Supplementary Resource Document for Bego et al. (2024) “Single-Paper Meta-Analyses of the Effects of Spaced Retrieval Practice in Nine Introductory STEM Courses: Is the Glass Half Full or Half Empty?”

Learning Objectives for All Courses

Chemical Engineering Thermodynamics

1. At the conclusion of this module students will correctly identify closed and isolated systems and impermeable and adiabatic boundaries.
2. At the conclusion of this module students will differentiate between an extensive and an intensive thermodynamic property.
3. At the conclusion of this module students will identify the standard SI units for thermodynamic properties.
4. At the conclusion of this module students will use the ideal gas equation to work problems involving gas pressure, volume, temperature and moles.
5. At the conclusion of this module students will use the phase rule to calculate the number of degrees of freedom for a system.
6. At the conclusion of this module students will sketch a P-T phase diagram for a one-component system and identify the phase fields, transition lines and special points.
7. At the conclusion of this module students will sketch a P-v phase diagram for a one-component system and identify one and two phase regions of the diagram.
8. At the conclusion of this module students will use steam tables to determine the properties of water.
9. At the conclusion of this module students will calculate the work involved in changing the volume of a system. [W = -Pext*ΔV]
10. At the conclusion of this module students will relate a change in the internal energy of a closed system to work and heat exchanges.
11. At the conclusion of this module students will understand that a reversible process is always "best" in terms of work produced or work required by a process.
12. At the conclusion of this module students will identify a described process as reversible or irreversible.
13. At the conclusion of this module students will understand the difference between an adiabatic and an isothermal process.
14. At the conclusion of this module students will understand that the internal energy of a ideal gas depends only on temperature.
15. At the conclusion of this module students will calculate heat exchange for an irreversible isothermal expansion or compression of an ideal gas. [Q = Pext*ΔV]
16. At the conclusion of this module students will predict temperature change during adiabatic expansion or compression of an ideal gas. [W = Cv*ΔT]
17. At the conclusion of this module students will understand how heat capacity relates to heat exchange and temperature change. [Q = Cp*ΔT]
18. At the conclusion of this module students will understand that enthalpy change is equal to heat exchange for closed systems at constant pressure.

19. At the conclusion of this module students will understand that internal energy change is equal to heat exchange for closed systems at constant volume.
20. At the conclusion of this module students will understand that the heat capacity of a diatomic gas is greater than that of a monatomic gas.
21. At the conclusion of this module students will understand that the difference Cp-Cv is equal to R for an ideal gas.
22. At the conclusion of this module students will understand that the enthalpy of a reaction is related to the balanced chemical equation for that reaction.
23. At the conclusion of this module students will understand the difference between an exothermic and an endothermic reaction.
24. At the conclusion of this module students will understand the difference between a turbine and a compressor.

Chemistry for Health Professionals

1. Classify a sample of matter as an element, compound, or mixture, based on name or formula.
2. Classify a sample of matter as an element, compound, or mixture, based on description or molecular-level representation.
3. Given the symbols of C, Ca, Cl, Cr, Cu, write the name, with correct spelling, for each element; given name, write symbol, with correct formatting.
4. Given the symbols of Ag, Au, Hg, Fe, write the name, with correct spelling, for each element; given name, write symbol, with correct formatting.
5. Classify elements as metals or nonmetals, and as transition elements or main group elements.
6. Classify elements according to their row and period in the periodic table.
7. Convert quantities within the metric system.
8. Classify compounds as ionic or molecular/covalent.
9. Use the bonding patterns of C, H, N to identify correct or reasonable structures. (C has 4 bonds/0 lone pairs, H has 1 bond/0 lone pairs, N has 3 bonds/1 lone pair)
10. Given the name of a monatomic ion, complete the formula by giving the correct charge.
11. Given the name of a polyatomic ion, write the correct formula.
12. Given the name of an ionic compound, write the formula.
13. Given the formula of an ionic compound, write the name.
14. Given the name of a linear alkane, alkene or alkyne, identify its structure.
15. Given the name of a cyclic or branched alkane, identify its structure.
16. Match full or condensed structures of hydrocarbons with the corresponding line structures.
17. Identify functional groups in organic molecules (alcohols, aldehydes, alkenes, amines, carboxylic acids).
18. Correctly match the names and structures of functional groups with the suffixes used in naming their compounds (alcohols, aldehydes, alkenes, amines, carboxylic acids).
19. Link states of matter to the amount of energy present.
20. Link states of matter to their relative likelihood of existing at different temperatures.
21. Classify samples of matter as solid, liquid, or gas, based on particle-level representation.
22. Classify samples of matter as solid, liquid, or gas, based on name or formula.
23. State whether a substance will be solid, liquid, or gas at room temperature, based on melting and boiling point values.

24. Apply appropriate terms to changes in state.

Diversity of Life

1. Identify species-level diversity from a description or example.
2. Identify a regulating ecosystem service from a description or example.
3. Identify an invasive species from a description or example.
4. Identify commensalism from a description or example.
5. Given a graph of population growth over time, find the carrying capacity (K) of the population.
6. Recognize situations in which density-dependent regulation of population growth is occurring.
7. Given a phylogenetic tree, determine which groups of species are monophyletic.
8. Determine whether an unknown organism belongs to Domain Bacteria based on a description of its characteristics.
9. Distinguish bryophytes from other plants using its unique suite of characteristics
10. Recreate the generalized plant life cycle
11. Use the definition of the ovary in a flower to identify it on an image or in a description.
12. Connect flower characteristics to their likelihood of having a bat as a pollinator
13. Identify characteristics generally found in monocots from a diagram, image, or description
14. Identify characteristics that are commonly seen in fungi.
15. Recreate the generalized fungal life cycle
16. Distinguish between plasmogamy and karyogamy.
17. Distinguish between the three body cavity types seen in Metazoans
18. Identify characteristics commonly seen in Deuterostomes
19. Label the four basal characteristics of Chordates on an image
20. Identify characteristics that distinguish Tetrapoda from other organismal groups within Sarcopterygii.
21. Distinguish between examples of tropism, morphogenesis, and nastic movement
22. Recall the major functions of auxin in a plant.
23. Put the events of transpiration in a plant in the correct order
24. Put the events of sugar translocation in a plant in the correct order

Engineering Analysis I

1. Shift graphs of functions and write equations for the shifted graphs.
2. Find the domains and ranges of functions.
3. Determine the domain of the function.
4. Use long division to divide polynomials.
5. Form composite functions.
6. Solve applications involving modeling with functions.
7. Finding the limits of polynomial functions.
8. Find the limit of functions defined by graphs
9. Determine at which points functions are differentiable.
10. Match a graphed function with the graph of its derivative.
11. Analyze the motion of an object given a graph of its acceleration or velocity.
12. Find slopes, tangents, and normal lines of a function.
13. Use the Chain Rule to evaluate derivatives at given values.

14. Find derivatives using implicit differentiation.
15. Find derivatives using the chain rule.
16. Find limits related to derivatives.
17. Evaluate trigonometric functions.
18. Graph and identify characteristics of trigonometric functions.
19. Identify the transformations of sine curves and graph the functions.
20. Find the limits of trigonometric functions using the limit of sin(theta)/theta
21. Find derivatives of trigonometric functions.
22. Use the Chain Rule to find first derivatives.
23. Use implicit differentiation to find first derivatives.
24. Solve applications involving linearization and differentials.

Fundamentals of Physics I

1. Calculate the components of vectors in a given coordinate system.
2. Calculate the magnitude of a vector given its components.
3. Calculate the direction of a vector given its components.
4. Recognize the definition for average velocity and average acceleration.
5. Relate the normal and friction components of the force due to contact between surfaces.
6. Relate the direction of the velocity and acceleration vectors given the description of an object's motion in one dimension.
7. Draw the free-body diagram for an object.
8. Recognize how vectors are combined graphically to illustrate vector addition.
9. Determine which kinematic quantities have the same sign in a given coordinate system.
10. Describe the velocity of a projectile in terms of its horizontal and vertical components.
11. Relate the period of an object undergoing uniform circular motion to its speed.
12. Identify the direction of the centripetal acceleration of an object traveling in a circle at a constant speed.
13. Calculate the magnitude of the centripetal force acting on an object traveling in a circle at a constant speed.
14. Describe the displacement of a projectile in terms of its horizontal and vertical components.
15. Recognize the direction of the centripetal force acting on an object undergoing uniform circular motion.
16. Describe how the accelerations acting on the individual pieces of a system of objects connected by a string that runs across a massless pulley. (accelerations are equal)
17. Determine whether a particular force does positive, negative, or zero work through a given displacement.
18. Calculate the work done by the gravitational force on an object as it changes heights.
19. Calculate the work done by the spring force on an object as it moves from one position to another while attached to a spring.
20. Recognize situations where the gravitational potential energy of a system increases, decreases, or remains the same.
21. Recognize situations where the elastic potential energy of a system increases, decreases, or remains the same.
22. For a clearly defined system, calculate the total mechanical energy of a system.

23. Use the equation for momentum to calculate either momentum, velocity, or mass of an object.
24. Determine the change in momentum vector for an object graphically.

General Chemistry

1. Classify elements as metals or nonmetals, and as transition elements or main group elements.
2. Classify a sample of matter as an element, molecular/covalent compound, or ionic compound, based on formula.
3. Given the symbols of Ag, Au, Hg, Fe, write the name, with correct spelling, for each element; given name, write symbol, with correct formatting.
4. Given the name of a monatomic ion, complete the formula by giving the correct charge.
5. Given the name of an ionic compound, write the formula.
6. Given the name of a molecular/covalent compound, write the formula.
7. Calculate formula masses of compounds.
8. Balance a given chemical reaction.
9. Relate the formula and charge of an aqueous ion to a particle-level representation of its interaction with water molecules.
10. Apply solubility rules to identify soluble and insoluble ionic compounds.
11. Assign appropriate phase labels to reactants and products in aqueous reactions.
12. Identify species that should be written as dissociated ions, when writing ionic equations for reactions in aqueous solution.
13. Given the name of an acid, write the formula.
14. Classify acids as weak or strong.
15. Identify acids and bases.
16. Identify strong, weak, and nonelectrolytes.
17. Classify reactions as acid/base, precipitation, redox, and/or combustion.
18. Assign oxidation numbers to atoms in elements or monatomic ions.
19. Assign oxidation numbers to atoms in chemical formulas.
20. Classify changes in oxidation number as oxidations or reductions.
21. Qualitatively relate changes in pressure, volume, temperature, and number of particles in gas samples.
22. Use principles of kinetic molecular theory to qualitatively predict and relate particle energies, particle speeds, and effusion/diffusion rates in gas samples.
23. Given two samples of gas, compare properties including density, number of particles, pressure.
24. Identify relationships between particle mass, kinetic energy, particle speed, and temperature.

Research Methods for Psychology

1. Differentiate between descriptive and inferential statistics
2. Read histograms
3. Reject causation from observational studies
4. Calculate SD
5. Define SD as the average amount by which scores differ from the mean
6. Identify the number of explanatory variables in an investigation
7. Reject sample differences as providing evidence about a population in the absence of inferential statistical tests

8. Creating groups that are similar to each other is essential for establishing causation
9. Define outlier as 2.5 SD or greater from the mean
10. Calculate Z score
11. Treatment of outliers is at the discretion of researchers
12. Determine the percentage of people scoring above a negative Z score
13. What does sigma squared stand for? The variance of individual scores in a population
14. Identify a research hypothesis from a word problem (> or < only)
15. Define what $p < .05$ means; it is the probability of obtaining a sample result assuming the null hypothesis is true; I will have to hammer this point in Lecture 9
16. Determine the percentage of people scoring above a positive Z score
17. Two-tailed tests are more common than one-tailed because they are more stringent
18. Identify the variance, SD, and shape of a comparison distribution for a Z test (see PUREMEM question 4 in Lecture 10, Fall 2019)
19. What are you looking for when you do a two-tailed test? Whether the sample result is among the rarest 2.5% of low scores or the rarest 2.5% of high scores
20. Distributions of means are always less variable than distributions of individual scores
21. Z tests are rare because you must know the mean and variance of an existing population
22. Larger sample sizes are preferred because they yield less variable comparison distributions
23. The mean of the comparison distribution for one-sample t is whatever you want it to be
24. What is the shape of the comparison distribution when doing a one-sample t test?

Quantitative Methods in Psychology

1. Know the reasons why learning about research methods (i.e., thinking like a scientist) is important
2. Identify and describe belief perseverance as a non-scientific way of knowing
3. Compare and contrast basic research vs. applied research
4. Know the main goals of research in psychology (describe, explain, predict, control/change)
5. Know the difference between a theory and a hypothesis
6. List the characteristics of a good theory
7. Know the sources of research ideas (systematic or unsystematic observation/experience, theory, applied issues)
8. Know the definition and importance of conducting a literature review before conducting a research study
9. Understand how generating operational definitions is important to conducting research
10. List the important aspects of developing good research questions (asking answerable q's, important q's, empirical q's)
11. List the sections of an APA formatted research paper in order
12. Know the contents of an APA formatted Introduction section of a research paper
13. List the conditions under which a correlational design is best used
14. List the defining features of a true experiment
15. State the disadvantages/ limitations of experimental research
16. Know the difference between internal validity and other kinds of validity
17. Know the definition and importance of a confounding variable to experimental research
18. Distinguish between the reliability and validity of a measure

19. Know the definition of a nominal scale of measurement as compared to the other scales of measurement
20. Know the four basic kinds of dependent variables
21. Know the significance of demand characteristics to psychological research
22. Distinguish between the terms sample and population
23. Understand issues related to volunteer bias / volunteerism in psychological research
24. Know the term deception and how it may be involved in psychological research

Unity of Life

1. Explain how an element's valence electrons can predict the number of chemicals bonds that it can form
2. Differentiate between dehydration reactions for joining monomers to build a polymer & hydrolysis reactions for breaking polymers to make monomers
3. List the types of bonds in the first three levels of protein structures
4. Identify what cellular components are common to all life
5. State that there are three types of glucose polymers (glycogen, starch, cellulose)
6. List the evidence in support of the endosymbiotic theory
7. Calculate the hydroxide concentration of a solution given the pH by subtracting the pH from 14 and making it the negative exponent of 10.
8. Differentiate between the ends of proteins (N & C termini) and the ends of nucleic acids (5' and 3' termini)
9. Recall that higher membrane fluidity is dependent on cholesterol, and lipid fatty acid length and double bonds
10. Given two concentrations of salt across a membrane and a pore size that prevents the movement of salt, determine the net flow direction of water to equalize the salt concentrations across the membrane.
11. Given two concentrations across a membrane, determine the net flow direction of salt to equalize the salt concentrations across the membrane.
12. Differentiate between the spontaneity and the ΔG of an endergonic (not spontaneous, positive ΔG) vs exergonic reaction (spontaneous, negative ΔG)
13. Identify the signs for ΔH and ΔS to make ΔG spontaneous or not spontaneous
14. Compare the change in free energy and activation energy in a reaction when an enzyme is used vs when an enzyme is not used.
15. Using an enzyme in a reaction changes the activation energy of that reaction but never changes the free energy.
16. State that hydrogens are moved from the matrix to the inner membrane space during the ETC (Electron Transport Chain) and back to the matrix during chemiosmosis
17. Order the steps of cellular respiration: 1. glycolysis, 2. pyruvate oxidation, 3. TCA, 4. ETC
18. Identify the net input (1 glucose) and net output (2 ATP, 2 NADH, 2 pyruvate) of glycolysis
19. State how many carbons are in glucose (6), pyruvate (3), and acetyl co-A (2) in cellular respiration
20. Describe the differences between aerobic respiration & fermentation
21. Recognize that cellular respiration & photosynthesis are opposite reactions (water + energy + CO2 --> glucose, and oxygen in photosynthesis.)

22. Distinguish between the light reactions and the Calvin cycle in photosynthesis
23. Identify where the photosynthetic & cellular respiration reactions occur within the chloroplast and mitochondria, respectively
    a. glycolysis--cytoplasm
    b. TCA--matrix
    c. light reactions--thylakoid membranes
    d. Calvin cycle--stroma
    e. ETC--mitochondrial inner membrane
24. Identify the order and reason for each stage of the Calvin cycle
    a. carbon fixation--Rubisco makes CO_2 into an organic molecule, 3-PGA
    b. reduction--energy from ATP & NADPH is added to make organic sugar
    c. regeneration--RuBP is remade