshopper biomass produced is greater than the amount of snake biomass produced.

Knowledge statements

a) The removal of a predator will result in an increase in the population size of its prey, assuming that the prey have access to sufficient resources.
b) An increase in the population size of a predator will lead to a decrease in the population size of its immediate prey. A decrease in these prey will lead to a subsequent decrease in other predators that target these same prey.
c) When a non-biodegradable chemical enters a food web, it will tend to become more concentrated in organisms that are higher on the food chain. This phenomenon stems from the fact that as organisms eat many of their prey over time, they will be unable to degrade and thus accumulate the chemicals present in their prey, resulting in the predator having a higher net concentration of the chemical than the individual prey.
d) Within a food web, the amount of biomass added at lower levels limits the amount of biomass that can be added at higher levels, since lower levels are the only source of biomass for higher levels and assimilation across trophic levels is incomplete. Thus, the cumulative biomass of an organism at higher levels will be lower than the cumulative biomass of an organism at a lower level, provided that the lower trophic-level organism serves as the sole source of biomass for all the organisms that are consumed by the higher trophic-level organism.

GBM-18

A protein exists in two forms that differ only in their folded shapes. Form A is found in normal brain tissue and performs normal cellular processes. Form B is found in animals with certain brain diseases and is thought to play a causative role in these diseases. Form B is infectious, meaning that when it is introduced to normal brain tissue, it can cause Form A to be converted to Form B, thereby increasing the amount of the disease form.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

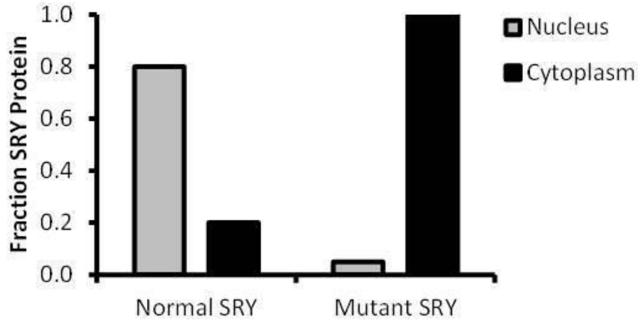
a) T/F Form A likely functions differently than Form B because they have different shapes.
b) T/F Form A and Form B folding are determined entirely by their amino acid sequences.
c) T/F Form A and Form B must be expressed from two different genes.
d) T/F Form A to Form B conversion likely requires a change in Form A's amino acid sequence.

Knowledge statements

a) The structure of a protein dictates its function. For two proteins that differ only in their folded shapes, differences in their functions can be attributed to differences in structure.
b) While amino acid sequence affects the folded structure of a protein, there are other factors that can influence a protein's conformation. Proteins with the same amino acid sequence can adopt different shapes based on environmental factors.
c) Proteins with identical amino acid sequences are likely encoded by the same gene. In the event that a gene has become duplicated, it is likely that the genes will accumulate at least some changes in their corresponding amino acid sequences.
d) Proteins are polymers composed of amino acid monomers. If two proteins differ only in their folded shape, they will still have the same amino acid sequence.

GBM-19

SRY is a protein that binds to certain DNA sequences and activates genes involved in male sexual development. Mutations in the *SRY* gene can result in abnormal sexual development and possible fertility issues. To investigate this phenomenon, separate cells are constructed to express either normal or mutant SRY protein. The relative amount of SRY protein located in the nucleus and cytoplasm of these cells is shown below.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

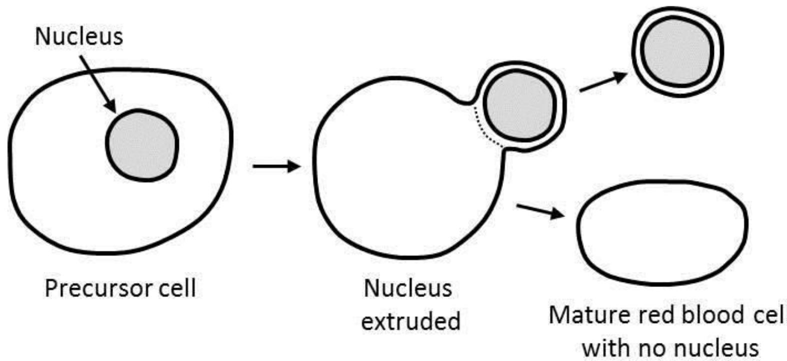
a) T/F Normal SRY protein is made in the nucleus.
b) T/F The mutant *SRY* gene is unable to be transcribed in the nucleus.
c) T/F Mutant SRY protein is likely less able to be imported into the nucleus.
d) T/F Normal SRY protein will be more likely to directly activate genes than the mutant SRY protein.

Knowledge statements

a) Protein synthesis occurs in the cytoplasm.
b) mRNA synthesis occurs in the nucleus.
c) Mutations can affect the ability of a protein to be imported into the nucleus.
d) A protein that activates genes by binding to certain DNA regulatory sequences must be able to enter the nucleus in order to access DNA and activate downstream gene expression.

GBM-20

Red blood cells (RBCs) are full of hemoglobin, a protein that allows them to carry oxygen. During the maturation process of typical mammalian RBCs, a precursor cell loses its nucleus as well as many organelles, including mitochondria. Though mature RBCs are smaller than precursor cells, they can carry more hemoglobin proteins as a result of this maturation process. Individuals within a species have natural variation in the concentration of hemoglobin in their mature RBCs.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F Mature RBCs are no longer able to produce new mRNA molecules.
b) T/F Mature RBCs have a surface-area-to-volume ratio that is less than that of the precursor cells.
c) T/F Mature RBCs can undergo mitosis to produce additional RBCs.
d) T/F Precursor cells are better able to travel through capillaries than mature RBCs.
e) T/F All else being equal, in populations living at high altitudes, natural selection would likely favor individuals with a higher concentration of hemoglobin in their mature RBCs.

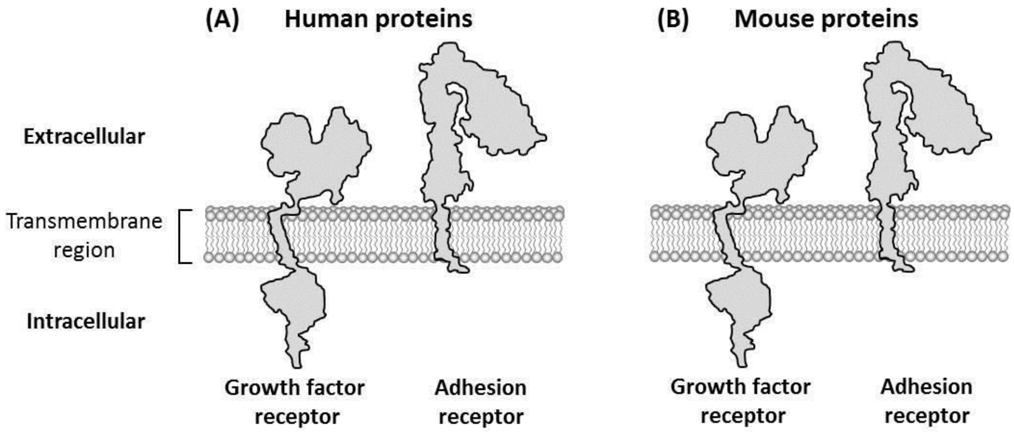
Knowledge statements

a) After a eukaryotic cell becomes enucleated, it will no longer have a DNA template from which to transcribe new mRNA molecules.
b) Smaller spherical cells have a higher surface-area-to-volume ratio than larger spherical cells.
c) Eukaryotic cells lacking a nucleus are unable to undergo mitosis.
d) Blood cells flow through small capillary vessels in target tissues. Small red blood cells are better able to flow through small vessels than larger precursor cells.
e) Partial pressures of oxygen are lower in the atmosphere at high altitudes. Adaptations that increase oxygen binding and delivery to tissues are often favored by natural selection for populations living at high altitudes.

GBM-21

Figure A depicts two functional receptor proteins found in human cells: the growth factor receptor (GFR) and the adhesion receptor (ADR). The structures of these two receptors are completely different from each other, except that both proteins have similar transmembrane regions. The amino acid sequences of these proteins are also completely different from each other, including within the transmembrane regions.

Figure B depicts the equivalent functional receptor proteins found in mice. The structures of the mouse receptors are similar to their human counterparts. The amino acid sequences of the mouse receptors are also 88% identical to the amino acid sequences of the human receptors.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

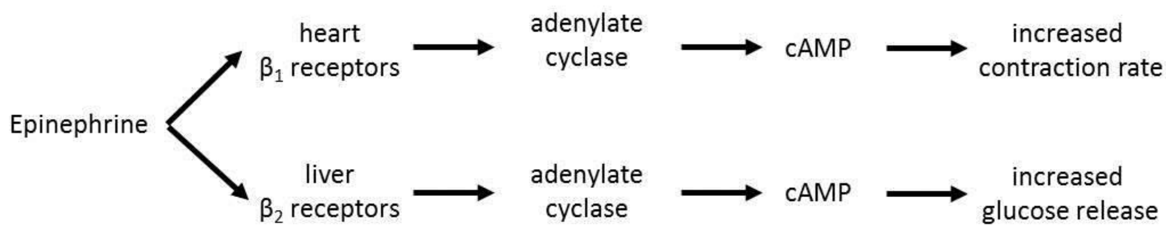
a) T/F The transmembrane region of the proteins will mostly be comprised of amino acids with hydrophilic side chains.
b) T/F The sequence and structure of the transmembrane regions together indicate that the human GFR gene and the human ADR gene likely evolved from the same ancestral gene.
c) T/F The GFR genes found in humans and mice likely arose from a common ancestral gene.
d) T/F A growth factor signal has to bind to the intracellular region of the GFR receptor to cause an intracellular response.

Knowledge statements

a) The interior region of a phospholipid bilayer is comprised of hydrophobic fatty acids. To be stable in this hydrophobic environment, transmembrane proteins tend to have amino acids with hydrophobic side chains in their transmembrane region.
b) Structures can have common forms based on homology or analogy. Homologous structures are similar due to common ancestry. Analogous structures are similar due to common function. Homologous and analogous structures can be distinguished based on the underlying composition of the genes that give rise to the structures. In this case, while the two receptors share similar transmembrane structures, differences in the amino acid sequence within the transmembrane region suggest that these similar structures did not arise through common ancestry.
c) A high degree of sequence similarity in two proteins found in two different species suggest that the protein arose from a common ancestral gene.
d) Signals can be transduced across the plasma membrane by binding to the extracellular domain of a transmembrane receptor and eliciting a change in the intracellular domain of the receptor.

GBM-22

During periods of heavy exercise, the human body increases the production and release of the hormone epinephrine. Epinephrine can bind to specific membrane receptors on the heart, increasing the heart's contraction rate. Epinephrine can also bind to receptors on liver cells, increasing glucose release by liver cells. Epinephrine initiates the following signaling cascades.



In each cell type, epinephrine binds to β receptors, which activates adenylate cyclase enzymes. These enzymes catalyze the production of cAMP, leading to different physiological effects.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F Injection of epinephrine into the bloodstream will initiate the specified pathways in the absence of exercise.
b) T/F Any cells in the body that have β_2 receptors will release glucose when epinephrine binds to those receptors.
c) T/F The different effects of epinephrine binding to receptors in liver and heart cells is likely due to the presence of different proteins downstream of cAMP in these two cell types.
d) T/F Binding of one molecule of epinephrine to one β_1 receptor in a heart cell will lead to the production of one cAMP molecule.

Knowledge statements

a) Physiological process are often initiated by the production of a specific signaling molecule in response to a stimulus. A signaling molecule that is exogenously added to an organism can still elicit a downstream response in the absence of the corresponding stimulus, provided the signaling molecule can reach its intended location.
b) Different responses can occur downstream of the same molecule in different cell types, depending on the downstream proteins present in each cell type.
c) As cells differentiate during development, they express a unique combination of proteins that enable them to respond differently to a common signal.
d) Signals transduction pathways can amplify signals through chemical catalysis or other mechanisms. For this pathway, activation of adenylate cyclase will lead to the production of many cAMP molecules.

GBM-23

A palm tree adapted to the desert grows approximately one meter in a growing season. In the statements below, biomass refers to an organism's total mass, excluding water.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F Carbon from carbon dioxide gas makes up a large portion of the tree's biomass.
b) T/F Cellular respiration does not occur in the tree.
c) T/F In the tree, light energy is transformed into chemical energy stored in glucose.
d) T/F The primary purpose of photosynthesis is to produce oxygen for animals to breathe.

Knowledge statements

a) Carbon dioxide serves as the primary source of carbon for plant biomass.
b) Cellular respiration occurs in plants.
c) The process of photosynthesis converts solar energy into chemical energy in the form of glucose.
d) The primary purpose of photosynthesis is to convert solar energy into chemical energy in the form of glucose. The production of oxygen is a byproduct of this reaction.

GBM-24

During DNA replication in a human liver cell, DNA polymerase mistakenly adds a guanine (G) nucleotide instead of an adenine (A) nucleotide to a newly made strand of DNA in a gene that codes for a protein. This mutation occurs in a protein-coding region of the gene and is not repaired by the cell.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

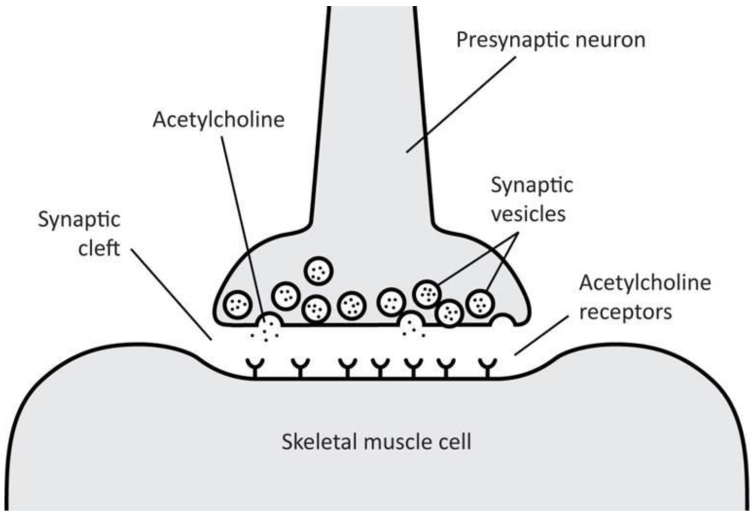
a) T/F This mutation will likely not change the sequence of the mRNA produced from this gene.
b) T/F This mutation will likely be copied into the DNA of other existing neighboring liver cells.
c) T/F More proteins produced from this gene will be affected by this mutation than if a similar mistake had occurred during mRNA synthesis.
d) T/F This mutation represents an effort by the cell to adapt to altered environmental conditions.
e) T/F Cells derived from this liver cell will likely contain this mutation on both the maternal and paternal versions of this gene.

Knowledge statements

a) A mutation within the transcribed region of a gene will alter the sequence of the mRNA encoded by this gene.
b) A mutation in the DNA of one somatic cell will not be copied into other existing neighboring cells.
c) DNA is the long-term storage molecule for genetic information in a cell. A mutation in the DNA will affect all future RNA molecules transcribed from that gene. Typically multiple mRNA molecules are transcribed from a given gene, and each of these molecules is relatively short-lived. Therefore, while a mistake made during transcription of an mRNA molecule will affect some resulting proteins, fewer proteins will be affected than if the change occurred at the DNA level.
d) Mutations continuously occur in a semi-random fashion throughout the genome. Organisms cannot induce specific mutations to adapt to environmental conditions.
e) There are two copies of each gene located on homologous chromosomes. A mutation that occurs in one copy of a gene will typically not affect the sequence of the other copy. The genomes of daughter cells will be the same as the initial cell, with the mutation occurring on only one copy of a gene.

GBM-27

At the neuromuscular junction of vertebrates, the neurotransmitter acetylcholine is released from the pre-synaptic neuron into the synaptic cleft, where it interacts with specific acetylcholine receptors on skeletal muscle cells. The diagram below illustrates the release of acetylcholine into the synaptic cleft.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F When acetylcholine is in the synaptic cleft, the acetylcholine receptor sends out chemical signals to attract acetylcholine.
b) T/F Decreasing the distance across the synaptic cleft will increase the probability that acetylcholine binds to its receptors on the skeletal muscle cell.
c) T/F Drugs that increase the amount of time that acetylcholine remains in the synaptic cleft will increase acetylcholine signaling.
d) T/F Once bound to its receptor, acetylcholine cannot dissociate from the receptor.
e) T/F The response of the skeletal muscle cell requires that acetylcholine enters into the muscle cell after it binds its receptor.

Knowledge statements

a) Molecules encounter their receptors through random diffusion. Receptors do not send out chemical signals to attract their ligands.
b) Decreasing the area in which a molecule diffuses will increase its effective concentration and the likelihood that it will encounter its receptor. For signals that are released from a particular source, shortening the distance from the source to the receptor will result in increased probability of binding to its receptor.
c) The frequency of binding of a ligand to its receptor depends on the concentration of the ligand. Neurotransmitters are normally absorbed or degraded leading to termination of the downstream signal. Drugs that increase the amount of time a neurotransmitter remains in the synaptic cleft would maintain the neurotransmitter at a high concentration and thus lead to prolonged signaling.
d) The binding of a ligand to its receptor is a reversible reaction whose frequency and duration is determined by the biochemical properties of the macromolecules and the local environmental conditions.
e) Signaling molecules, particularly neurotransmitters, can cause downstream responses in cells that express a receptor for that signal without the signal entering into the cell.

GBM-28

The table below summarizes some characteristics of three types of cells found in an individual brown bear. The “+” signs indicate the relative amount of mitochondria found in a given cell type, with more “+” signs indicating relatively more mitochondria being present.

Characteristic	Type 1 Cell	Type 2 Cell	Type 3 Cell
Primary function of cell	Organism movement	Nutrient absorption	Energy storage
Presence of mitochondria	+++	+	+
ATP production	Yes	Yes	Yes

Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F Type 1 cells likely have different genes compared to Type 2 cells.
b) T/F The amount of CO_2 released from Type 1 cells is likely higher than the amount of CO_2 released from Type 3 cells when the bear is moving.
c) T/F An increase in the release of CO_2 from Type 3 cells will contribute to an increase in the bear’s breathing rate.
d) T/F Assuming the same density of nutrient transport proteins, Type 2 cells with a lower surface-area-to-volume ratio would have an increased capacity to absorb nutrients than Type 2 cells with a higher surface-area-to-volume ratio.
e) T/F Increasing the number of Type 1 cells in the body would have a larger impact on the energetic demands of the organism than increasing the number of Type 3 cells.

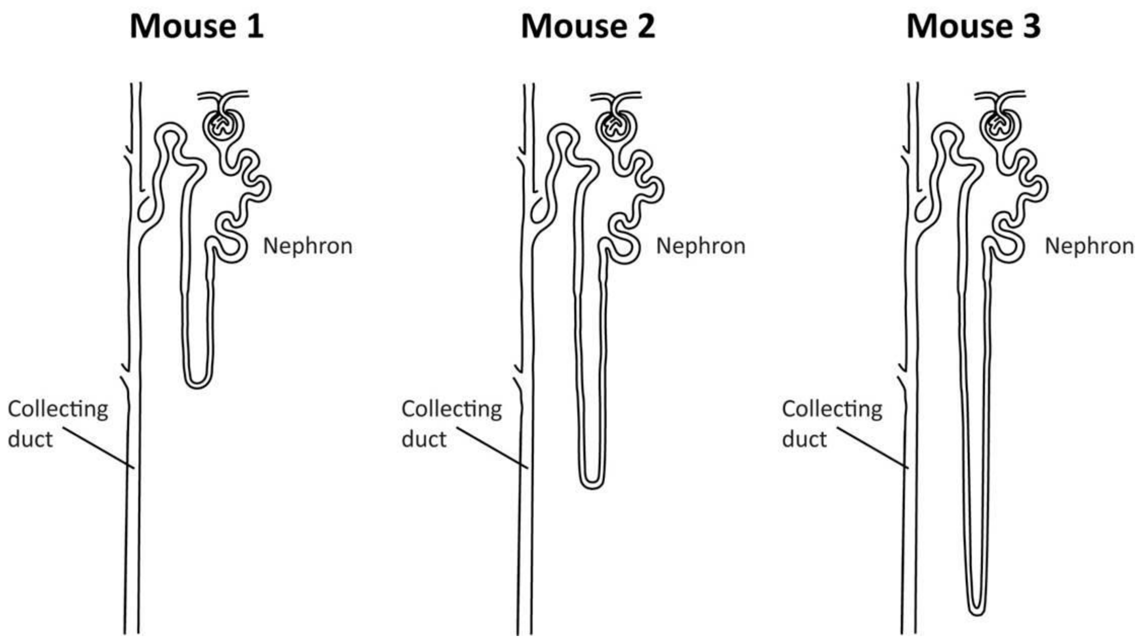
Knowledge statements

a) With some exceptions, the genetic content is the same for all cells in an organism.
b) Cells with a greater number of mitochondria have an increased capacity to perform cellular respiration, which results in increased production and release of CO2.
c) Increased CO2 production will lead to changes in blood chemistry that cause an increase in breathing rate.
d) The amount of surface area can limit a cell’s capacity to absorb nutrients. Cells involved in nutrient absorption often have irregularly shaped projections of their cell surface that creates a large surface area for absorption.
e) Cells with a higher rate of cellular respiration will have greater energetic demands than cells with lower rates of cellular respiration.

GBM-30

The nephron is the functional unit of the kidney that is responsible for processing blood. The nephron also generates a concentration gradient in the kidney, which facilitates the diffusion of water out of the urine in the collecting duct and back into the blood. This mechanism ultimately helps to concentrate the urine.

Below are images of nephrons from three different species of mice that occupy different habitats. For this scenario, assume the mice are equivalent in all other aspects of their physiology and behavior, excluding their nephron structure.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F Mouse 1 likely has less capacity to remove water from its urine than Mouse 2.
b) T/F Mouse 1's nephron is less evolved than Mouse 3's nephron.
c) T/F An increase in blood volume in Mouse 2 will likely lead to increased solute concentration in its urine.
d) T/F The longer nephron in Mouse 3 compared to Mouse 1 could represent an adaptation to a dry, desert habitat.

Knowledge statements

a) Greater surface area in its nephrons enables an organism to generate a steeper osmotic gradient and have a greater capacity to absorb water from its urine.
b) All organisms evolve over time. Organisms do not become more or less evolved than each other.
c) An increase in blood volume will lead to less water being absorbed from urine and thus a lower concentration of solutes in urine.
d) A longer nephron enables greater capacity to absorb and retain water from urine, which could lead to greater fitness in a dry habitat.

GBM-31

Consider a scenario where a person eats a cupcake composed of glucose molecules. The person has digested the cupcake, and the glucose has been absorbed into the bloodstream.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F Carbon atoms from glucose could be exhaled by the person as carbon dioxide.
b) T/F Carbon atoms from glucose could later be found in a plant cell.
c) T/F Some of the energy stored in glucose will eventually be transformed into heat.
d) T/F Carbon atoms from glucose could be converted into oxygen during metabolism.

Knowledge statements

a) Carbon in glucose can be converted to carbon dioxide during cellular respiration. Carbon dioxide is later exhaled from the lungs.
b) Carbon in glucose can be converted to carbon dioxide during cellular respiration. Carbon dioxide is later exhaled from the lungs. Carbon dioxide in the atmosphere can then be fixed into plant cells during the process of photosynthesis.
c) The reactions of cellular respiration are not 100% efficient, and some of the energy stored in glucose is ultimately released as heat during chemical reactions.
d) In the absence of radioactive decay, one type of atom cannot convert into another type of atom.

GBM-32

Leptin is a protein that controls appetite. Leptin is secreted by fat cells and binds to specific receptors in the brain to signal that the organism is no longer hungry. As shown below, mice engineered to not produce either the leptin protein or the leptin receptor become severely obese.

Strain	1	2	3
Leptin protein	+	–	+
Leptin receptor	+	+	–
Body weight	normal	obese	obese
+ = present – = not present			

Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F Administering leptin into the blood of Strain 3 mice will reduce their appetite.
b) T/F Administering leptin receptors into the blood of Strain 3 mice will reduce their appetite.
c) T/F If abnormally high levels of leptin were administered to Strain 1 mice for an extended period of time, leptin receptors in the brain may be downregulated to maintain homeostasis.
d) T/F Administering an antibody that binds to and blocks leptin receptors in Strain 2 mice will reduce their appetite.
e) T/F Fat cells located far from the brain in Strain 1 mice will not have an effect on appetite.

Knowledge statements

a) A signaling molecule will only elicit a response in cells that express a receptor for that signaling molecule.
b) Cellular receptors are normally either located within a cell or embedded in a cell membrane. Receptors circulating in the blood will not readily cross or become inserted into a membrane. Circulating receptors may bind to a signal but will not transduce the signal into a cellular response.
c) Receptors are often downregulated in response to high levels of a stimulus. This represents a homeostatic response to prevent over-response to a stimulus.
d) Antibodies can bind to and obstruct the binding surface of a molecule. If the normal function of a signaling molecule is to reduce appetite, then blocking the function of this molecule will likely increase appetite.
e) Cells within an organism are able to communicate over long distances by releasing factors into the circulatory system.

GBM-33

In rodents, certain stimuli can induce a signaling pathway that ultimately causes the release of the nonpolar steroid hormone corticosterone from the adrenal gland into the blood. Corticosterone can bind to intracellular receptors in kidney cells. After binding corticosterone, corticosterone receptors function as transcription factors by binding DNA and activating gene expression.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

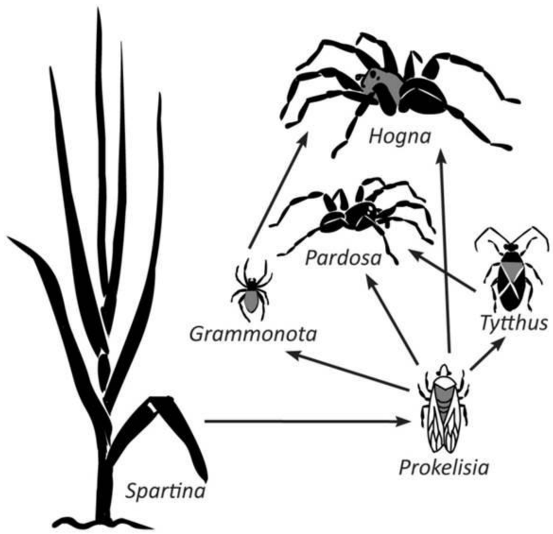
a) T/F Corticosterone has a specific three-dimensional shape that is essential for proper binding to its receptor.
b) T/F Corticosterone can have indirect effects on cells that do not have corticosterone receptors.
c) T/F Corticosterone receptors can bind to any DNA sequence in order to activate transcription.
d) T/F Corticosterone can enter target cells through simple diffusion across the plasma membrane.
e) T/F Under normal conditions, corticosterone levels in the blood will eventually return to their original levels once the initial stimulus is removed.

Knowledge statements

a) The binding between two molecules is influenced by their three-dimensional structure.
b) Signaling molecules, such as hormones, that are released into the blood stream can directly affect cells containing receptors that bind to the specific signaling molecules. These cells can alter their activities in ways that cause additional indirect changes in other cells, which may not have receptors for the specific signaling molecule.
c) Transcription factors bind to specific DNA sequences to affect the expression of specific genes.
d) Small, nonpolar molecules, such as hormones, can readily cross through plasma membranes.
e) In response to a stimulus, organisms often release signaling molecules that initiate specific downstream processes. After an initial stimulus, negative feedback mechanisms typically lead to reduced production and/or perception of the signaling molecule to achieve homeostasis.

GBM-35

The arrows in this diagram represent relationships between organisms with the arrowheads pointing to consumers. For example, *Prokelisia* are eaten by *Tytthus*. Biomass refers to the total mass of living biological material, excluding water. For this question, assume that no other outside organisms affect the biomass or population sizes of the organisms shown.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

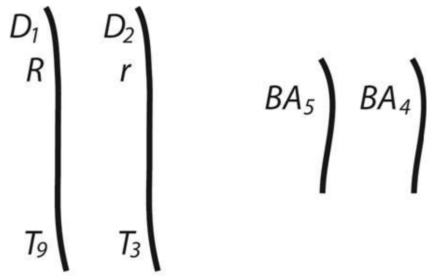
a) T/F If nitrogen run-off flows into this habitat from nearby farm fields and acts as a fertilizer for *Spartina*, there is likely to be no impact on *Pardosa* population size.
b) T/F If a viral disease eliminates only the *Pardosa* population, there is likely to be an increase in *Tytthus* population size.
c) T/F Over one growing season, the total biomass of all of the *Prokelisia* that is produced is greater than the combined biomass of all of the *Grammonata*, *Pardosa*, *Tytthus*, and *Hogna* that is produced.
d) T/F *Spartina* biomass is higher when all of the species pictured are present than when only *Spartina* and *Prokelisia* are present.

Knowledge statements

a) If the population size of a primary producer increases, then this will likely have an impact on the population size of consumers in that system.
b) If the population size of a consumer decreases, then there is likely to be an increase in the population size of its prey.
c) Within a food web, the amount of biomass present at lower levels limits the amount of biomass that can be added at higher levels, since lower levels are the only source of biomass for higher levels and assimilation across trophic levels is incomplete. Thus, the cumulative biomass of a lower organism will be greater than the cumulative biomass of the other organisms that derive biomass from the lower organism, provided that the lower organism serves as the sole source of biomass for all the other organisms.
d) If Species B consumes Species A, then the presence of additional species that consume Species B will result in a net increase in Species A.

GBM-36

The chromosomes drawn below are found in a human skin cell. The lines represent the chromosomes themselves. The letters indicate the location of a particular version of a gene.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

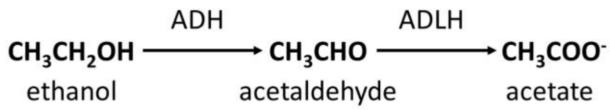
a) T/F An individual's offspring are more likely to inherit a D_1 and *R* together than a D_1 and T_9 together.
b) T/F About 50% of the egg cells from this individual will have both T_9 and BA_5.
c) T/F Because *r* is recessive, the frequency at which the *r* version of the gene occurs in a population is lower than the frequency at which the *R* version occurs in the population.
d) T/F If the protein produced by the *BA* gene is involved in the formation of ovaries, then the *BA* gene is likely located on a sex chromosome.
e) T/F Because the genes shown here are found in skin cells, these genes code for proteins required for skin cell function.

Knowledge statements

a) Genes located close together on a chromosome will tend to be inherited together more frequently than genes located far apart on chromosomes or on different chromosomes.
b) The probability of inheriting either allele for a heterozygous gene is 50%. The compound probability of inheriting two specific alleles for genes located on different chromosomes is the product of their individual probabilities, which in this case is 25%.
c) The prevalence of an allele within in a population is independent from whether the allele is dominant or recessive.
d) Many genes involved in the formation of sex organs are located on autosomes.
e) With some exceptions, all genes are found in all of an organism's cells.

GBM-37

For the following reaction sequence, not all substrates and products are shown.



ADH and ADLH are enzymes that catalyze each reaction in liver cells. A buildup of acetaldehyde is toxic to cells. Many different versions of the enzymes are present in human populations. Some versions have faster or slower reaction rates than others.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

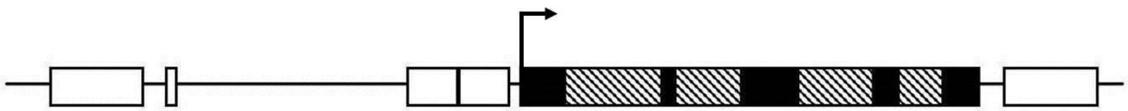
a) T/F Different versions of the ADH and ADLH enzymes could have arisen in the population through errors that occurred during DNA replication.
b) T/F The observation that many different versions of these enzymes exist in human populations means that the enzymes are not critical for survival and reproduction.
c) T/F Individuals with slow ADLH enzymes are more likely to suffer adverse effects from ethanol consumption than individuals with fast ADLH enzymes.
d) T/F The genes that code for the ADH and ADLH enzymes are found only in liver cells.
e) T/F If a person takes in large quantities of ethanol in a short amount of time, mutations will occur that lead to faster ADH reaction rates.

Knowledge statements

a) Mutations occur semi-randomly during DNA replication. Unrepaired mutations can lead to different versions of a gene.
b) The presence of different versions of a gene within a population is not directly related to whether that gene is critical for survival and reproduction.
c) If a particular enzyme helps metabolize a substance within an organism, individuals with a slower version of that enzyme are likely to have a higher concentration of the substance and experience stronger effects of the substance.
d) With some exceptions, all genes are found in all of an organism's cells.
e) Mutations arise semi-randomly in an organism. Existing mutations can influence an individual's fitness within a given environment, but the environment cannot induce directed mutations in a specific gene to increase fitness.

GBM-38

The diagram below shows different sections of the *AJC* gene.



White boxes are regulatory sequences. Black boxes are exons that contain information that specifies part of this gene's protein. Striped boxes are introns, which are sections that do not code for the final protein. The bent arrow indicates the transcription start site. There is only one transcription start site for this gene.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F Only mutations that occur in the exons can have an impact on the cell.
b) T/F A protein that binds to a regulatory sequence could reduce the amount of mRNA produced from this gene.
c) T/F The gene sequence shown in the diagram above could code for proteins of different sizes.
d) T/F Signals originating from outside the cell could regulate expression of this gene.
e) T/F A mutation in the regulatory region will likely result in a change in the nucleotide sequence of the mRNA produced from this gene.

Knowledge statements

a) Mutations that occur in non-coding regions of the genome can impact the cell, for example by changing the expression level of a gene.
b) Changes in transcription can be mediated through the binding of a repressor protein to a regulatory sequence.
c) Alternative splicing enables one gene to code for many different proteins.
d) Gene expression in a cell can be regulated by signals that originate outside of that particular cell.
e) Mutations within regulatory regions can affect the level of gene expression, but will not alter the sequence of the mRNA produced from this gene. In some cases, a mutation in a regulatory sequence can cause transcription to begin at an alternative start site, which could alter the mRNA sequence.

GBM-40

Compound X is a molecule that is used to kill cockroaches. It acts by binding to and blocking the function of nR proteins in cockroaches. A mutation occurs in the *nR* gene that leads to a mutated nR protein. Compound X is less likely to bind to this mutated nR protein.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F This mutation will only occur in cockroaches that are exposed to Compound X.
b) T/F If the mutated form of the *nR* gene increases in frequency in the population, alleles that are located nearby the *nR* gene on the same chromosome are also likely to increase in frequency.
c) T/F The ability of Compound X to bind to a specific site on the nR protein depends on that site's shape and charge.
d) T/F When Compound X binds to the nR protein in a cockroach, it changes that cockroach's genetic information.

Knowledge statements

a) Mutations arise semi-randomly in an organism. Existing mutations can influence an individual's fitness for a given environment, but the environment cannot induce directed mutations in a specific gene in order to increase fitness.
b) If a particular allele increases in frequency in a population, alleles that are located nearby this allele on the same chromosome are also likely to increase in frequency.
c) The frequency and duration of binding between two molecules depends on their biochemical properties.
d) Genetic information is stored in DNA. Interaction between two molecules within an organism can impact the function of the molecules but does not change the organism's DNA.

GBM-43

Bigleaf maple trees have the largest leaves of any of the 128 maple species. Leaf size varies within and among individual bigleaf maple trees.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

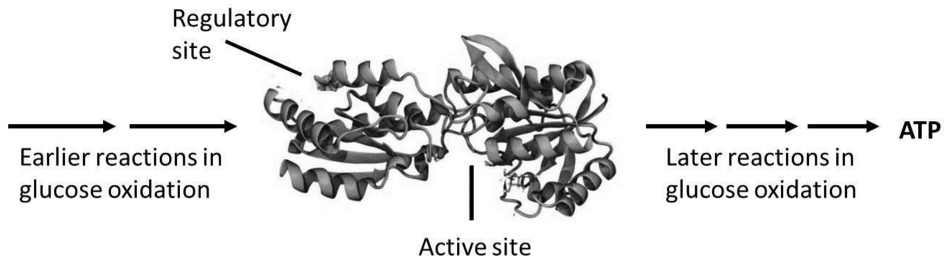
a) T/F Bigleaf maple trees absorb water for photosynthesis primarily through their leaves.
b) T/F A difference in genotype could explain why leaf size varies among different trees within the same species.
c) T/F A difference in genotype likely explains why leaf size varies within a single individual tree.
d) T/F If a habitat becomes hotter and drier, trees with more total leaf surface area would likely have higher fitness than trees with less total leaf surface area.
e) T/F In response to shading, leaves on the lower branches of a bigleaf maple may grow larger than leaves on the upper branches of the same tree.

Knowledge statements

a) Plants primarily absorb water through their root systems.
b) Differences in genotype can explain differences between individuals in the same species.
c) With some exceptions, the genetic content is the same for all cells in a single organism.
d) Trees with more total leaf surface area are likely to lose more water than trees with less total leaf surface area. Trees with less total leaf surface area will likely have higher fitness in hotter, drier habitats.
e) Organisms can exhibit phenotypic plasticity based on environmental conditions. For example, leaves in the shade can grow larger than leaves in direct sunlight in order to maximize photosynthetic capacity.

GBM-44

ATP is produced when glucose is metabolized in cells. In addition to being a product of metabolism, ATP serves as both a substrate and as a regulator for one of the enzymes involved in glucose metabolism. This enzyme has two sites where ATP binds: an active site where the reaction required for glucose metabolism occurs and a regulatory site. ATP binding to the regulatory site blocks the enzyme's activity.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

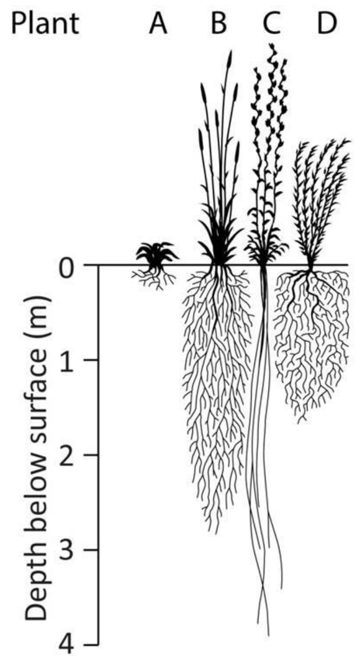
a) T/F At low cellular ATP concentrations, ATP is more likely to be bound to the active site than the regulatory site.
b) T/F At high cellular ATP concentrations, the glucose oxidation pathway will speed up.
c) T/F At high temperatures, ATP will bind to the regulatory site longer.
d) T/F ATP binding to the regulatory site likely induces a change in the structure of the active site.
e) T/F The regulatory site and the active site have identical structures because they both bind ATP.

Knowledge statements

a) For an enzymatic reaction to proceed, the substrate must be able to bind the active site. If the substrate can also serve as an allosteric inhibitor, the active site must have a higher affinity than the regulatory site for the substrate otherwise the forward reaction would have a low probability of occurring.
b) At high ATP concentrations, the regulatory site would become saturated with ATP, and the glucose oxidation pathway would slow down.
c) Increased thermal energy causes increased molecular movement leading molecules to dissociate more readily.
d) Binding of a ligand to an allosteric regulatory site induces a change in the structure and activity of the active site.
e) Common functions can be achieved by different structures.

GBM-45

The drawing below shows the shoot and root systems for different species of grassland plants.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F To transport water from the soil to leaves, species with deep roots must expend more energy than species with shallow roots.
b) T/F Sugars found in the roots of these plants have been primarily transported from the leaves.
c) T/F If two root systems have the same total surface area, less sugar can be stored in a system of many thin roots versus a few thick roots.
d) T/F The shallow root system found in Species A is advantageous in soils that have low oxygen levels.
e) T/F Species with deep root systems like those found in Species C will likely outcompete species with shorter root systems in habitats with frequent, light rains that do not penetrate the soil deeply.

Knowledge statements

a) Evapotranspiration from leaves draws water from the roots towards the leaves of a plant. This process does not require the plant to expend energy.
b) Sugars are synthesized in the leaves of plants during photosynthesis and transported to the roots.
c) For two structures with the same volume, an irregularly shaped structure will have a greater surface area than a structure that is closer to spherical. Thus, for two structures with the same surface area, an irregularly shaped structure will have less volume than a structure that is closer to spherical. Structures that are closer to spherical provide the greatest amount of volume for a given surface area.
d) Roots require the absorption of oxygen to support cellular respiration. In soils with low oxygen levels, oxygen will form a gradient with highest concentrations being located closest to the surface. In these habitats, plants with roots that reside near the surface will have a fitness advantage because they can more readily access the limited oxygen.
e) In habitats where water does not deeply penetrate the soil, species that have shallow roots will likely outcompete species with deep roots because plants with shallow roots will have greater access to water and plants with deep roots will have invested energy and matter into their deep roots while gaining no additional water access.

GBM-49

Many marine bacteria have a protein called proteorhodopsin in their plasma membranes. Absorption of light causes proteorhodopsin to change shape and move protons from inside the cell to outside the cell.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

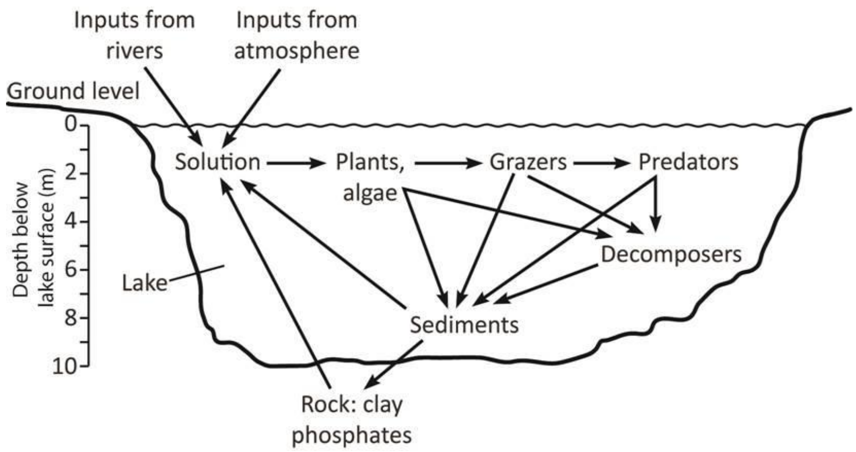
a) T/F These marine bacteria do not require ATP.
b) T/F Proteorhodopsin transforms light energy into electrochemical energy in the form of a proton gradient.
c) T/F Over time, proteorhodopsin has likely evolved to be 100% efficient under optimal conditions of light, temperature, and pH.
d) T/F These marine bacteria would likely grow faster in the presence of a molecule that increases the permeability of their plasma membranes to protons.

Knowledge statements

a) Organisms require ATP to drive energetically unfavorable reactions.
b) Light energy can be transformed into an electrochemical gradient through the movement of charged species across a membrane.
c) Chemical reactions are not 100% efficient, and some amount of energy is lost as heat in every reaction.
d) Energy can be stored in the form of a gradient. To maintain an electrochemical gradient across a membrane, the flow of atoms and molecules across the membrane must be regulated.

GBM-50

The figure below shows a cross-sectional view of a lake. The arrows in the diagram below indicate how phosphorus moves through the lake. Phosphorus is a growth-limiting nutrient for the organisms in this ecosystem, meaning that adding phosphorus results in their increased growth. For the statements below, assume that no organisms enter or leave the lake ecosystem.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

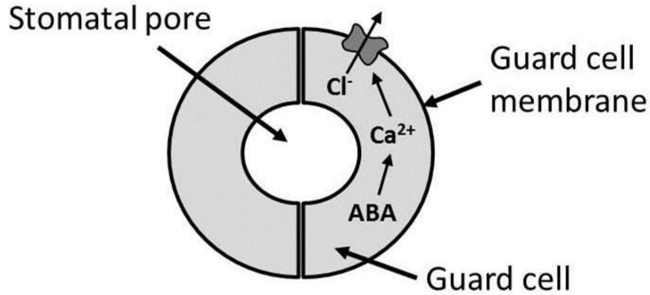
a) T/F Phosphorus in the lake water could be incorporated into the newly synthesized DNA of a plant in the lake.
b) T/F All of the phosphorus in the lake will likely eventually be permanently deposited in the sediments.
c) T/F Continually adding excess amounts of phosphorus to the lake will eventually lead to a decrease in average oxygen levels in the lake.
d) T/F An increase in the release of phosphorus from sediments back into solution could result in a short-term increase in the population size of predators.
e) T/F A phosphorus atom found in a predator could not become part of a plant in the lake.

Knowledge statements

a) The surrounding environment provides the matter for an organism to grow. Phosphorus is incorporated into DNA in the form of the nucleotide phosphate groups.
b) Nutrients constantly cycle throughout an ecosystem. In this case, phosphorus that becomes deposited in sediments can return to solution.
c) Cellular respiration consumes oxygen. An increase in phosphorus will lead to an increase in the number of respiring organisms in the lake, which will lead to a decrease in lake oxygen levels.
d) An increase in the bioavailability of a nutrient-limiting resource will lead to an increase in the population size of organisms that utilize this resource. In this case, an increase in soluble phosphorus will lead to an increase in plants and algae as well as an increase in organisms that use plants and algae as a direct or indirect food source.
e) Matter cycles throughout an ecosystem. Chemical elements can be transferred between biotic and abiotic components in an ecosystem through different processes, including decomposition, predation, and nutrient acquisition.

GBM-54

Air and water are exchanged through openings in plant leaves called stomatal pores. Guard cells that surround the stomatal pores regulate the size of the opening in response to the hormone ABA. In response to low humidity, ABA levels increase in guard cells causing the stomatal pores to close. The diagram below shows the first steps in the ABA signal transduction pathway leading to stomatal closure. ABA binding to its receptor results in an increase in Ca^{2+}, which in turn opens Cl^- channels that allow the movement of Cl^- out of the cell.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

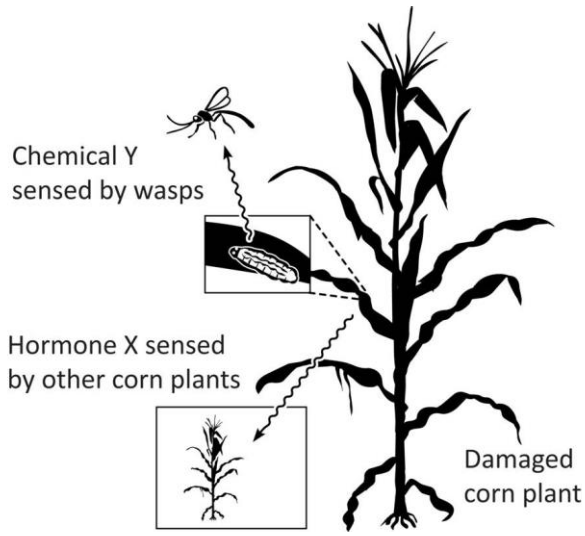
a) T/F All else being equal, plants with larger stomatal pores are more adapted to low humidity environments than plants with smaller stomatal pores.
b) T/F An increase in free cytosolic Ca^{2+} in guard cells in the absence of ABA would likely cause stomatal pores to close.
c) T/F A decrease in Cl^- concentration in guard cells would be expected to lead to an increase in water movement across the guard cell membrane and into the guard cells.
d) T/F Movement of Cl^- ions out of the guard cell will initially make the membrane potential more positive.

Knowledge statements

a) The flux of material through an opening depends on the size of the opening. Plants with smaller stomata will have decreased flow of water out of stomata and increased adaptation for dry climates.
b) Secondary messengers do not have specificity for particular downstream pathways. As a result, an increase in a secondary messenger will initiate downstream responses, even in the absence of specific upstream signals.
c) Osmosis will result in the net movement of water into an area of greater solute concentration.
d) Membrane potential is achieved through establishment of an electrochemical gradient. Cells at resting membrane potential have a net negative charge on the inside of the cell and a net positive charge on the outside of the cell. Under this condition, membrane potential is considered negative. Moving negative charges to the outside of a cell will decrease the charge imbalance and lead to a more positive membrane potential.

GBM-55

Corn plants have several different responses after being damaged by moth larvae. Damaged cells in the corn plant produce a hormone called Hormone X. Hormone X diffuses to other tissues in the plant and triggers the production of compounds called protease inhibitors that help the plant defend against moths. Damaged corn plants also release Hormone X into the air. Hormone X is sensed by other corn plants that respond by producing protease inhibitors. Corn plants also release Chemical Y into the air in response to damage by moth larvae. Chemical Y is only produced by corn plants. Female wasps respond to Chemical Y by laying eggs in the moth larvae, eventually killing them. The wasps only parasitize moth larvae, and this species of moth larvae only eats corn plants.



Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F A corn plant growing near a corn plant that has been damaged by moths is likely to be more resistant to moth attacks than a corn plant growing far from any damaged plant.
b) T/F Eliminating corn plants from this system would likely cause a reduction in the wasp population.
c) T/F Corn plants that produce protease inhibitors all the time are likely to have increased fitness compared to corn plants that produce protease inhibitors only in response to moth attacks.
d) T/F If a subpopulation of these wasps evolved to prey on a different moth species found on other plants, these wasps could lose the ability to recognize Chemical Y after many generations.
e) T/F Female wasps likely express a receptor that binds to Chemical Y.

Knowledge statements

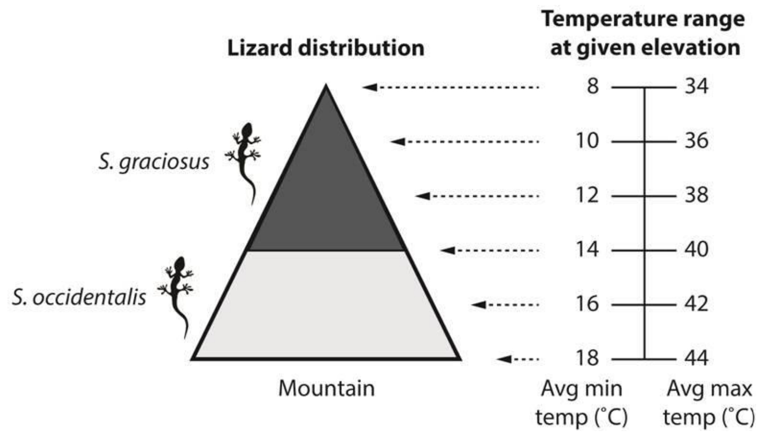
a) Damaged corn plants release a hormone into the air that elicits a protective response in neighboring corn plants. Diffusion will cause this signal to be more concentrated around the damaged plant and less concentrated at more distant sites.
b) If Species A serves as a host site for larvae that are consumed by species B, then a loss of species A will likely cause a reduction in the Species B population.
c) Constitutive production of the defense system in the absence of a predator represents an energetic cost without additional benefit. Thus, organisms that are able to turn on defense systems only in response to predation are likely to have a fitness advantage over organisms that produce the defense system constitutively.
d) If a biological structure no longer confers an evolutionary advantage, that structure could be lost from a population over time, particularly if the structure has additional energetic cost without corresponding benefit.
e) Signaling molecules typically initiate a response by binding to a receptor.

GBM-59

There are two species of mountain lizards: *S. graciosus* and *S. occidentalis*. The table shows the minimum and maximum temperatures tolerated by each lizard species. The figure shows where these two species are found on a mountain. The black lines and numbers indicate the average minimum and maximum air temperatures at different elevations on the mountain in a typical year. For the statements below, assume that (1) both species of lizards rely on the same resources, (2) all of the shared resources are limited and evenly distributed across the mountain, and (3) aside from temperature, the abiotic and biotic environment is similar at all elevations.

Lizard temperature tolerace

Lizard species	Min temp (˚C)	Max temp (˚C)
S. graciosus	6	40
S. occidentalis	8	48



Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F Removing *S. occidentalis* from the mountain would likely enable *S. gracious* to rapidly expand its habitat to include lower elevations.
b) T/F Removing *S. graciosus* from the mountain would likely enable *S. occidentalis* to rapidly expand its habitat to include higher elevations.
c) T/F If an allele arises in the population of *S. graciosus* that increases the maximum temperature individuals can tolerate, the fitness of *S. occidentalis* lizards would likely be unaffected.
d) T/F If the average minimum and maximum temperatures at all elevations on the mountain increased by 3^0C, but the thermal tolerance of the lizards did not change, the area of the mountain inhabited by *S. graciosus* would likely decrease.

Knowledge statements

a) Species distributions can be limited by abiotic factors, such as temperature. In this case, removing S. occidentalis does not affect S. graciosus, because the range of S. gracious is limited by temperature.
b) Species distributions can be limited by biotic factors, such as competition with other species. In this case, removing S. graciosus affects S. occidentalis, because the range of S. occidentalis is likely limited by competition with S. graciosus.
c) Species distribution can be limited by biotic factors, such as competition with other species. In this case, expansion of S. graciosus into lower elevations would likely decrease the range of S. occidentalis, because S. graciosus already outcompetes S. occidentalis at higher elevations.
d) Species distribution can be limited by abiotic factors, such as temperature. Species with a narrower thermotolerance range are likely to be more dramatically impacted by climate change. In this case, an increase in temperature would cause maximum temperatures to occur at higher elevations. Since S. graciosus range is limited by temperature, this is likely to cause S. graciosus to be unable to survive at lower elevations where it previously lived.

GBM-60

Researchers established four test plots in a grassland area. Each plot was one square meter in size and was planted with 100 seeds of either a single grass species (Plot A) or an increasing number of different grass species (Plots B, C and D). At the end of one growing season, the total plant biomass from each plot was harvested and measured. The results are shown in the table below. Biomass refers to an organism's total mass, excluding water.

Test plot	Number of seeds planted	Number of grass species planted	Total plant biomass (grams)
A	100	1	20
B	100	5	80
C	100	10	120
D	100	15	140

Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F Increased species diversity correlates with decreased productivity.
b) T/F Once one plant is infected by a pathogen, the entire plant community in Plot A is likely to be more susceptible to spreading of that pathogen than the entire plant community in Plot D.
c) T/F The increase in biomass that occurs as a plant grows in any of these plots comes primarily from carbon dioxide.
d) T/F The increased biomass observed in Plot D compared to Plot A could be explained by different species using resources differently.
e) T/F An ecosystem similar to Plot D would likely support a more diverse community of consumers than an ecosystem similar to Plot A.

Knowledge statements

a) Increased species diversity enables increased biomass for a given area because different species are able to exploit resources differently and thereby enable more complete usage of available resources.
b) Increased species diversity provides greater resistance to the spread of pathogens because there are more likely to be species present that are resistant to a given pathogen.
c) Plant biomass largely derives from carbon dioxide that is fixed during photosynthesis.
d) Increased species diversity enables increased biomass for a given area because different species are able to exploit resources differently and thereby enable more complete usage of available resources.
e) Increased species diversity among primary producers enables increased species diversity among consumers because it provides a broader range of food sources for different specialist consumers.

GBM-61

Human Hormone F is a peptide hormone that causes increased heart rate in humans. When human Hormone F is injected into a mouse's bloodstream, no changes are observed in the mouse's heart rate.

Based on this information and your knowledge about biology, select true or false for each of the following statements.

a) T/F The lack of response could be because Hormone F must be injected directly into heart tissue to have an effect on this mouse's heart.
b) T/F The lack of response could result from this species of mice having genetic differences that prevent their Hormone F receptor from binding human Hormone F.
c) T/F The lack of response could result from this particular mouse having a genetic mutation that prevents expression of its own Hormone F.
d) T/F The lack of response could be because the dose of Hormone F injected was too low to observe an effect in this mouse.

Knowledge statements

a) Hormones are able to circulate throughout the body and permeate into target tissues.
b) Orthologous proteins in different species may have functional differences based on differences in amino acid sequence.
c) The lack of a particular hormone in a particular organism cannot explain why a homologous hormone from a different species did not have an effect in this organism. This organism could still express homologous receptors that could bind to the homologous hormone.
d) Binding of a signaling molecule to its target receptor depends on the concentration of the signaling molecule. At low concentrations, there may be insufficient numbers of signaling molecules binding to their target receptors to elicit an observable effect.

Supplementary Materials 2. Demographic questions answered by students at the end of the survey.

Are you 18 years of age or older?
_____ Yes
_____ No

Note: You may choose to leave any or all of these questions blank. Your answers will be used to better understand characteristics of students taking this survey.

What is your current class standing?
_____ First-year
_____ Sophomore
_____ Junior
_____ Senior
_____ Postbaccalaureate
_____ Graduate student
_____ Other:________________

Are you a Transfer Student?
_____ Yes
_____ No

Did you take AP Biology in high school?
_____ Yes
_____ No

Have you declared or are you planning to declare a major in biology or another life science?
_____ Yes
_____ No

What is your approximate current overall G.P.A.?
_____ 0.00 – 0.69 (E or F)
_____ 0.70 – 1.69 (D- to D+)
_____ 1.70 – 2.69 (C- to C+)
_____ 2.70 – 3.69 (B- to B+)
_____ 3.70 – 4.00 (A- to A+)

Gender:
_____ Female
_____ Male
_____ Other

Race/Ethnicity (select all that apply):
_____ African American/Black
_____ Asian/Asian American
_____ Caucasian/White
_____ Filipino
_____ Hispanic/Latino
_____ Native American/Alaska Native
_____ Native Hawaiian

_____ Pacific Islander
_____ Other: ________________

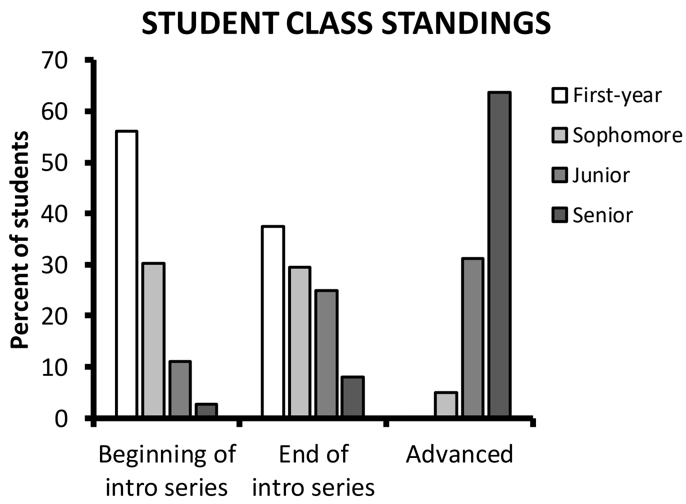
Did you speak English at home when you were growing up?
_____ Yes
_____ No

Highest level of education completed by at least one of your parents:
_____ Did not complete high school
_____ High school/GED
_____ Some college (but did not complete college)
_____ Associate’s degree (2-year degree)
_____ Bachelor’s degree
_____ Master’s degree
_____ Advanced graduate degree (for example, DVM, MD, PhD)
_____ Not sure

Supplementary Materials 3. Course sections and total students for each institution grouped by Carnegie basic classification

Inst. ID[1]	Number of course sections[2] Beginning of intro series	End of intro series	Advanced
Associate's Colleges: Mixed Transfer/Career & Technical-High Nontraditional			
1	2 (16)	1 (9)	n/a
2	4 (13)	0	n/a
Baccalaureate Colleges: Arts & Sciences Focus			
3	2 (45)	3 (23)	4 (38)
4	3 (38)	0	0
5	3 (37)	0	0
Master's Colleges & Universities: Larger or Medium Programs			
6	2 (194)	2 (156)	2 (48)
7	2 (131)	5 (89)	9 (100)
8	10 (74)	7 (103)	4 (20)
9	2 (53)	3 (42)	3 (29)
10	2 (69)	0	2 (17)
11	1 (194)	0	0
12	1 (63)	0	0
Doctoral Universities: Higher or Moderate Research Activity			
13	9 (284)	9 (273)	5 (68)
14	1 (68)	1 (58)	2 (59)
15	9 (88)	5 (33)	3 (36)
Doctoral Universities: Highest Research Activity			
16	2 (554)	1 (293)	8 (226)
17	1 (321)	1 (203)	2 (150)
18	1 (137)	3 (176)	5 (127)
19	1 (46)	1 (172)	0
20	0	3 (202)	0

[1] Institutions have been given arbitrary ID numbers for the purpose of this display.
[2] Numbers in parentheses indicate total number of students.



Supplementary Materials 4. Student class standings at different time points. Shaded bars represent the percent of students for each time point at the given class levels: n = 2,425 students for beginning of intro series, 1,832 for end of intro series, and 918 for advanced time point.

Supplementary Materials 5. Scale reliabilities

Model subcategory	Number of items	Rasch person reliability
General biology		
Full scale	175	0.82
Core concepts		
Evolution	39	0.42
Structure function	31	0.33
Information flow	41	0.50
Matter and energy	37	0.42
Systems	27	0.18
Subdisciplines		
Molecular/cellular	86	0.72
Physiology	42	0.41
Ecology/evolution	47	0.45

Supplementary Materials 6. Item alignments, fit statistics, differential item functioning, and percent correct.

					Differential item functioning (DIF)[2]										
					Gender		Ethnicity		Language		Parent education				
					Ref: Female		*Ref: non-URM*		*Ref: English at home*		*Ref: College grad*		Percent correct		
	Label	CC-SD[1]	Point measure	Outfit mean-squared	Contrast	p	Contrast	p	Contrast	p	Contrast	p	Beginning of intro series	End of intro series	Advanced
1	01a	SF-M	0.30	1.00	0.08	0.45	-0.06	0.96	-0.07	0.35	0.03	0.56	47.1	55.0	60.5
2	01b	SF-M	0.11	1.16	0.24	0.25	-0.23	0.68	-0.07	0.80	-0.24	0.86	61.8	59.6	67.9
3	01c	SF-M	0.33	0.96	0.07	0.47	0.00	0.95	-0.05	0.86	0.09	0.71	57.3	66.4	75.4
4	01d	IF-M	0.26	1.03	-0.10	0.32	-0.23	0.38	-0.17	0.66	0.00	0.85	45.2	50.9	59.1
5	01e	EV-M	0.27	0.90	0.23	0.07	0.18	0.72	0.23	0.38	0.02	0.93	78.2	83.7	88.7
6	02a	EM-M	0.12	1.26	0.25	0.24	-0.29	0.75	0.21	0.10	0.02	0.22	79.2	75.8	81.1
7	02b	IF-P	0.18	1.11	0.08	0.59	-0.47	0.17	-0.32	0.20	-0.34	0.25	54.8	60.3	73.5
8	02c	EM-M	0.43	0.84	-0.42	0.00	0.00	0.21	-0.20	0.02	0.27	0.24	51.3	69.6	77.2
9	02d	EV-P	0.15	1.13	-0.11	0.04	-0.05	0.30	0.32	0.00	-0.13	0.80	58.3	60.0	59.0
10	03a	EV-M	0.21	1.00	0.16	0.05	-0.09	0.34	0.30	0.34	-0.12	0.34	82.1	81.2	85.9
11	03b	SF-M	0.30	0.88	-0.02	0.98	0.48	0.03	0.13	0.96	-0.03	0.25	75.3	78.3	87.6
12	03c	SF-M	0.34	0.91	0.00	0.30	0.00	0.84	0.09	0.53	0.12	0.54	59.8	69.7	78.9
13	03d	SF-M	0.25	0.81	0.12	0.28	0.04	0.61	0.17	0.88	0.17	0.61	86.2	89.1	94.9
14	03e	IF-M	0.34	0.89	-0.03	0.98	0.02	0.70	0.08	0.95	-0.03	0.58	70.3	71.4	82.3
15	04a	IF-M	0.46	0.88	-0.18	0.63	0.11	0.81	-0.11	0.15	0.22	0.83	36.3	49.3	60.6
16	04b	IF-M	0.22	1.12	0.03	0.36	-0.39	0.49	-0.31	0.76	-0.26	0.44	32.9	33.0	43.1
17	04c	EV-M	0.26	1.03	-0.06	0.19	-0.18	0.44	-0.08	0.97	-0.15	0.32	45.1	54.9	74.6
18	04d	IF-M	0.28	0.87	0.30	0.00	-0.09	0.21	0.23	0.58	-0.03	0.20	77.0	84.7	91.8
19	07a	EV-M	0.20	1.02	0.09	0.38	-0.10	0.64	-0.49	0.00	-0.15	0.85	78.5	78.9	88.7
20	07b	EV-P	0.21	1.11	0.00	0.69	-0.11	0.84	-0.03	0.96	-0.17	0.70	49.7	49.0	55.8
21	07c	EV-P	0.30	0.90	-0.02	0.69	0.07	0.77	0.50	0.00	0.15	0.67	71.6	79.5	87.0
22	07d	EV-M	0.28	0.72	-0.18	0.96	0.06	0.19	0.54	0.07	0.53	0.04	89.3	91.5	93.1
23	07e	EV-M	0.21	1.09	0.08	0.90	-0.19	0.86	0.00	0.39	-0.26	0.11	46.9	57.6	57.5
24	08a	EV-E	0.27	0.89	0.00	0.76	-0.07	0.12	0.27	0.26	0.00	0.26	80.3	86.3	87.0
25	08b	EV-E	0.30	0.83	-0.15	0.70	0.25	0.29	0.03	0.51	0.29	0.12	80.7	83.3	89.6
26	08c	IF-E	0.22	0.91	0.29	0.07	0.29	0.27	0.22	0.51	0.13	0.70	88.6	89.9	94.5
27	08d	EV-E	0.12	1.29	0.48	0.00	-0.12	0.57	0.00	0.54	-0.21	0.32	86.4	88.1	85.3
28	12a	SY-M	0.32	0.93	0.06	0.34	-0.03	0.63	0.26	0.11	0.10	0.76	55.3	66.6	86.1
29	12b	SY-M	0.36	0.96	-0.02	0.91	-0.27	0.06	-0.36	0.00	0.14	0.30	38.2	46.6	57.1
30	12c	IF-M	0.21	1.06	0.11	0.72	-0.24	0.30	0.08	0.61	-0.14	0.46	63.5	64.6	74.1
31	12d	SF-M	0.29	0.90	0.09	0.18	-0.15	0.22	-0.10	0.15	-0.14	0.07	66.6	79.7	87.8
32	12e	EM-M	0.11	1.20	0.19	0.97	-0.38	0.14	-0.08	0.93	-0.26	0.50	55.8	58.7	53.7
33	13a	SY-M	0.27	0.98	-0.18	0.37	-0.21	0.37	-0.05	0.80	-0.41	0.00	65.9	76.9	81.7
34	13b	SY-M	0.20	1.09	0.12	0.43	-0.54	0.20	-0.27	0.35	-0.22	0.98	48.3	48.4	56.0
35	13c	IF-M	0.25	0.87	0.47	0.00	-0.37	0.02	0.00	0.79	0.07	0.48	82.9	86.7	90.9
36	13d	IF-P	0.37	0.91	-0.29	0.01	0.04	0.61	-0.25	0.13	0.08	0.70	57.9	67.1	78.5
37	14a	EV-E	0.35	0.84	-0.38	0.01	0.26	0.43	0.18	0.81	0.10	0.35	72.2	79.8	88.6
38	14b	EV-E	0.27	0.71	-0.30	0.71	0.44	0.23	0.24	0.66	0.22	0.79	87.4	93.4	97.1
39	14c	EV-E	0.30	0.91	0.00	0.27	0.27	0.29	0.36	0.13	-0.03	0.23	71.5	80.9	85.1
40	14d	EV-E	0.27	0.97	-0.13	0.35	-0.24	0.06	-0.28	0.12	-0.11	0.20	71.8	80.9	83.6
41	15a	SY-E	0.30	0.96	-0.02	0.99	0.06	0.63	-0.06	0.67	-0.12	0.12	56.4	66.1	74.9
42	15b	EV-E	**-0.05**	1.43	0.58	0.11	-0.48	0.99	-0.71	0.12	-0.59	0.06	23.6	24.8	22.0
43	15c	SY-E	0.27	0.83	-0.49	0.04	0.23	0.84	0.52	0.02	0.30	0.14	83.9	86.6	90.8
44	15d	EV-E	0.34	0.95	-0.14	0.24	0.31	0.08	0.27	0.14	0.14	0.48	56.0	58.8	71.4
45	16a	SY-E	0.22	0.78	0.04	0.44	0.17	0.91	0.43	0.21	-0.07	0.39	90.9	94.4	95.2
46	16b	SY-E	0.22	0.99	-0.34	0.08	0.33	0.02	0.26	0.14	0.06	0.45	79.1	83.5	83.2
47	16c	EM-E	0.30	1.02	0.17	0.76	0.25	0.02	-0.29	0.06	0.21	0.06	38.2	40.1	50.6
48	16d	EM-E	0.29	0.99	-0.34	0.00	0.35	0.00	0.36	0.01	0.26	0.01	56.6	62.8	67.3
49	18a	SF-M	0.33	0.79	0.11	0.15	0.51	0.09	0.24	0.53	0.33	0.19	75.0	86.9	90.2
50	18b	SF-M	0.35	0.97	0.00	0.53	-0.08	0.64	0.25	0.07	0.25	0.02	37.9	44.9	59.9
51	18c	IF-M	0.34	0.93	0.00	0.72	0.00	0.67	0.00	0.42	0.00	0.63	57.0	65.1	80.7
52	18d	IF-M	0.33	1.02	-0.26	0.10	-0.09	0.76	0.02	0.65	0.09	0.29	25.6	33.4	42.9
53	19a	IF-M	0.30	1.03	0.00	0.91	-0.24	0.42	-0.22	0.28	-0.08	0.96	30.3	33.6	45.7
54	19b	IF-M	0.24	1.04	0.03	0.74	0.18	0.08	0.00	0.87	0.00	0.83	57.6	57.3	65.7
55	19c	SF-M	0.19	1.04	-0.07	0.72	-0.13	0.61	0.20	0.21	-0.25	0.02	81.3	81.7	87.0
56	19d	SF-M	0.27	0.95	0.13	0.28	0.19	0.54	0.15	0.60	-0.13	0.25	70.2	74.3	84.5
57	20a	SF-M	0.38	0.86	0.04	0.18	0.03	0.19	0.08	0.84	0.29	0.06	61.7	72.2	80.2
58	20b	SF-M	0.28	1.04	0.07	0.82	0.11	0.10	-0.17	0.93	0.09	0.10	41.2	50.6	54.8
59	20c	SF-M	0.41	0.85	-0.11	0.57	0.08	0.81	0.00	0.40	0.00	0.08	58.2	67.8	80.7
60	20d	SF-M	0.34	0.85	-0.11	0.95	0.35	0.24	0.10	0.68	0.25	0.34	71.7	79.2	85.1

Supplementary Materials 6. Continued from previous page.

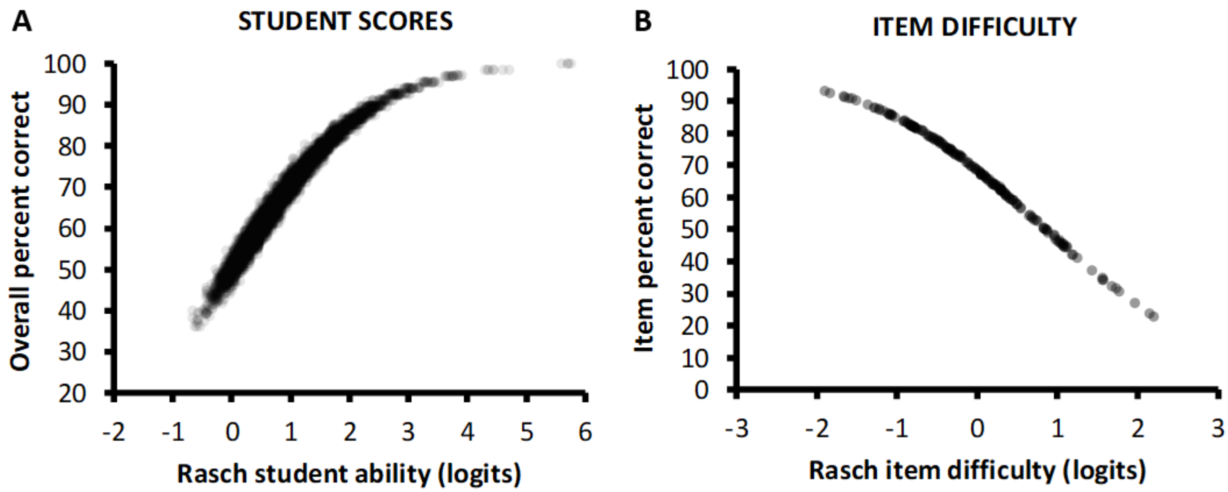
					Differential item functioning (DIF)[2]										
					Gender		Ethnicity		Language		Parent education				
					Ref: Female		*Ref: non-URM*		*Ref: English at home*		*Ref: College grad*		Percent correct		
	Label	CC-SD[1]	Point measure	Outfit mean-squared	Contrast	p	Contrast	p	Contrast	p	Contrast	p	Beginning of intro series	End of intro series	Advanced
61	20e	EV-P	0.29	0.77	-0.10	0.99	0.55	0.04	0.46	0.04	0.35	0.26	84.8	87.2	92.6
62	21a	SF-M	0.31	1.01	0.00	0.74	-0.17	0.41	-0.40	0.01	-0.14	0.30	38.7	51.2	65.4
63	21b	SF-M	0.22	1.09	0.18	0.22	-0.23	0.70	-0.34	0.06	-0.11	0.79	40.3	43.8	56.9
64	21c	SF-M	0.27	0.81	-0.19	0.30	0.33	0.35	-0.23	0.06	0.31	0.32	84.3	89.0	92.4
65	21d	IF-M	0.35	0.97	0.00	0.96	0.00	0.95	0.00	1.00	-0.07	0.35	39.1	46.8	65.1
66	22a	IF-P	0.34	0.82	-0.27	0.20	**0.65**	**0.00**	0.29	0.27	0.31	0.31	72.6	82.9	90.6
67	22b	IF-P	0.34	0.97	0.00	0.76	0.18	0.24	-0.03	0.37	0.17	0.26	48.7	55.1	62.6
68	22c	IF-M	0.24	1.00	0.16	0.36	-0.19	0.36	0.03	0.91	-0.10	0.54	70.6	76.6	82.0
69	22d	IF-M	0.38	0.94	-0.08	0.50	0.16	0.40	-0.11	0.24	0.14	0.46	39.4	54.3	62.9
70	23a	EM-E	0.21	1.09	0.04	0.65	0.00	0.39	-0.05	0.98	-0.19	0.30	70.6	79.7	77.5
71	23b	EM-P	0.18	1.04	-0.33	0.14	0.15	0.14	-0.25	0.25	-0.10	0.97	81.3	86.7	85.0
72	23c	EM-P	0.11	1.12	0.38	0.16	0.20	0.21	0.18	0.29	-0.30	0.15	91.4	91.2	92.2
73	23d	EM-E	0.31	0.76	-0.39	0.04	0.41	0.12	0.26	0.44	0.35	0.15	82.2	87.7	91.9
74	24a	IF-M	0.18	1.13	0.09	0.66	-0.09	0.95	-0.08	0.82	0.02	0.15	78.5	78.2	80.2
75	24b	EV-M	0.38	0.92	-0.14	0.73	-0.09	0.22	-0.07	0.33	0.07	0.93	49.5	61.4	72.9
76	24c	IF-M	0.15	1.11	0.04	0.90	-0.28	0.31	-0.15	0.83	-0.15	0.53	70.4	72.1	78.7
77	24d	EV-M	0.38	0.80	-0.11	0.61	0.27	0.80	0.05	0.89	0.36	0.11	69.6	79.0	84.8
78	24e	EV-M	0.17	1.13	0.37	0.07	-0.33	0.79	-0.09	0.88	-0.27	0.65	38.9	48.2	54.2
79	27a	EM-M	0.42	0.91	-0.33	0.04	0.00	0.83	-0.26	0.01	0.17	0.51	35.3	55.4	66.3
80	27b	EM-M	0.31	0.89	-0.12	0.67	0.35	0.17	0.09	0.76	0.00	0.80	70.4	78.7	89.0
81	27c	EM-M	0.21	1.06	0.00	0.25	-0.23	0.30	-0.32	0.04	0.11	0.13	68.8	73.7	81.7
82	27d	EM-M	0.33	0.86	-0.07	0.91	0.31	0.22	-0.23	0.25	0.00	0.86	66.0	81.3	85.9
83	27e	IF-P	0.46	0.85	-0.37	0.00	0.36	0.07	0.03	0.96	0.22	0.38	41.5	60.3	76.0
84	28a	EV-M	0.39	0.93	0.00	0.59	-0.08	0.23	0.06	0.75	0.16	0.50	36.4	52.9	55.6
85	28b	EM-P	0.32	0.83	-0.03	0.94	0.17	0.95	0.11	0.71	0.02	0.38	77.8	80.7	87.4
86	28c	SY-P	0.16	1.14	-0.04	0.22	-0.17	0.51	0.06	0.85	0.00	0.46	63.3	68.4	66.4
87	28d	SF-M	0.30	0.98	-0.06	0.39	0.39	0.03	0.10	0.96	0.00	0.78	61.0	70.5	74.2
88	28e	EM-P	0.29	0.93	-0.22	0.17	-0.18	0.21	-0.24	0.07	-0.24	0.01	69.4	75.8	79.7
89	30a	SF-P	0.24	0.99	0.00	1.00	0.16	0.19	0.31	0.04	-0.05	0.80	73.1	75.7	81.1
90	30b	EV-E	0.35	0.92	-0.07	0.85	0.04	0.51	-0.02	0.26	0.36	0.01	56.5	68.1	74.9
91	30c	SY-P	0.20	1.10	0.13	1.00	0.00	0.03	-0.15	0.56	-0.14	0.88	42.8	44.2	48.6
92	30d	EV-P	0.22	1.02	-0.03	0.63	0.16	0.35	0.16	0.92	0.15	0.20	79.3	83.5	85.0
93	31a	EM-P	0.28	0.94	-0.40	0.00	-0.06	0.58	-0.27	0.11	-0.06	0.48	69.7	79.6	82.2
94	31b	EM-E	0.29	1.00	**-0.64**	**0.00**	-0.04	0.43	0.19	0.70	-0.09	0.32	57.3	66.0	68.8
95	31c	EM-P	0.23	0.77	0.22	0.17	0.03	0.30	0.63	0.03	0.32	0.60	89.8	94.0	96.7
96	31d	EM-M	0.41	0.84	-0.49	0.00	0.30	0.94	0.14	0.69	0.30	0.26	62.9	70.8	78.6
97	32a	SY-P	0.32	0.89	-0.10	0.86	0.19	0.83	0.06	0.97	0.11	0.92	71.8	78.0	85.0
98	32b	SY-P	0.07	1.30	0.06	0.57	-0.63	0.31	-0.32	0.98	-0.31	0.95	26.5	25.6	29.8
99	32c	SY-P	0.17	1.15	-0.03	0.41	-0.25	0.29	0.24	0.03	0.15	0.15	72.5	74.1	79.2
100	32d	IF-P	0.19	1.11	0.19	0.28	-0.49	0.00	-0.20	0.20	-0.19	0.24	59.8	64.5	65.6
101	32e	SY-P	0.32	0.92	0.03	0.23	0.21	0.19	0.06	0.52	0.14	0.31	66.6	73.8	81.9
102	33a	SF-M	0.29	0.84	-0.07	0.75	0.31	0.31	0.35	0.02	0.34	0.13	77.3	86.0	88.2
103	33b	SY-P	0.18	1.11	0.09	0.99	-0.04	0.97	0.18	0.11	0.00	0.76	57.8	65.4	69.4
104	33c	IF-M	0.39	0.85	0.09	0.06	0.45	0.08	0.10	0.98	0.48	0.00	60.7	77.2	80.3
105	33d	EM-M	0.07	1.21	0.04	0.23	-0.42	0.69	-0.21	0.50	-0.30	0.31	53.3	51.2	53.5
106	33e	SY-P	0.27	0.88	0.14	0.10	0.11	0.93	0.22	0.24	0.20	0.55	81.4	88.7	90.8
107	35a	SY-E	0.31	0.82	0.00	0.64	0.43	0.57	0.37	0.56	0.06	0.44	79.0	83.6	91.7
108	35b	SY-E	0.25	0.91	-0.18	0.34	0.11	0.61	0.16	0.49	0.11	0.90	82.8	83.2	86.4
109	35c	EM-E	0.24	1.05	-0.33	0.01	0.00	0.89	0.03	0.71	0.00	0.69	61.0	61.7	65.9
110	35d	SY-E	0.21	1.05	0.02	0.97	-0.13	0.84	-0.03	0.21	-0.19	0.22	64.4	65.3	75.7
111	36a	EV-M	0.27	1.00	0.14	0.30	-0.15	0.38	0.04	0.31	0.00	0.69	54.6	61.6	74.2
112	36b	EV-M	0.19	1.08	0.29	0.06	0.26	0.01	-0.10	0.62	0.00	0.26	53.1	54.6	56.5
113	36c	EV-E	0.35	0.97	-0.09	0.55	0.23	0.04	-0.41	0.01	0.08	0.71	32.9	46.4	56.5
114	36d	IF-M	**-0.03**	1.36	0.34	0.93	-0.08	0.17	-0.41	0.23	-0.09	0.07	22.4	21.7	24.4
115	36e	IF-M	0.40	0.92	-0.07	0.90	-0.08	0.53	0.00	1.00	0.20	0.11	37.3	47.9	65.2
116	37a	EV-M	0.28	0.83	0.33	0.02	0.12	0.42	0.15	0.97	0.24	0.56	83.5	85.3	92.9
117	37b	EV-E	0.18	1.24	0.12	0.98	-0.09	0.33	-0.11	0.41	-0.35	0.01	70.1	75.3	79.8
118	37c	EM-M	0.28	0.89	-0.25	0.41	-0.05	0.35	0.05	0.64	0.12	0.66	78.0	82.3	89.5
119	37d	IF-M	0.39	0.86	-0.17	0.45	0.31	0.44	0.29	0.15	0.15	0.94	61.0	68.4	81.3
120	37e	EV-M	0.40	0.87	-0.03	0.68	-0.09	0.10	-0.06	0.65	0.08	0.94	56.9	65.9	79.3

Supplementary Materials 6. Continued from previous page.

					Differential item functioning (DIF)[2]										
					Gender		Ethnicity		Language		Parent education				
					Ref: Female		*Ref: non-URM*		*Ref: English at home*		*Ref: College grad*		Percent correct		
	Label	CC-SD[1]	Point measure	Outfit mean-squared	Contrast	p	Contrast	p	Contrast	p	Contrast	p	Beginning of intro series	End of intro series	Advanced
121	38a	EV-M	0.18	1.10	0.00	0.98	-0.06	0.81	0.08	0.25	-0.19	0.42	56.0	59.8	67.4
122	38b	IF-M	0.29	0.95	-0.29	0.03	0.44	0.01	0.03	0.83	0.15	0.53	59.7	72.1	81.9
123	38c	IF-M	0.09	1.22	0.00	0.80	**-0.70**	**0.00**	-0.30	0.13	-0.38	0.07	60.2	65.9	71.0
124	38d	IF-M	0.33	0.89	0.00	0.86	-0.05	0.46	-0.07	0.66	0.08	0.79	61.2	72.8	85.0
125	38e	IF-M	0.35	0.99	-0.17	0.27	-0.16	0.80	-0.25	0.13	-0.08	0.91	28.4	40.1	53.8
126	40a	EV-M	0.41	0.84	0.00	0.17	0.39	0.30	0.00	0.89	0.43	0.01	60.8	67.1	82.7
127	40b	EV-M	0.11	1.20	-0.10	0.01	-0.35	0.50	0.00	0.37	-0.25	0.21	60.6	57.0	65.6
128	40c	SF-M	0.34	0.78	-0.11	0.95	0.46	0.23	0.39	0.07	0.45	0.02	75.0	86.6	92.1
129	40d	IF-M	0.37	0.87	-0.17	0.32	0.14	0.89	0.00	0.49	0.10	0.99	57.6	71.7	82.1
130	43a	SF-P	0.34	0.92	-0.15	0.54	0.16	0.98	0.22	0.23	0.28	0.03	64.0	69.2	73.2
131	43b	IF-E	0.18	1.03	0.26	0.12	0.07	0.65	-0.14	0.18	-0.19	0.22	87.3	88.5	88.6
132	43c	IF-E	0.39	0.90	0.00	0.27	0.45	0.05	0.14	0.46	0.30	0.28	55.9	63.5	74.1
133	43d	EV-P	0.32	0.95	0.14	0.13	-0.07	0.34	-0.25	0.01	-0.14	0.14	51.8	68.1	72.6
134	43e	IF-E	0.16	1.17	0.09	1.00	-0.21	0.79	0.07	0.16	-0.14	0.99	46.0	55.2	52.1
135	44a	SF-M	0.24	1.06	0.12	0.55	-0.29	0.33	-0.32	0.04	-0.07	0.58	57.6	62.9	72.4
136	44b	EM-M	0.39	0.94	-0.14	0.44	-0.19	0.13	-0.27	0.07	0.05	0.35	31.0	46.2	63.8
137	44c	EM-M	0.27	0.98	0.00	0.71	-0.09	0.45	-0.08	0.36	-0.03	0.75	68.2	76.8	79.4
138	44d	SF-M	0.27	0.92	-0.03	0.71	-0.10	0.40	-0.05	0.42	-0.08	0.25	68.9	82.6	91.1
139	44e	SF-M	0.21	1.06	0.36	0.00	0.21	0.07	0.31	0.07	-0.16	0.26	60.9	70.5	77.8
140	45a	EM-P	0.20	1.12	0.08	0.52	-0.36	0.95	-0.26	0.27	-0.24	0.21	27.9	39.4	30.3
141	45b	EM-P	0.25	0.98	-0.26	0.03	0.00	0.84	-0.05	0.73	0.00	0.98	64.5	73.9	71.9
142	45c	SF-P	0.11	1.17	0.00	0.07	-0.43	0.24	-0.24	0.86	-0.25	0.83	44.6	47.5	46.6
143	45d	SF-E	**-0.01**	1.35	**0.70**	**0.00**	-0.47	0.45	-0.40	0.30	-0.20	0.59	56.2	56.8	58.4
144	45e	SF-E	0.33	0.93	-0.15	0.38	0.40	0.33	0.16	0.63	0.21	0.04	63.6	70.8	73.9
145	49a	EM-P	0.20	1.03	0.09	0.78	0.13	0.62	-0.10	0.70	-0.18	0.40	79.1	83.4	85.1
146	49b	EM-M	0.21	0.98	0.32	0.03	0.00	0.33	0.25	0.30	0.06	0.75	80.3	88.3	90.4
147	49c	EM-P	0.30	0.99	0.08	0.86	0.10	0.51	0.06	0.30	-0.08	0.59	52.1	60.6	68.1
148	49d	EM-M	0.25	1.10	0.03	0.98	-0.51	0.06	-0.25	0.34	-0.21	0.44	25.0	31.8	42.0
149	50a	EM-E	0.18	1.09	-0.07	0.14	-0.20	0.20	0.46	0.00	-0.07	0.60	68.9	71.3	75.3
150	50b	EM-E	0.32	0.97	-0.14	0.19	0.31	0.10	0.08	0.43	0.22	0.08	58.3	63.5	74.7
151	50c	SY-E	0.14	1.19	0.18	0.97	-0.13	0.53	0.00	0.32	-0.21	0.34	70.9	73.6	75.6
152	50d	SY-E	0.22	1.06	0.08	0.38	-0.26	0.41	-0.25	0.22	-0.22	0.08	71.5	76.4	80.6
153	50e	EM-E	0.31	0.84	-0.09	0.86	0.27	0.98	0.31	0.32	0.20	0.98	77.3	81.6	88.3
154	54a	EV-P	0.34	0.95	-0.10	0.84	0.02	0.67	-0.15	0.20	0.14	0.20	52.4	60.1	66.0
155	54b	IF-P	0.22	1.06	0.09	0.98	-0.11	0.84	-0.03	0.92	-0.24	0.16	56.4	59.1	64.9
156	54c	EM-M	0.23	1.06	0.31	0.01	0.00	0.99	-0.23	0.38	0.00	0.34	44.7	56.5	52.4
157	54d	EM-M	0.23	1.02	0.17	0.20	0.09	0.95	0.06	0.62	0.00	0.86	78.0	82.1	88.0
158	55a	EM-E	0.31	0.89	-0.08	0.65	-0.03	0.23	-0.11	0.26	0.07	0.84	71.3	76.1	80.7
159	55b	SY-E	0.23	1.00	-0.12	0.24	0.04	0.97	0.16	0.57	-0.02	0.78	76.9	80.3	81.8
160	55c	EV-P	0.26	1.05	-0.12	0.27	0.05	0.36	-0.46	0.01	-0.37	0.01	40.5	47.6	54.7
161	55d	EV-E	0.24	1.01	0.04	0.68	-0.06	0.46	0.35	0.02	-0.13	0.43	71.6	74.1	77.4
162	55e	IF-P	0.23	0.95	-0.10	0.78	0.08	0.58	0.00	0.96	-0.18	0.28	77.6	80.2	81.0
163	59a	SY-E	0.31	0.97	-0.10	0.58	-0.08	0.24	0.06	0.41	0.08	0.99	58.1	60.3	70.0
164	59b	SF-E	0.27	0.96	-0.09	0.64	0.04	0.54	0.00	0.95	-0.05	0.80	66.9	70.5	79.5
165	59c	EV-E	0.20	1.12	0.14	0.40	0.15	0.13	-0.02	0.83	0.00	0.88	63.5	66.6	70.6
166	59d	SY-E	0.24	1.01	0.17	0.13	-0.08	0.39	0.18	0.10	0.00	0.93	70.6	68.5	76.2
167	60a	SY-E	0.28	0.90	0.28	0.03	0.17	0.50	0.24	0.19	0.26	0.16	78.6	83.5	86.7
168	60b	SY-E	0.31	0.87	0.07	0.66	0.09	0.95	0.09	0.86	0.14	0.92	73.3	79.7	86.1
169	60c	EM-P	0.21	1.09	0.00	0.77	-0.31	0.51	-0.06	0.96	-0.20	0.66	42.3	56.2	54.0
170	60d	SF-E	0.24	0.90	0.19	0.11	-0.10	0.26	0.42	0.01	0.00	0.56	81.8	87.5	90.6
171	60e	SY-E	0.25	0.83	0.42	0.00	0.07	0.98	0.00	0.37	0.09	0.90	86.1	87.3	92.8
172	61a	IF-P	0.10	1.25	-0.07	0.11	-0.11	0.92	-0.39	0.18	-0.29	0.40	69.8	70.1	67.2
173	61b	IF-P	0.25	0.76	0.17	0.10	0.28	0.97	0.42	0.18	0.20	0.64	88.5	91.5	94.6
174	61c	IF-P	0.27	1.05	0.16	0.76	-0.16	0.96	0.04	0.37	-0.12	0.76	29.5	32.5	50.6
175	61d	IF-P	0.17	1.10	0.28	0.09	0.00	0.58	0.09	0.39	-0.11	0.61	62.6	60.5	73.3

[1] Core concept: EV = evolution; SF = structure and function; IF = information flow, exchange, and storage; EM = pathways and transformations of energy and matter; SY = systems. Subdiscipline: M = molecular/cellular; P = physiology; E = ecology/evolution.

[2] Contrasts represent difference in logit estimates between the reference group and the non-reference group. A negative value indicates that the item was more challenging for the non-reference group.



Supplementary Materials 7. Comparisons of Rasch and classical student and item metrics. (A) Rasch student ability measures versus overall percent correct. Dots represent individual students, n = 5,175 students. (B) Rasch item difficulty versus item percent correct. Dots represent individual T/F items, n = 175 items. Note that harder items have more positive logit values, while easier items have more negative logit values.

Supplementary Materials 8. Planned interactions for linear mixed effects model[1]

Interaction term	$F_{(df)}$	p
Gender × Time Point	$F_{(2,4781.2)} = 0.26$	0.769
Race/Ethnicity × Time Point	$F_{(2,4801.2)} = 0.09$	0.916
Language × Time Point	$F_{(2,4801.9)} < 0.01$	0.996
Parent Education × Time Point	$F_{(2,4804.4)} = 0.37$	0.692
Institution × Time Point	$F_{(42,49.8)} = 6.22$	<0.001

[1] Interaction terms were individually added to the model from Table 3