Supplemental Material

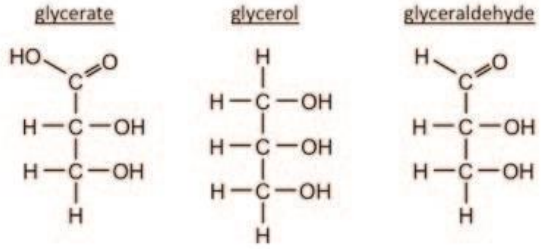
CBE—Life Sciences Education

Walck-Shannon *et al.*

Supplemental Material 1: Pre/post test items

1. Which of the following best describes the process by which a protein-coding gene is expressed?
   a. DNA is chemically converted into RNA, which is then chemically converted into a protein molecule, all within the same cell.
   b. DNA is chemically converted into RNA, which is used as a template for building a protein molecule that is then transported to another cell.
   c. DNA is transported from one cell to another, where it is chemically converted first into RNA and then into a protein molecule.
   d. DNA is used as a template to build a new RNA strand, which is used as a template to build a protein molecule, all within the same cell.
   e. DNA is used as a template to build a new RNA strand, which is transported to another cell and then chemically converted into a protein molecule.

2. Order the following three molecules, from least reduced to most reduced:



   a. Glyceraldehyde, glycerate, glycerol
   b. Glycerate, glyceraldehyde, glycerol
   c. Glycerol, glycerate, glyceraldehyde
   d. Glyceraldehyde, glycerol, glycerate
   e. Glyceraldehyde, glycerate, glycerol

3. Which of the following statements are true of prokaryotic cells?
   1. Their chromosomes are surrounded by a nuclear envelope.
   2. They contain ribosomes.
   3. They have a plasma membrane.
   4. They contain a Golgi apparatus and rough and smooth endoplasmic reticulum.
   5. They are usually much larger than eukaryotic cells.

   a. 1, 2, 3, 4
   b. 2, 3, 4, 5
   c. 1, 2, 3
   d. 2 and 3
   e. 1, 2, 5

4. Which of the following sites is NOT found on a ribosome?
   a. tRNA exit site
   b. Site for a tRNA covalently attached to the growing peptide chain
   c. Site that helps translation factors hydrolyze GTP
   d. tRNA charging site
   e. mRNA binding site

5. The main bonds that hold atoms together within a single glucose molecule are formed by:

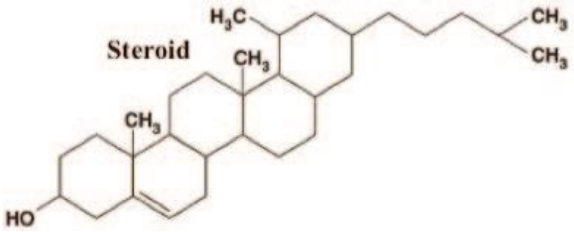
a. Sharing of electrons between atoms
b. Attraction between atoms with opposite charges
c. Gravitational attraction between atoms
d. Interactions between partial charges on individual atoms
e. Attraction between polar and nonpolar atoms

6. Order the following types of sequences from most abundant to least abundant in the human genome.

1. Intergenic noncoding sequences
2. Exon sequences
3. Intron sequences

a. 1,2,3
b. 3, 2, 1
c. 1, 3, 2
d. 2, 1, 3
e. 3, 1, 2

7. Arrange the following substances in order of DECREASING permeability (from most permeable to least permeable) through an artificial lipid bilayer. The structure of a representative steroid is shown below.



a. Chloride ion, water, steroid
b. Steroid, water, chloride ion
c. Steroid, chloride ion, water
d. Water, steroid, chloride ion
e. Water, chloride ion, steroid

8. What molecule in the light reactions of photosynthesis plays the same role that oxygen plays in the mitochondrial electron transport chain?

a. chlorophyll
b. water
c. CO2
d. NADP+
e. ATP

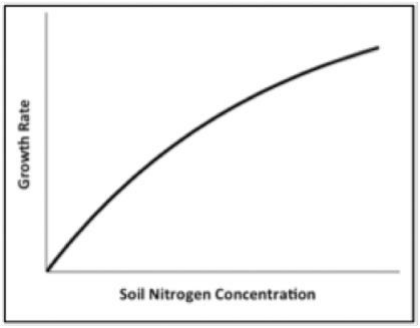
9. Of the following mutations, ____ is likely most deleterious, and ____ is likely least deleterious. A table of the genetic code is shown below.

TTT, TTC: Phe TTA, TTG: Leu	TCT, TCC, TCA, TCG: Ser	TAT, TAC: Tyr TAA: Stop TAG: Stop	TGT, TGC: Cys TGA: Stop TGG: Trp
CTT, CTC, CTA, CTG: Leu	CCT, CCC, CCA, CCG: Pro	CAT, CAC: His CAA, CAG: Gln	CGT, CGC, CGA, CGG: Arg
ATT, ATC, ATA: Ile ATG: Met	ACT, ACC, ACA, ACG: Thr	AAT, AAC: Asn AAA, AAG: Lys	AGT, AGC: Ser AGA, AGG: Arg
GTT, GTC, GTA, GTG: Val	GCT, GCC, GCA, GCG: Ala	GAT, GAC: Asp GAA, GAG: Glu	GGT, GGC, GGA, GGG: Gly

1. A change from TCA to TCG near the beginning of the open reading frame
2. A change from TAC to TAA near the beginning of the open reading frame
3. The insertion of an A near the end of the open reading frame
4. A change from TCT to CCT near the middle of the open reading frame

a. Most deleterious: 3, least deleterious: 4.
b. Most deleterious: 4, least deleterious: 2.
c. Most deleterious: 2, least deleterious: 3.
d. Most deleterious: 2, least deleterious: 1.
e. Most deleterious: 3, least deleterious: 1.

10. The graph at below represents data collected over a period of 50 years, monitoring the relationship between soil nitrogen concentration and the growth rate in soybean plants. How would you interpret this graph?

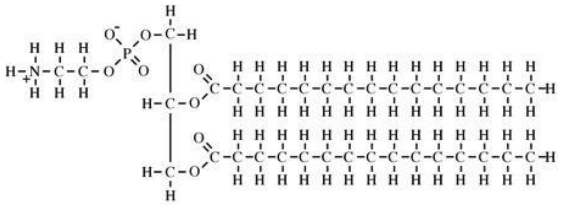


a. As soil nitrogen levels increase, growth rate increases.
b. As soil nitrogen levels increase, growth rate decreases.
c. As growth rate increases, soil nitrogen levels decreases.
d. As growth rate increases, soil nitrogen levels decrease.
e. Soil nitrogen levels and growth rates are both increasing over time.

11. Certain cells found inside a leaf have unusually large numbers of ribosomes and an extensive rough ER (endoplasmic reticulum), as well as many vesicles near the plasma membrane. These cells have probably adapted to...

a. conduct photosynthesis
b. store water
c. secrete proteins
d. undergo rapid cell division
e. provide structural support

12. Which of the following terms correctly describe features of the molecule shown below?



1. Phospholipid
2. Contains amino acids
3. Polyunsaturated
4. Amphipathic

a. 1 and 4
b. 2, 3, 4
c. 1, 2, 3
d. 2 and 4
e. 1 and 3

13. In the DNA double helix, the two DNA strands are held together by...
a. hydrogen bonds between the sugar/phosphate backbones
b. hydrogen bonds between nitrogenous bases
c. covalent bonds between the sugar/phosphate backbones
d. covalent bonds between nitrogenous bases
e. all of the above

14. In eukaryotes, which of the following is NOT a major target for transcriptional activator proteins?
a. Complexes that acetylate histones.
b. Complexes that hydrolyze ATP to remodel nucleosomes.
c. The general transcription factor TFIID.
d. The mediator complex.
e. RNA polymerase.

15. By which of the following mechanisms could a tumor suppressor gene be altered in a way that contributes to the development of cancer?
1. Gene amplification
2. Single base pair changes
3. DNA cytosine methylation
4. Histone acetylation

a. 1, 2, 4
b. 1, 2, 3
c. 1 and 3
d. 2 and 3
e. 3 and 4

16. How do enzymes speed up the rate at which a biological reaction occurs?
a. By increasing the energy of the reactant molecules.
b. By increasing the total amount of energy released by the reaction.
c. By decreasing the amount of energy needed to proceed through the reaction.
d. By increasing the energy of the product molecules.
e. By making the reaction release energy rather than requiring energy.

17. Starting from the outer side of a cell membrane and ending on the inner side, what is the order of polar (P) and nonpolar (N) regions within the membrane?

a. P, N
b. N, P
c. P, N, P
d. N, P, N
e. P, N, P, N

18. Repair of DNA damage in eukaryotic cells involves which of the following processes?

1. Detection of DNA damage
2. DNA synthesis
3. Excision of DNA damage
4. Transcription of repaired DNA

a. 1 and 2
b. 1, 3, 4
c. 1, 2, 3
d. 2, 3, 4
e. All of 1-4

19. Assume you want to set up a transformation experiment. Your instructor gives you bacterial cells to use, but warns you to include controls to double check that the cells are sensitive to ampicillin, as is needed for the experiment. What controls would be important for this experiment?

1. Plating the cells on an agar plate that contains all nutrients essential for bacterial growth, and does not contain ampicillin.
2. Plating the cells on an agar plate that does not contain all the nutrients essential for bacterial growth.
3. Plating the cells on an agar plate that contains all nutrients essential for bacterial growth, and contains ampicillin.
4. Plating the cells on an agar plate that contains all nutrients essential for bacterial growth, and contains tetracycline and ampicillin.

a. 1 and 3
b. 1, 3, 4
c. 3 and 4
d. 1, 2, 3
e. All of 1-4

20. Assume you did the transformation experiment described in the previous question, including the correct controls to check that cells are sensitive to ampicillin. When you look at the results, you see 65 colonies on the experimental plate, which matches your expectations. However you also see 60 colonies on the control plate where you expected no growth. What is the best interpretation of these results?

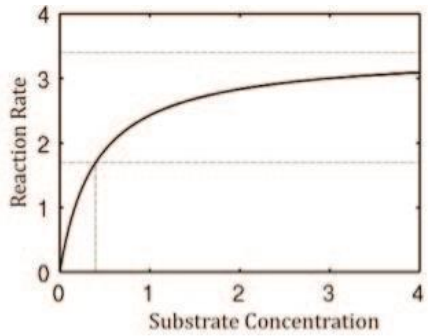
	# colonies observed
Experimental plate (expect some colonies)	65
Control plate (do NOT expect any colonies)	60

a. Something is probably wrong with the agar plates. The experiment should be repeated with different agar plates.
b. Only the control was set up incorrectly, so you can assume the results on the experimental plate are valid
c. Five of the colonies on the experimental plate were successfully transformed, so you should test all 65 to find the correct five.
d. Something is probably wrong with either the starting cells or the plates. Further experiments are needed to determine which.
e. Five of the colonies on the experimental plate were successfully transformed; you can choose any five and continue with the experiment.

21. What is the main criterion that determines whether a cell must expend ATP to take up a solute via a transport protein?

a. Whether the cell's membrane actively repels the solute
b. Whether the solute is electrically charged
c. The solute's diameter
d. The solute's concentration on each side of the membrane
e. Whether the solute is hydrophobic or hydrophilic

22. What two important properties of an enzyme can be determined from the graph shown below?



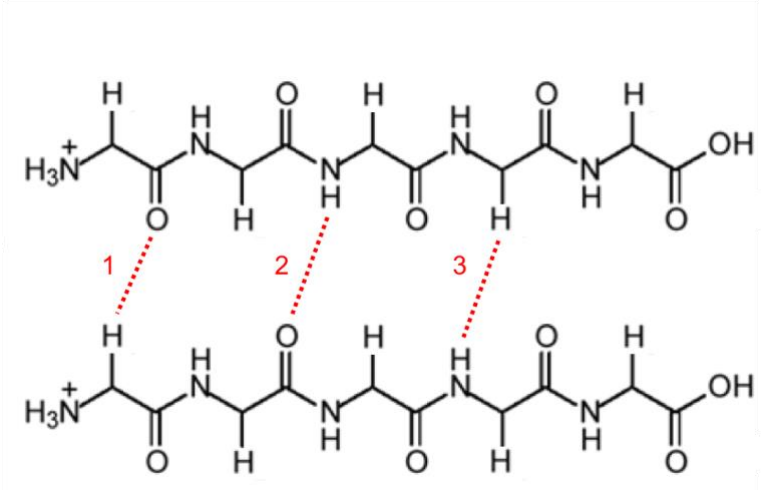
1. An indication of the affinity an enzyme has for its substrate
2. The total amount of product produced at the end of the reaction
3. The number of substrate molecules that can be converted into product per unit time
4. The difference in free energy between the products and the substrates
5. The difference in free energy between the transition state and the substrates

a. 1 and 2
b. 1 and 3
c. 4 and 5
d. 1 and 4
e. 2 and 3

23. What role does tRNA play in gene expression?

a. It helps the newly synthesized protein fold up into the correct shape.
b. It adds the correct amino acid to the protein being synthesized
c. It serves as a starting point for building the new RNA strand.
d. It temporarily separates the two strands of the DNA double helix.
e. It binds to the gene's promoter to start the process of transcription.

24. The structures of two small peptides are shown below. Which of the red dotted lines indicate chemical interactions between the atoms in the two peptides that are most likely to form a hydrogen bond?



a. 1
b. 2
c. 3
d. 1 and 2
e. all of the above

25. Which statement about oxidative phosphorylation is NOT true?
    a. It generates ATP using energy provided by the respiratory electron transfer chain.
    b. It requires aerobic conditions.
    c. It takes place in the cell's cytosol.
    d. It requires a proton motive force.
    e. It is powered by NADH and $FADH_2$ produced by the tricarboxylic acid (TCA) cycle.

26. Give the correct order of the following steps in the "flight or fight" response.
    1. Stored glucose molecules are released from glycogen.
    2. Epinephrine binds to its receptor outside the cell.
    3. cAMP activates a protein kinase.
    4. A G-protein is activated.
    5. Glucose is released into the bloodstream.

    a. 2, 1, 3, 4, 5
    b. 2, 4, 3, 1, 5
    c. 2, 3, 4, 1, 5
    d. 1, 2, 4, 3, 5
    e. 1, 4, 3, 2, 5

27. A protein coding gene consists of...
    a. the entire set of DNA contained within a cell's nucleus
    b. one of the many chromosomes found in the nucleus
    c. a long stretch of several thousand DNA nucleotides
    d. a short stretch of 10-20 DNA nucleotides
    e. a single DNA nucleotide

28. Which of the following pairs constitute a monomer and the corresponding polymer?
    1. Glucose:starch
    2. Amino acid:polypeptide
    3. Fatty acid:triglyceride
    4. Glucose:cellulose

    a. 1, 2, 4
    b. 1 and 3
    c. 3 and 4
    d. 2, 3, 4
    e. 1 and 2

29. Which of these sequences do NOT contribute to the proper expression of a eukaryotic protein-coding gene?
    a. Core promoter elements (TATA Box etc.) that bind general transcription factors
    b. Binding sites for transcription activator proteins.
    c. Consensus -10 and -35 sequences that directly bind RNA polymerase.
    d. A signal for RNA cleavage and polyA addition
    e. 5' and 3' splice sites.

30. Within a mitochondrion, in what direction do protons move through ATP synthase?
    a. From both the cytosol and mitochondrial matrix into the intermembrane space
    b. From the cytosol into the intermembrane space
    c. From the intermembrane space into the mitochondrial matrix
    d. From the mitochondrial matrix into the intermembrane space
    e. From the intermembrane space into the cytosol

31. Kinases are essential in the cell because they...
    1. help regulate protein function through changes in protein phosphorylation status.
    2. are enzymes that denature damaged proteins.
    3. destroy second messengers, thereby turning off a signal transduction pathway.
    4. provide a mechanism for amplifying the effect of the original signaling molecule.
    a. 1
    b. 2
    c. 2 and 3
    d. 1 and 4
    e. All of 1-4

32. The information encoded within a gene results primarily from...
    a. the overall shape of the DNA molecule
    b. the way in which particular bases in one strand pair with those in the other
    c. the order of the individual bases
    d. the percentage of the individual bases within the gene
    e. the precise location of the chromosomes within the nucleus

33. Short interfering RNAs (siRNAs) are important tools for genome-wide functional analysis of eukaryotic sequences. Which of the following can be learned by the use siRNAs?
    a. The location of any histone modifications.
    b. Patterns of alternative gene splicing.
    c. Quantitative mRNA expression
    d. Null phenotypes of individual genes.
    e. The intracellular location of specific proteins.

34. How do most plants and animals differ in the way they obtain energy?
    a. Animals use ATP; plants don't

b. Plants store energy in carbohydrate molecules; animals don't.
c. Animals eat food; plants use water and soil as their food.
d. Plants synthesize their own food; animals don't.
e. Animals carry out cellular respiration: plants don't.

35. Which of the following help maintain the three-dimensional structure of a typical protein?

1. Attractions between residues with opposite charges
2. Interconversions between alpha helices and beta sheets
3. Disulfide bonds between cysteine residues
4. Hydrogen bonding between different amino acids in a polypeptide chain

a. 1, 3, 4
b. 1 and 2
c. 2, 3, 4
d. 2 and 4
e. All of 1-4

36. In prokaryotes (bacteria), transcriptional activator proteins work primarily by...

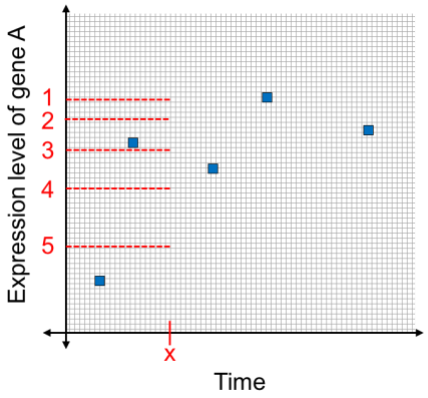
a. changing the structure of DNA so that RNA polymerase can bind to promoter DNA.
b. changing the structure of RNA polymerase so that RNA polymerase can bind to promoter DNA.
c. binding to DNA and recruiting RNA polymerase to promoter DNA.
d. preventing repressors from binding to DNA, allowing RNA polymerase to bind to promoter DNA.
e. making chromatin accessible so that RNA polymerase can bind to promoter DNA.

37. Unlike the lagging strand, the leading strand of DNA is synthesized...

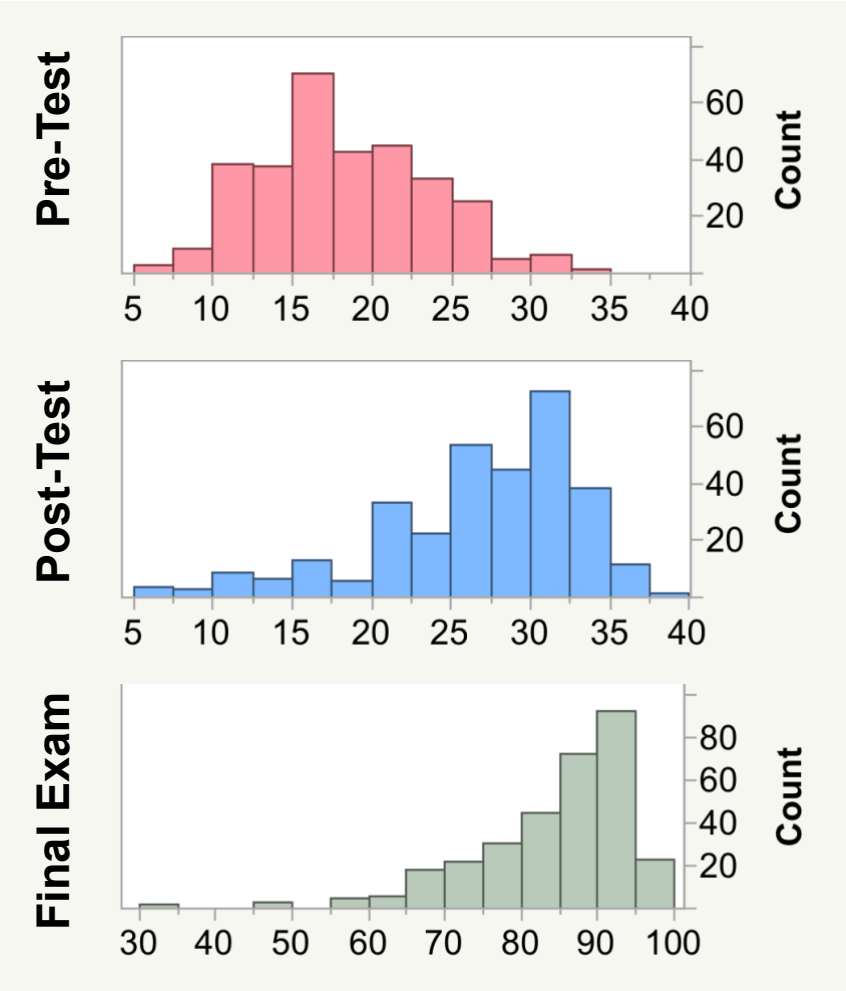
a. from a single RNA primer
b. from the 3' end to the 5' end
c. using thymine instead of uracil bases
d. in both directions from the origin of replication
e. semiconservatively

38. Data points for the expression level of gene A at different time points are plotted in the graph below. Assuming that expression of gene A increases linearly over time, what level of gene expression do you estimate for gene A at time “x” (see graph)?

a. 1
b. 2
c. 3
d. 4
e. 5



Supplemental Material 2: Histograms and descriptive statistics for the pre/post test and the final exam. The median is given for the completion time of the pre/post test because the mean was skewed by students who left their browsers open for multiple hours as they completed the test.



Statistical Measure	Pre-Test (out of 38)	Post-Test (out of 38)	Final Exam (out of 100)
Mean Score	17.945	26.735	84.334
Std Dev	5.206	6.258	9.929
Std Err Mean	0.296	0.355	0.564
Median Time to Complete (mm:ss)	30:54	27:46	N/A
N	310	310	310

Supplemental Material 3: Selection of predictor control variables. A) Pairwise correlations (r) between performance and potential control variables, where the following symbols indicate significance, *p≤0.05, **p≤0.01, ***p≤0.001. The number of students included in the correlations is in parentheses. B)-C) Model-level statistics (R^2 and adjusted R^2 values) predicting Biology post-test scores with listed predictor variables. In both cases, biology pre-test score and chemistry final exam score were added in at step 1, and other variables were added in step 2. Neither the addition of ACT composite and AP proportion (B) or conscientiousness (C) at step 2 significantly improved the model (the p-values for F-test of ΔR^2 were >0.05, see text). For B), the n=283, which represents the subsample for which ACT scores were available. And for C), the n=231, which represents the subsample for which personality data were available.

A)

	r to Biology Post-Test	r to Final Exam
Biology Pre-Test	0.4325*** (310)	0.3049*** (310)
Chemistry Final Exam Score	0.4981*** (310)	0.6455*** (310)
AP Proportion[&]	0.3718*** (310)	0.3940*** (310)
ACT Composite	0.2278*** (283)	0.2364*** (283)
Agreeableness	-0.1001 (228)	-0.0203 (228)
Openness	-0.0311 (227)	0.0593 (227)
Conscientiousness	0.0937 (231)	0.0720 (231)
Extraversion	-0.0722 (227)	-0.1134 (227)
Neuroticism	0.0489 (229)	0.1163 (229)

B)

Model Level Statistics	Step 1	Step 2
	Biology Pre-Test and Chemistry Final	Biology Pre-Test, Chemistry Final, ACT composite and AP Proportion
R^2	0.3090	0.3103
R^2 Adjusted	0.3041	0.3004
ΔR^2	--	0.0013

C)

Model Level Statistics	Step 1	Step 2
	Biology Pre-Test and Chemistry Final	Biology Pre-Test, Chemistry Final, and Conscientiousness
R^2	0.3066	0.3090
R^2 Adjusted	0.3005	0.2999
ΔR^2	--	0.0024

[&]AP proportion is the ratio of the STEM AP courses (out of 4 categories: Bio; Chem; Calc [or AB or BC]; Physics [B or CE or CM]) for which a student scored a 4 or greater.

Supplemental Material 4: Models that account for quiz first-attempt scores. Standardized β values for each predictor variable (β_{std}) and model levels statistics of hierarchical regression analysis that predicts Biology post-test score (A) and final exam score (B). For the model level statistics, an F-test was performed to ask if each step significantly improved the fit of the model relative to the previous step. The following symbols indicate significance, *p≤0.05, **p≤0.01, ***p≤0.001, n=310.

A) Post-test

Standardized Predictor Coefficients				
	Step 1	Step 2	Step 3	Step 4
Chem. Final Exam Score	0.404***	0.334***	0.313***	0.294***
Bio. Pre-Test	0.309***	0.280***	0.300***	0.298***
First Attempt Average	--	0.176***	0.162**	0.170**
Number of Quizzes Retaken	--	--	0.124**	0.139**
Chem. Final Exam Score x Number of Quizzes Retaken	--	--	--	-0.111*
Bio. Pre-Test x Number of Quizzes Retaken	--	--	--	0.004
First Attempt Average x Number of Quizzes Retaken	--	--	--	0.040
Model Level Statistics				
R^2	0.335	0.359	0.373	0.382
R^2_{adj}	0.331	0.353	0.365	0.368
ΔR^2	--	0.024***	0.014**	0.009

B) Final Exam

Standardized Predictor Coefficients				
	Step 1	Step 2	Step 3	Step 4
Chem. Final Exam Score	0.565***	0.447***	0.436***	0.415***
Bio. Pre-Test	0.265***	0.214***	0.224***	0.226***
First Attempt Average	--	0.298***	0.291**	0.279**
Number of Quizzes Retaken	--	--	0.063	0.085*
Chem. Final Exam Score x Number of Quizzes Retaken	--	--	--	-0.116*
Bio. Pre-Test x Number of Quizzes Retaken	--	--	--	-0.023
First Attempt Average x Number of Quizzes Retaken	--	--	--	0.000
Model Level Statistics				
R^2	0.480	0.549	0.552	0.567
R^2_{adj}	0.477	0.544	0.547	0.557
ΔR^2	--	0.069***	0.003	0.015*

Supplemental Material 5: Interaction plot relating biology final-exam free-response sub-score to the number of quizzes re-taken during the semester. The graph is split up into four panes, which represent quartiles for the final-exam score in a previous STEM course (General Chemistry I). Blue line indicates best-fit, while the shaded area around it represents the 95% confidence interval for the fit.