**Online Appendix**

**Examples of Proposed Analogous Multiple Choice Questions in Pools With Student Outcome Variation**

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| **1. Quantitative questions** |
| **Question stem**  | **Variation/options** | **Number of variations in pool** | **Range of percentage correct (%)** | ***p* value** |
| *Upper-level physiology*  |
| Pavarti and Ron used two sets of electrodes to record action potentials in their earthworm. They found that the action potential at the first set of electrodes occurred 1.5 msec later than the action potential at the second set of electrodes, and that the electrodes were **1.25 cm apart**. What is the action potential velocity in meters per second? (NR) | Distance value (1.25 cm) changed to other numbers | 4 | 74–85 | 0.7787 |
| *General chemistry I & II* |  |
| What is the half-life (minutes) of a reaction that has a rate constant, **k = X M/min** where the initial concentration is **Y M**? (NR) | Change the rate constant given in minutes or seconds, X and change the concentration value, Y | 2 | 88–91 | 0.2248 |
| *Introductory physics II* |
| A positively charged particle (**q1 = +1.5 μC**) is a distance of **5.5 cm** from another charged particle q2. The x and y components of the electric force from q2 on q1 are **Fx = 45 N** and **Fy = 60 N**. What is the charge of q2 in μC? (MC) | Change q1, q2, Fx, and Fy | 5 | 75–80 | 0.9702 |
| **2. Questions that are easy to rearrange or make substitutions** |
| **Question stem**  | **Variation/options** | **Number of variations in pool** | **Range of percentage correct (%)** | ***p* value** |
| *Upper-level physiology*  |
| The Smithsonian Zoo’s ring-tailed lemur, Andry, is reported to the zoo vet with symptoms of excessive testosterone production, such as hair loss, stunted growth, and aggression. Testosterone release from the testis is controlled by LH from the anterior pituitary, which is controlled by GnRH from the hypothalamus, in a typical hypothalamus-pituitary-target organ relationship. The vet thinks Andry has a benign tumor making too much of one of these hormones. **Here are the levels of Andry’s hormones, below**. Where should the vet look for the hormone-secreting tumor? (MC) | Table of hormone levels showed different hormones (just testosterone, LH and testosterone, or GnRH, LH and testosterone) elevated compared to a normal lemur | 3 | 62–76 | 0.3881 |
| *General chemistry I & II* |
| Calculate E°cell for the unbalanced redox reaction **A(s) + B2+(aq) → A+(aq) + B(s)** given the **reduction half-reactions** and standard reduction potentials below. (NR) | Generic half-reactions were varied  | 8 | 57–90 | < 0.0001 |
| *Introductory physics II* |
| The **field-line representation** of the E-field in a certain region in space is shown. The dashed lines represent equipotential lines. For each of the following, assume you are moving a positively charged particle between the two points at a constant speed. The change in electric potential energy when moving from **D to C**? The work done by the electric field when moving from **B to D**? (MC) | Associated image is rotated for each version and the location of points in space is changed | 6 | 77–82 | 0.9904 |
| A proton travels at a constant velocity in a region with a constant magnetic field. An electric field also exists in this region with just the right strength such that the proton moves in a straight line. If the direction of the electric field is **into the page**, determine the directions of the magnetic force and magnetic field. (MC) | Direction of electric field and direction of proton | 8 | 24–70 | 0.0485 |
| **3. Questions using conceptual opposite counterparts** |  |
| **Question stem**  | **Variation/options** | **Number of variations in pool** | **Range of percentage correct (%)** | ***p* value** |
| *Upper-level physiology* |
| If you double the amount of sodium **outside** an axon’s cell membrane, what happens to its action potential? (MC) | Change “inside” to “outside”  | 2 | 37–93 | 0.0014 |
| Which is the correct order, from highest to lowest, of the partial pressure of **oxygen** in different places in your body? (MC) | Replace “oxygen” with “carbon dioxide” | 2 | 66–91 | 0.0084 |
| *General chemistry I & II* |
| For the galvanic cell represented below, identify the **reaction** that takes place at the anode. (MC) | Reactions were varied in a cell notation | 6 | 93–97 | 0.7965 |
| Which of the following half-reactions would occur at the **anode** of a Galvanic cell consisting of an SHE as the cathode? (MC) | Change the electrode from “anode” to “cathode” | 4 | 55–76 | 0.0003 |
| *Introductory physics II* |
| An isolated capacitor (not connected to a battery) has an initial charge Q; its plates have an area of A; and the distance between the plates is d. If you **increase** the distance between the plates, how do the following quantities change? The magnitude of the electric potential between the plates? The electric field between the plates? (MC) | Change “increase” to “decrease” | 2 (subset of pool) | 51–59 | 0.3935 |
| **4. Questions that are different but address the same learning objective** |
| **Question stem**  | **Variation/options** | **Number of variations in pool** | **Range of percentage correct (%)** | ***p* value** |
| *Upper-level physiology*  |
| **Basal metabolic rate** is the metabolic rate of an animal that: (MC) | “Basal metabolic rate” changed to “Standard metabolic rate” | 2 | 45–95 | 0.0001 |
| You are unsure whether the uterine contractions that occur when a woman is in labor are controlled by nervous or endocrine signaling. Which of the following observations supports the idea that it is **nervous**? (MC) | Change “nervous” to “endocrine” | 2 | 62–87 | 0.0047 |
| *General chemistry I & II* |
| At constant pressure, **decreasing** the temperature of a sample will cause the volume to \_\_\_. At constant volume, **increasing** the pressure of a sample will cause the temperature to \_\_\_. (MC) | Decreasing/increasing a gas property causes another property to decrease/increase | 4 | 85–91 | 0.7237 |
| **Dissolving a compound** is a \_\_\_\_ change. (MC) | Identify a process as a physical or chemical change | 6 | 71–100 | < 0.0001 |
| *Introductory physics II* |
| A **heat engine** is operated with an ideal gas using the Carnot cycle shown. A Carnot cycle has two isothermal processes B and C and two adiabatic processes A and D. How is heat energy transferred during process **A**? (MC) | Change heat engine to heat pump and change process A to be B, C, or D | 4 | 81–88 | 0.1344 |

*Note.* MC = multiple choice; NR = numerical response.