Supplemental Material

CBE—Life Sciences Education

**Hester** *et al.*

1. In which way are plants and animals **different** in how they obtain or use energy?
    a) Animals use ATP; plants do not.
    b) Plants capture energy from sunlight; animals capture chemical energy.
    c) Plants use the energy stored in sugar molecules; animals do not.
    d) Animals can synthesize sugars from simpler molecules; plants cannot.

2. How many unique nucleotide-base sequences can a 20-nucleotide-long DNA strand have? (Note: There are 4 nucleotide bases in DNA.)
    a) Hundreds to thousands (100 to 9,999)
    b) Tens of thousands to hundreds of thousands (10,000 to 999,999)
    c) Millions (1,000,000 to 9,999,999)
    d) Millions of millions (1,000,000,000,000 to 9,999,999,999,999)

3. Chargaff's rules describe the relative proportions of the four different nucleotides in a cell's DNA (*i.e.*, A=T and C=G). No such rules exist for a cell's RNA. Which of the following is responsible for this difference?
    a) Most of the DNA in a cell is packaged in chromosomes, while most of the RNA in the cell is free-floating.
    b) Where DNA has thymine nucleotides, RNA has uracil nucleotides.
    c) RNA nucleotides cannot form base pairs.
    d) Most of the DNA in a cell is double-stranded, while most of the RNA in a cell is single-stranded.

4. If a bacterial genome (all the genes) contains 30% thymine nucleotides, what percentage of cytosine nucleotides does it contain?
    a) 20%
    b) 30%
    c) 40%
    d) 70%

5. Which of the following DNA strands are correctly paired?

6. The type of RNA polymerase that synthesizes mRNAs is inhibited by a poison called alpha-amanitin. RNA polymerase enzymes inhibited by this toxin work at rates of only 5 nucleotides added to the new strand per minute, as opposed to the normal rate of approximately 5,000 nucleotides added to the new strand per minute. At the rate of **5 nucleotides per minute**, how long would it take one of these poisoned RNA polymerase molecules to transcribe an mRNA that is **1000 nucleotides** long?
   a) 2000 minutes
   b) 200 minutes
   c) 20 minutes
   d) 2 minutes

7. When a DNA double-helix replicates, it uses building blocks from its surroundings. You label these building blocks so that you can tell the difference between "old" (part of the original DNA double helix) and "new" (from the surroundings) building blocks. Which of the following is **TRUE** about the two DNA double-helices produced by one round of DNA replication?
   a) One DNA double helix will have two old strands and one DNA double helix will have two new strands.
   b) One DNA double helix will have two old strands and one DNA double helix will have one old strand and one new strand.
   c) Each DNA double helix will have one old strand and one new strand.
   d) Each of the strands in both DNA double helices will be a combination of old and new building blocks.

8. Human chromosome 3 consists of about 200 million base pairs. In humans, DNA is replicated at a rate of about 100 base pairs per second per origin of replication. If it takes about an hour for a human cell to replicate chromosome 3, about how many origins of replication does human chromosome 3 have?
   a) One
   b) Hundreds (100-999)
   c) Thousands (1,000-9,999)
   d) Hundreds of thousands (100,000-999,999)

9. A single somatic (non-sperm or -egg) cell from *Castor canadensis* (an American beaver) contains 40 chromosomes. How many chromosomes will a *Castor canadensis* sperm or unfertilized egg contain?
   a) 10
   b) 20
   c) 40
   d) 80

10. A single somatic (non-sperm or -egg) cell from *Castor canadensis* (an American beaver) contains 40 chromosomes. How many chromosomes will a *Castor canadensis* zygote (fertilized egg) contain?
    a) 10
    b) 20
    c) 40
    d) 80

11. Polydactyly is a dominant, autosomal (not sex-linked) genetic disorder that results in too many digits (fingers or toes). Mike, 38 years old, has one copy of the mutant polydactyl allele (version of the gene) and one copy of the normal allele. His wife Carol is normal (she does not have polydactyly). What is the probability that Mike and Carol's first child will have the polydactyly trait?
    a) Practically zero
    b) 25%
    c) 50%
    d) 100%

12. Mike and Carol (from the previous question) have three children without polydactyly. What is the chance that their fourth child will have the polydactyly trait?
    a) Practically zero
    b) 25%
   c) 50%
    d) 100%

13.
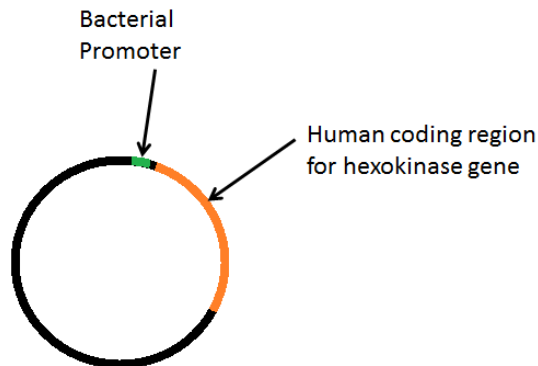
You have obtained a mutant bacterial strain in which the gene for hexokinase and its promoter (the upstream regulatory region) are missing. If you introduce into your mutant strain a DNA plasmid engineered to contain the coding sequence of the human hexokinase gene driven by the normal bacterial promoter (see figure), the resulting bacteria will now produce:

a) hexokinase with the bacterial amino-acid sequence.
b) hexokinase with the human amino-acid sequence.
c) hexokinase with an amino-acid sequence that is partly human, partly bacterial.
d) no hexokinase enzyme, because bacteria cannot read human genes.

Question #13 is adapted from Question #23 of the Introductory Molecular and Cell Biology Assessment (Shi *et al.*, 2010)
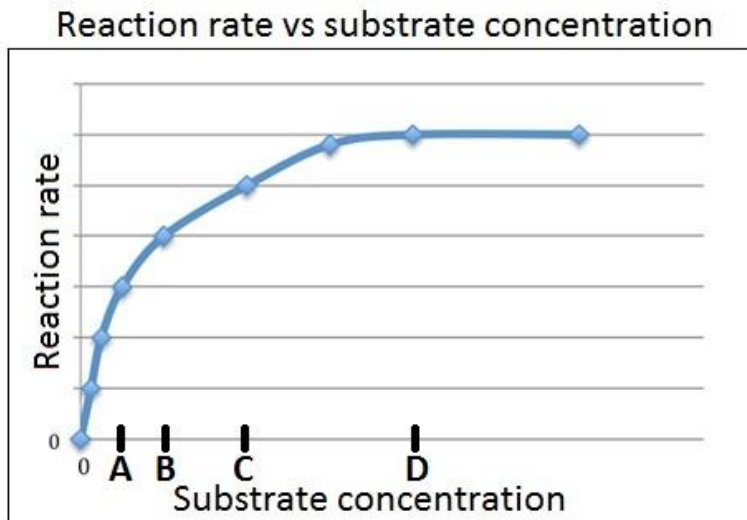
14. In the graph above, at which of the marked substrate concentrations will a small increase in the substrate concentration result in the greatest increase in reaction rate?
    a) A

15. The equation for calculating the change in Gibbs free energy for a reaction or process is

$$\Delta G = \Delta H - T\Delta S.$$

A reaction or process for which ΔH is positive (the reactants absorb heat) and ΔS is negative (the entropy of the reactants is decreased)…
    a) …will always be energetically favorable (will always occur spontaneously).
    b) …will never be energetically favorable (will never occur spontaneously).
    c) …may be energetically favorable (occur spontaneously) at high temperatures and energetically unfavorable (not occur spontaneously) at low temperatures.
    d) …may be energetically favorable (occur spontaneously) at low temperatures and energetically unfavorable (not occur spontaneously) at high temperatures.
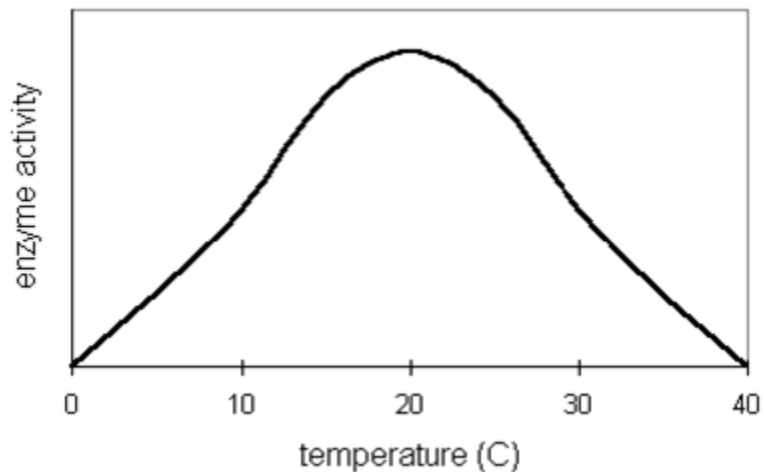
16.
    The graph above shows enzyme activity as a function of temperature for a typical enzyme. At what temperature(s) is the activity approximately 1/2 of the maximum activity for this enzyme? (The vertical axis is linear.)
   a) 10°C
    b) 20°C
    c) 0°C & 40°C
    d) 10°C & 30°C

17. In cells, genetic information is stored in DNA. Which of the following statements BEST outlines how that information is used in cells?
    a) DNA sequences (genes) directly carry out most of the processes of the cell.
    b) DNA sequences (genes) are templates for making proteins, which carry out most of the processes of the cell.
    c) DNA sequences (genes) are templates for making intermediate molecules called mRNA, which are templates for making proteins, which carry out most of the processes of the cell.
    d) DNA sequences (genes) are templates for making intermediate molecules called proteins, which are templates for making mRNAs, which carry out most of the processes of the cell.

18. The common mosquito has 3 pairs of chromosomes in its somatic (non-sperm or -egg) cells. If there is no crossing over during meiosis, how many genetically unique types of sperm cells can a single male mosquito make?
    a) 3
    b) 6
    c) 8
    d) 9

19. The short curly coat characteristic of Devon Rex cats is an **autosomal** (not sex-linked) **recessive trait**. Neither Spanky nor Peach has the Devon Rex trait, but in their first litter, 3 of the 8 kittens have the Devon Rex trait. Which of the following statements is **TRUE**?
    a) Spanky and Peach each have two copies of the Devon Rex allele (version of the gene).
    b) Spanky and Peach each have one copy of the Devon Rex allele (version of the gene).
    c) One of them has one copy of the Devon Rex allele (version of the gene) and the other has two copies.
    d) One of them has one copy of the Devon Rex allele (version of the gene) and the other has zero copies.
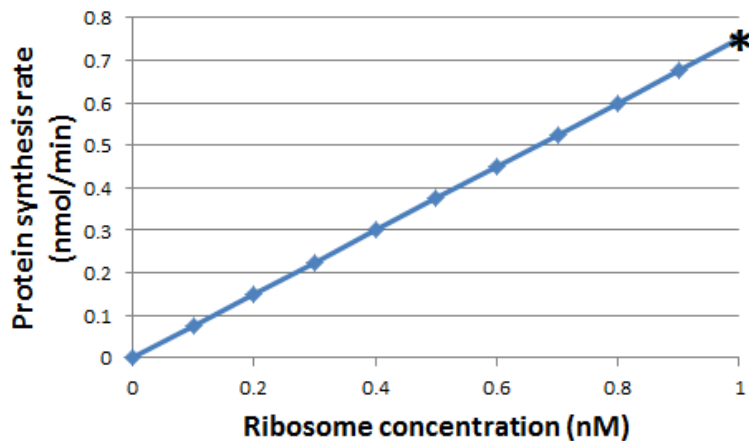
20.

The graph above shows the protein-synthesis rates in reaction mixtures with different ribosome concentrations. The reaction mixtures contain ribosomes, mRNA, "charged" tRNAs (tRNAs with amino acids attached), GTP and ATP. The concentrations of mRNA, tRNA, GTP and ATP are the same for all of the reaction mixtures plotted in the graph.

Starting from the point marked with a * in the graph, which of the following would most likely increase the protein-synthesis rate in the reaction mixture?
a) Increasing ribosome concentration
b) Increasing mRNA concentration
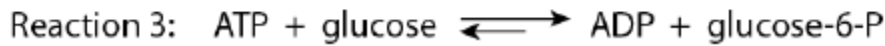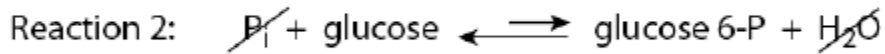c) Increasing tRNA concentration
d) All of the above.

21. In the presence of oxygen, our cells oxidize glucose to carbon dioxide and water according to the following chemical equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$
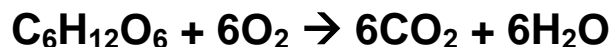
Which of the following is an important factor in O_2's primary role in this process?
a) Electrons "held" by oxygen in water have lower potential energy than electrons in C-H bonds.
b) O_2 contains high-potential-energy electrons that can be donated to an electron transport chain.
c) O_2 tends to form hydrogen bonds with H_2 to form water.
d) C=O bonds store more energy than O=O bonds.

Question #21 is adapted from Question #18 of the Introductory Molecular and Cell Biology Assessment (Shi *et al.* 2010).

Reaction 1: ATP + H_2O ⇌ ADP + P_i

Reaction 2: P_i + glucose ⇌ glucose 6-P + H_2O

Reaction 3: ATP + glucose ⇌ ADP + glucose-6-P
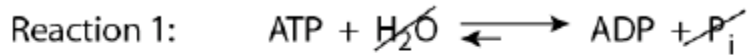
22.

The reaction catalyzed by the enzyme hexokinase (Reaction 3 above) can be thought of as the sum of Reactions 1 and 2. Reaction 1 is the breakdown of ATP to ADP, which releases energy. Reaction 2, in which glucose is phosphorylated, requires energy. When Reactions 1 and 2 are coupled in the enzyme active site, Reaction 3 will occur spontaneously because:

a) the enzyme active site effectively raises the temperature of the reaction.
b) both Reactions 1 and 2 can occur spontaneously alone (the enzyme just speeds up the reaction).
c) glucose-6-P and ADP contain more potential energy in their chemical bonds than ATP and glucose do.
d) the energy required to form glucose-6-P in Reaction 2 is less than the energy released by ATP breakdown in Reaction 1.

Question #22 is adapted from Question #14 of the Introductory Molecular and Cell Biology Assessment (Shi *et al.*, 2010).

23.

Just before mitosis, one of your chromosomes consists of two sister chromatids (see the figure above). The chromosome contains:

a) DNA from one of your parents in one sister chromatid and DNA from the other parents in the other sister chromatid.
b) a mixture of DNA from both of your parents in both sister chromatids as a result of recombination (crossing over) during meiosis.
c) a mixture of DNA from both of your parents in both sister chromatids as a result of recombination (crossing over) during fertilization.
d) DNA from only one of your parents.

Question #23 is adapted from Question #19 of the Introductory Molecular and Cell Biology Assessment (Shi *et al.*, 2010).

24. Which of the following describe(s) a molecular change that would be passed down through generations of cells?
    a) An enzyme mistakenly attaches the wrong amino acid to a tRNA, resulting in a protein with an error in its amino-acid sequence.
    b) An RNA polymerase mistakenly attaches an RNA nucleotide with the wrong base to a messenger RNA (mRNA), resulting in an mRNA with an error in its nucleotide-base sequence.
    c) A DNA polymerase mistakenly attaches a DNA nucleotide with the wrong base to a DNA strand, resulting in a DNA strand with an error in its nucleotide-base sequence.
    d) All of the above.

Supplementary Table S1. Comparing pre-/post-course assessment gains across sections

Sections Compared		Gain Category	Mean Difference (*significant)	Significance	Holm-Bonfferroni Correction
Experimental Section (n = 28)	**Section 2 (n = 158)**	Bio	0.056	0.399	N/A
		BioMath	0.174*	0.020	0.020
		Total	0.107	0.057	0.057
	Section 3 (n = 239)	Bio	0.138	0.038	N/A
		BioMath	0.221*	0.001	0.002
		Total	0.167*	0.001	0.002
	Section 4 (n = 220)	Bio	0.151	0.026	0.077
		BioMath	0.248*	0.001	0.002
		Total	0.188*	0.001	0.002
	Section 5 (n = 115)	Bio	0.189*	0.005	0.021
		BioMath	0.336*	0.000	0.000
		Total	0.245*	0.000	0.000

Gains measured as fraction of possible gain realized: Gain = (post score – pre score)/(total possible – pre score). Significance was calculated using an unpaired two-tailed t-test assuming equal variance using the IBM SPSS Statistics 20 software package. Within each gain category (Bio, BioMath, Total), the Holm-Bonferroni correction was applied to account for multiple-group comparisons within that category.

Table S2. Pre-/post-assessment gains by section.

Section	Assessment Section	Gain (mean +/- SEM)
Experimental (n = 28)	Bio	36.24% +/- 6.80%
	BioMath	35.97% +/- 6.26%
	Total	36.86% +/- 5.75%
2 (n = 158)	Bio	30.67% +/- 2.51%
	BioMath	18.55% +/- 2.94%
	Total	26.17% +/- 2.12%
3 (n = 239)	Bio	22.44% +/- 2.13%
	BioMath	13.89% +/- 2.06%
	Total	20.21% +/- 1.51%
4 (n = 220)	Bio	21.13% +/- 2.24%
	BioMath	11.20% +/- 2.50%
	Total	18.08% +/- 1.88%
5 (n = 115)	Bio	17.35% +/- 2.84%
	BioMath	2.36% +/- 3.45%
	Total	12.36% +/- 2.36%

Gains measured as percentage of possible gain realized: Gain = 100%(post score – pre score)/(total possible – pre score).

Supplementary Text ST1. Students perform poorly on math-application biology problems compared to math-only problems.

In Spring 2012, 284 incoming MCB 181R students completed a pre-course assessment that included mathematics problems outside of any additional context and biology problems requiring application of the same skills. Students correctly answered problems requiring application of math in a biological context substantially less frequently than they did problems requiring application of the skills outside of additional context. This phenomenon becomes more pronounced with increasing difficulty of the math skill and novelty of the biological context.

Examples are given below.

Mathematics-only problem
Solve the following for t.

$x = vt$
$x = 10$
$v = 2$

   a) $t = 0.2$
   b) $t = 0.5$
   c) $t = 5$
   d) $t = 20$

Bio-Math problem
The type of RNA polymerase that synthesizes mRNAs is inhibited by a poison called alpha-amanitin. RNA polymerase enzymes inhibited by this toxin work at rates of only 5 nucleotides added per minute, as opposed to the normal rate of approximately 5,000 nucleotides per minute. At the rate of **5 nucleotides per minute**, how long would it take one of these poisoned RNA polymerase molecules to transcribe an mRNA that is **1000 bases** long?
   e) 2000 minutes
   f) 200 minutes
   g) 20 minutes
   h) 2 minutes

Comparison

	Correct answers - Math	Correct answers - BioMath	Difference
Correct/Total students	260/284	236/284	24/284
Percentage	92%	83%	9%

Mathematics-only problem
Solve the following for x.

$x = y$
$z = w$
$x + y + z + w = 100$
$z = 20$

    a) $x = 70$
    b) $x = 60$
    c) $x = 40$
    d) $x = 30$
    e) $x = 20$

BioMath problem
The four types of nucleotides that make up DNA are guanine, cytosine, adenine and thymine. Chargaff's rules state that, in a cell's DNA, the number of guanine nucleotides should equal the number of cytosine nucleotides and the number of adenine nucleotides should equal the number of thymine nucleotides. If a bacterial genome (all the genes) contains 30% thymine nucleotides; what percentage of cytosine nucleotides does it contain?
    a) 20%
    b) 30%
    c) 40%
    d) 70%

Comparison

	Score on Math problem	Score on BioMath problem	Difference
Correct/Total students	230/284	131/284	99/284
Percentage	81%	46%	35%