Supplemental Material

CBE—Life Sciences Education

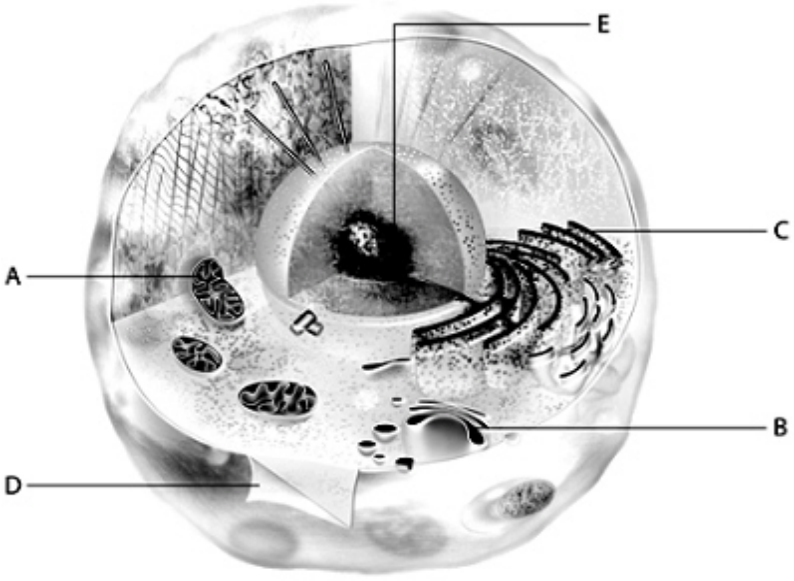
Barral *et al.*

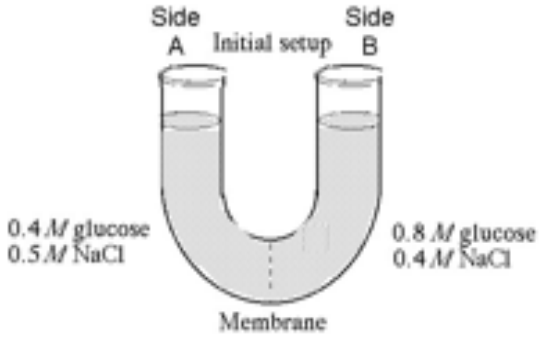
Table 1S. Learning Objectives of the BIO161 course. Learning Objectives in bold were assessed in the Post 1 and Post 2 quizzes.

1	**Describe fundamental concepts in chemistry and biochemistry, including the properties of water, important organic molecules, acids and bases.**
2	**Explain cell structure and function, and the difference between prokaryotes and eukaryotes.**
3	Describe metabolism at the cellular level, including enzyme activity, cellular respiration, and photosynthesis.
4	Explain the cell cycle, mitosis, and meiosis.
5	Describe DNA structure and function, including replication, transcription, and translation.
6	Explain Mendelian genetics and inheritance patterns.
7	Calculate expected genotypic and phenotypic frequencies using Punnett squares.

Figure 1S. Quiz questions in Post 1 and Post 2, per LO, Bloom's levels, and mapped activities (if applicable). Three independent investigators evaluated each question for Bloom's levels of taxonomy (knowledge, understanding, application, analysis, synthesis, and/or evaluation), and rankings were combined through consensus. Based on the rankings, questions were classified as low, medium, and high Bloom's level. Low Bloom's level pertained to questions with lower Bloom's Taxonomy (i.e. knowledge and understanding). Questions with medium Bloom's level assessed knowledge, understanding, application, and analysis. High Bloom's level, in addition, assessed synthesis and/or evaluation.

LO	Question	Bloom level	Activity
1	1. One difference between carbon-12 and carbon-14 is that carbon-14 has A) two more protons and two more neutrons than carbon-12. B) two more electrons and two more neutrons than carbon-12. C) two more neutrons than carbon-12. D) two more electrons than carbon-12. E) two more protons than carbon-12.	medium	N/A
1	2. A covalent chemical bond is one in which A) electrons are removed from one atom and transferred to another atom so that the two atoms become oppositely charged. B) protons and neutrons are shared by two atoms so as to satisfy the requirements of both atoms. C) an electron occupies a hybrid orbital located between the nuclei of two atoms. D) outer-shell electrons of two atoms are shared so as to satisfactorily fill the outer electron shells of both atoms. E) outer-shell electrons of one atom are transferred to fill the inner electron shell of another atom.	medium	Molecular models
1	3. Which of the following best explains why a particular atom may not form compounds readily? A) The atom has an uneven number of protons. B) The atom's outer valence shells are completely full. C) The atom has no protons. D) The atom has seven electrons in its outer valence shell.	medium	N/A
1	4. Why is each element unique and different from other elements in chemical properties? A) Each element has a unique atomic mass. B) Each element has a unique number of neutrons in its nucleus. C) Each element has a unique number of protons in its nucleus. D) Each element has different radioactive properties. E) Each element has a unique atomic weight.	low	N/A
1	5. In a single molecule of water, two hydrogen atoms are bonded to a single oxygen atom by A) ionic bonds. B) van der Waals interactions. C) nonpolar covalent bonds.	low	Molecular models

	D) polar covalent bonds. 1E) hydrogen bonds.		
1	6. Which of the following is NOT a compound? A) H_2O B) CH_4 C) CO_2 D) O_2 E) ATP	low	N/A
1	7. If the pH of a solution is decreased from 9 to 8, it means that the A) concentration of OH- has decreased to one-tenth (1/10) what it was at pH 9. B) concentration of H+ has increased tenfold (10X) compared to what it was at pH 9. C) concentration of H+ has increased tenfold (10X) and the concentration of OH- has decreased to one-tenth (1/10) what they were at pH 9. D) concentration of H+ has decreased to one-tenth (1/10) what it was at pH 9. E) concentration of OH- has increased tenfold (10X) compared to what it was at pH 9.	high	pH activity
1	8. Which type of bond must be broken for water to vaporize? A) polar covalent bonds B) ionic bonds C) both polar covalent bonds and hydrogen bonds D) both hydrogen bonds and ionic bonds E) hydrogen bonds	medium	N/A
2	9. Large numbers of ribosomes are present in cells that specialize in producing which of the following molecules? A) lipids B) proteins C) starches D) steroids E) glucose	medium	Cell structures diagrams
2	 10. Match the letters in the figure to the descriptions below. I. ___ The organelle that converts food energy to ATP (chemical energy)	medium	Cell structures diagrams Organelle function sheet

	II. ___ The type of ER that has ribosomes associated to it. III. ___ The site for packaging and shipping of proteins. IV. ___ Part of the nucleus, this is the site of ribosome assembly. V. ___ Consists of a phospholipid bilayer with embedded proteins and cholesterol.		
2	11. Which structure is common to both plant and animal cells? A) chloroplast B) wall made of cellulose C) central vacuole D) mitochondrion E) centriole	low	Cell structures diagrams Organelle function sheet
2	12. Which of the following statements is correct about facilitated diffusion? A) It does not require an expenditure of energy by the cell. B) It is a passive process in which molecules move from a region of higher concentration to a region of lower concentration. C) It requires a carrier protein. D) A and B E) A, B, and C.	medium	N/A
2	The solutions in the arms of a U-tube are separated at the bottom of the tube by a selectively permeable membrane. The membrane is permeable to sodium chloride but not to glucose. Side A is filled with a solution of 0.4 M glucose and 0.5 M sodium chloride (NaCl), and side B is filled with a solution containing 0.8 M glucose and 0.4 M sodium chloride. Initially, the volume in both arms is the same.  13. After a day, in side B the volume _____, the NaCl concentration _____, and the glucose concentration _____. A) increases, increases, stays the same B) decreases, decreases, increases C) stays the same, increases, stays the same D) decreases, increases, decreases E) increases, increases, decreases	high	Dialysis membrane
2	14. Which of the following substances would have the most difficulty crossing a biological membrane through the phospholipid bilayer? A) H_2O B) Na+ C) CO_2	high	Dialysis membrane

	D) O_2 E) a small, non-polar molecule		
2	15. A patient is severely dehydrated (his cells have lost water). Which IV solution would be better suited to rehydrate him? A) Isotonic saline (0.9% NaCl) B) A hypotonic solution such as D5W (5% dextrose in water). C) A hypertonic solution such as 3% saline.	high	Dialysis membrane

Table 2S. Description of all in-class activities used in the flipped sections. Activities mapped to quiz questions are bolded.

Name of activity	**Description**
Themes of biology on papers	Students write examples of the core concepts of biology per the Vision and Change report.
Cell surface volume handout	Students calculate the surface area and volume of a hypothetic cell (cube) and discuss the importance of the surface/volume ratio.
Agar cubes	Students observe the speed of diffusion of a solution (visualized by a pH change) in agar cubes of different volumes.
Cell structures sheet	Students complete handouts identifying structures in prokaryotic, animal, and plant cells.
Organelle function sheet	Students complete handouts identifying organelles and matching them to their functions.
pH activity	Students predict and then test the pH of household liquids.
Molecular models to go over organic chemistry	Students build biomolecules of increasing complexity using molecular models.
Prayer case study for scientific method https://goo.gl/tCnNJ8 National Center for Case Study Teaching in Science, University at Buffalo, State University of New York	Discussion about the scientific method using a case study.
Writing examples of molecules with functional groups, carbohydrates, lipids, etc.	Students identify the functional groups of biomolecules of interest.
Dialysis exercise	Students observe the processes of diffusion and osmosis using a dialysis bag containing permeable (glucose) and non-permeable (starch) solutes, immersed in water.
Writing examples of catabolism/anabolism	Students explore the catabolic or anabolic nature of metabolic pathways of their choice.
Beta-globin bioinformatics activity http://www.3dmoleculardesigns.com/Education-Products/Map-of-the-Human-Globin-Gene.htm	Students identify exons and introns using a 3D Molecular Design kit
Mitosis/meiosis handouts	Students identify and order phases of mitosis and meiosis using diagrams

Table 3S. Scoring rubric of activities. The criteria were chosen through a consensus process involving two of the authors and peers with experience in scientific teaching. They included aspects such as addressing core concepts of the VC framework and successful evidence-based practices in science education. Based on the total score, activities were classified as low (≤5), medium (6-9), or high (≥10) level.

Aspect evaluated	**Possible points**			**Factor**	**Total possible**
	Low	**Medium**	**High**		
Address VC core concept(s)	None or only one (0)	2	>2	1x	2
Inquiry-driven: students need to address of inquiry performed during the activity and interpret the results	0	1	2	2x	4
Tangible/ hands-on	0	1	2	2x	4
Requires quantitative reasoning	None 0	Minor 1	Problem solving 2	2x	4
Cooperative	No 0		Yes 2	2x	2
Total					16