# SUPPLEMENTARY INFORMATION

## SURVEY INSTRUMENT 1
### *Prior Chemistry Knowledge Assessment*

1) Compared to the charge and mass of a proton, an electron has _____.

A) the same charge and a smaller mass
B) the same charge and the same mass
C) an opposite charge and a smaller mass
D) an opposite charge and the same mass

2) When electrons in an atom in an excited state fall to lower energy levels, energy is _____.

A) only absorbed
B) only released
C) neither released nor absorbed
D) both released nor absorbed

3) Which symbols represent atoms that are isotopes?

A) C-14 and N-14
B) O-16 and O-18
C) I-131 and I-131
D) Rn-222 and Ra-222

4) Which atom contains exactly 15 protons?

A) P-32
B) S-32
C) O-15
D) N-15

5) An ion with 5 protons, 6 neutrons, and a charge of 3+ has an atomic number of _____.

A) 5
B) 6
C) 8
D) 11

6) What is the mass number of an atom which contains 28 protons, 28 electrons, and 34 neutrons?

A) 28
B) 56
C) 62

D) 90

7) Which three groups of the Periodic Table contain the most elements classified as metalloids (semimetals)?

A) 1, 2 and 13
B) 3, 13 and 14
C) 14, 15 and 16
D) 16, 17 and 18

8) When a metal atom combines with a nonmetal atom, the nonmetal atom will _____.

A) lose electrons and decrease in size
B) lose electrons and increase in size
C) gain electrons and decrease in size
D) gain electrons and increase in size

9) Atoms of elements in a group on the Periodic Table have similar chemical properties. This similarity is most closely related to the atoms' _____.

A) number of principal energy levels
B) number of valence electrons
C) atomic numbers
D) atomic masses

10) As atoms of elements in Group 16 are considered in order from top to bottom, the electronegativity of each successive element _____.

A) decreases
B) increases
C) remains the same

11) Given the unbalanced equation: $Al + O_2 \rightarrow Al_2O_3$, when this equation is completely balanced using the smallest whole numbers, what is the sum of the coefficients?

A) 9
B) 7
C) 5
D) 4

12) What is the empirical formula of the compound whose molecular formula is $P_4O_{10}$?

A) PO
B) $PO_2$
C) $P_2O_5$
D) $P_8O_{20}$

13) What is the total number of atoms represented in the formula $Cu_2SO_4 \cdot 5\ H_2O$?

A) 8
B) 13
C) 21
D) 27

14) What is the molar mass of $K_2CO_3$ ?

A) 138 g
B) 106 g
C) 99 g
D) 67 g

15) 5.21 cm is the same distance as _____.

A) 0.0521 m
B) 52.1 dm
C) 5.21 mm
D) 0.00521 km
E) 5210 m

16) A value of 25$^{°C}$ is a measurement of _____.

A) distance
B) volume
C) temperature
D) mass
E) density

17) The measurement of 0.0000043 m, expressed correctly using scientific notation is _____.

A) $4.3 \times 10^{-7}$ m
B) $4.3 \times 10^{-6}$ m
C) $4.3 \times 10^{6}$ m
D) $0.43 \times 10^{-5}$ m
E) 4.3

18) Which of the following measurements has three significant figures?

A) 0.005 m
B) 510 m
C) 0.510 m
D) 0.051 m
E) 5100 m

19) What is the density of a substance with a mass of 45.00 g and a volume of 26.4 mL?

A) 1.70 g/mL
B) 1.7 g/mL
C) 0.59 g/mL
D) 0.587 g/mL
E) 45.0 g/mL

20) Which of the following is an element?

A) tin
B) water
C) salt
D) sugar
E) iced tea

21) If the temperature is -55°F, what is the corresponding temperature on the Kelvin scale?

A) 225 K
B) 218 K
C) 55 K
D) 273 K
E) 328 K

22) What elements are in hydroxyapatite, $Ca_5(PO_4)_3OH$, a major compound in human bones and teeth?

A) carbon, potassium, oxygen, and hydrogen
B) carbon, phosphorus, oxygen, and hydrogen
C) carbon, phosphorus, oxygen, and helium
D) calcium, phosphorus, oxygen, and helium
E) carbon, potassium, oxygen, and helium

23) Which of the following is a nonmetal?

A) nitrogen
B) sodium
C) iron
D) silver
E) calcium

24) The atomic number of an atom is equal to the number of _____.

A) nuclei
B) neutrons
C) neutrons plus protons
D) electrons plus protons
E) protons

25) What is the mass number of an atom of potassium that has 20 neutrons?

A) 15
B) 19
C) 35
D) 39
E) 59

26) The elements sodium, magnesium, and silicon _____.

A) are isotopes of each other
B) are in the same period of elements
C) have the same number of neutrons
D) are in the same group
E) have the same mass number

27) The maximum number of electrons that may occupy the third electron energy level is _____.

A) 2
B) 8
C) 10
D) 18
E) 32

28) What is the symbol of the element in Group IVA (14) and Period 2?

A) Be
B) Mg
C) Ca
D) C
E) Si

29) Valence electrons are electrons located _____.

A) in the outermost energy level of an atom
B) in the nucleus of an atom
C) in the innermost energy level of an atom
D) throughout the atom
E) in the first shells of an atom

30) In a molecule with covalent bonding, _____.

A) oppositely charged ions are held together by strong electrical attractions
B) atoms of metals form bonds to atoms of nonmetals
C) atoms of different metals form bonds
D) atoms are held together by sharing electrons
E) atoms of noble gases are held together by attractions between oppositely charged ions

31) The correct name of the compound $NCl_3$ is _____.

A) nitrogen chloride
B) trinitrogen chloride
C) nitrogen (III) chloride
D) nickel chloride
E) nitrogen trichloride

32) The name of $Al_2(SO_4)_3$ is _____.

A) aluminum (III) sulfate
B) dialuminum trisulfate
C) dialuminum sulfate
D) dialuminum trisulfide
E) aluminum sulfate

33) Which of the following compounds contains a polar covalent bond?
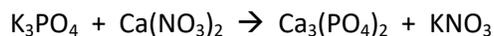
A) NaF
B) HCl
C) $Br_2$
D) MgO
E) $O_2$

34) Ionic bonding is expected in which of these compounds?

A) $Cl_2$
B) KF
C) $OF_2$
D) HF

35) The shape of the ammonia molecule ($NH_3$) is _____.

A) linear
B) square
C) trigonal pyramidal
D) hexagonal
E) octagonal

36) Which of the following gives the balanced equation for the reaction:

$$K_3PO_4 + Ca(NO_3)_2 \rightarrow Ca_3(PO_4)_2 + KNO_3$$

A) $KPO_4 + CaNO_3 + KNO_3$
B) $K_3PO_4 + Ca(NO_3)_2 \rightarrow Ca_3(PO_4)_2 + 3\ KNO_3$
C) $2\ K_3PO_4 + Ca(NO_3)_2 \rightarrow Ca_3(PO_4)_2 + 6\ KNO_3$
D) $2\ K_3PO_4 + 3\ Ca(NO_3)_2 \rightarrow Ca_3(PO_4)_2 + 6\ KNO_3$
E) $K_3PO_4 + Ca(NO_3)_2 \rightarrow Ca_3(PO_4)_2 + KNO_3$

37) A mixture is prepared by dissolving 2 g of KCl in 100 g of $H_2O$. In this mixture, $H_2O$ is the _____.

A) solute
B) solvent
C) solution
D) solid
E) ionic compound

38) When KCl is dissolved in water _____.

A) the $Cl^-$ ions are attracted to the dissolved $K^+$ ions
B) the $Cl^-$ ions are attracted to the partially negative oxygen atoms of the water molecule
C) the $K^+$ ions are attracted to the $Cl^-$ ions on the KCl crystal
D) the $K^+$ ions are attracted to the partially negative oxygen atoms of the water molecule
E) the $K^+$ ions are attracted to the partially positive hydrogen atoms of the water molecule

39) In water, a substance that ionizes completely in solution is called a _____.

A) weak electrolyte
B) nonelectrolyte
C) semiconductor
D) nonconductor
E) strong electrolyte

40) When some of the sugar added to iced tea remains undissolved at the bottom of the glass, the solution is _____.

A) dilute
B) polar
C) nonpolar
D) saturated
E) unsaturated

## SURVEY INSTRUMENTS 2
### *Pre-test and Post-test Assessment by Topic*

### *Density*

1) Which one of the following substances will float in gasoline, which has a density of 0.74 g/mL?  The density of each substance is shown in parentheses.

A) table salt     (D = 2.16 g/mL)
B) balsa wood   (D = 0.16 g/mL)
C) sugar          (D = 1.59 g/mL)
D) aluminum    (D = 2.70 g/mL)
E) mercury       (D = 13.6 g/mL)

2) What is the mass of 53.0 mL of ethanol, which has a density of 0.79 g/mL?

A) 67.1 g
B) 41.9 g
C) 42.0 g
D) 67.0 g
E) 53.0 g

3) A liquid has a volume of 34.6 mL and a mass of 46.0 g.  What is the density of the liquid?

A) 1.00 g/mL
B) 1.33 g/mL
C) 0.752 g/mL
D) 1330 g/mL
E) 0.663 g/mL

4) The ratio of the mass of a substance to its volume is its _____.

A) specific gravity
B) density
C) buoyancy
D) weight
E) conversion factor


5) In order to find out the volume of an irregular object, what method is used?

A) Triple Beam Balance
B) Volume Manipulation
C) Multiplication
D) Volume Displacement

6) A nugget of gold with a mass of 521 g is added to 50.0 mL of water.  The water level rises to a volume of 77.0 mL.  What is the density of the gold?

A) 10.4 g/mL
B) 6.77 g/mL
C) 1.00 g/mL
D) 0.0518 g/mL
E) 19.3 g/mL

7) Density is an example of a(n) _____ property.

A) intrinsic
B) extrinsic
C) nontrinsic
D) exact
E) inexact

8) Density is defined as _____.

A) volume per weight of a substance
B) weight per volume of a substance
C) volume per mass of a substance
D) mass per volume of a substance

9) There are two pieces of copper. Piece A is twice the mass and volume of piece B. How can we compare the two densities?

A) The density of A will be double the value of B
B) The density of B will be double the value of A
C) The density of A will be half the value of B
D) The density of B will be half the value of A
E) The densities of A and B will be the same

10) The most precise way to measure out 9.0 mL of liquid would be to use which instrument?

A) 10 mL beaker
B) 50 mL beaker
C) 100 mL beaker
D) 10 mL graduated cylinder
E) 50 mL graduated cylinder

## Acid-Base Chemistry

11) Which of the following solutions is NOT acidic?

A) vinegar, pH 2.8
B) shampoo, pH 5.7
C) honey, pH 3.9
D) seawater, pH 8.5

12) Identify the conjugate base in the following equation.

$HCl(aq) + Na_2CO_3(aq) \longrightarrow Na^+(aq) + Cl^-(aq) + HCO_3^-(aq)$

A) $Na^+$
B) $HCO_3^-$
C) $Cl^-$
D) HCl

13) Which of the following statements correctly describes the hydronium-hydroxide balance in the given solution?

A) In acids, $[OH^-]$ is greater than $[H_3O^+]$.

B) In bases, $[OH^-] = [H_3O^+]$.

C) In neutral solutions, $[H_3O^+] = [H_2O]$.

D) In bases, $[OH^-]$ is greater than $[H_3O^+]$.

E) In bases, $[OH^-]$ is less than $[H_3O^+]$.

14) When an acid reacts with a metal like Al, the products are _____.

A) water and a base
B) water and a salt
C) water and carbon dioxide
D) a salt and carbon dioxide
E) a salt and hydrogen

15) The neutralization reaction between $Al(OH)_3$ and $HNO_3$ produces the salt with the formula _____.

A) $H_2O$
B) $AlNO_3$
C) $AlH_2$
D) $Al(NO_3)_3$
E) $NO_3OH$

16) The function of a buffer is to _____.

A) change color at the end point of a titration
B) maintain the pH of a solution
C) be a strong base
D) maintain a neutral pH
E) act as a strong acid

17) The pH values of strong bases will always be _____ weak bases.

A) Greater than
B) Less than
C) The same as
D) Identical to

18) Which of the following can be used to measure pH of solutions?

A) A Buffer system
B) Universal Indicator Paper
C) Acetic acid solution
D) pH cannot be measured

19) The pH values of acids will always be _____.

A) Exactly 7.0
B) Greater than 7.0
C) Less than 7.0
D) Neutralized

20) According to the Arrhenius concept, if $HNO_3$ were dissolved in water, it would act as _____.

A) a base
B) an acid
C) a source of hydroxide ions
D) a source of $H^-$ ions
E) a proton acceptor

## Molecular Modeling

21) Isomers are molecules that share the same formula and have _____.

A) a different shape to the molecule
B) the same arrangement of atoms within the molecule
C) a different arrangement of atoms within the molecule
D) identical boiling points
E) the same shape in each molecule

22) In the three-dimensional structure of methane, $CH_4$, the hydrogen atoms attached to a carbon atom are aligned _____.

A) in a straight line
B) at the corners of a square
C) at the corners of a tetrahedron
D) at the corners of a rectangle
E) at the corners of a cube

23) A hydrocarbon contains only the elements _____.

A) hydrogen and oxygen
B) carbon and oxygen
C) carbon and hydrogen
D) carbon, hydrogen, and oxygen
E) carbon, hydrogen, and nitrogen

24) Carbon atoms always have how many covalent bonds?

A) one
B) two
C) three
D) four
E) five

25) The simplest cycloalkane has _____.

A) one carbon atom
B) two carbon atoms
C) three carbon atoms
D) four carbon atoms
E) five carbon atoms

26) Compounds that have the same molecular formula but different arrangements of atoms are called _____.

A) isomers
B) isotopes
C) indicators
D) isozymes
E) isometrics

27) Some alkenes have geometric (cis-trans) isomers because _____.

A) the carbon atoms in the double bond cannot rotate
B) each of the carbon atoms in the double bond has four different groups attached to it
C) one of the carbon atoms in the double bond has two identical groups attached to it
D) the carbon atoms in the double bond are free to rotate
E) all of the carbon atoms in the compound are rigid and cannot rotate

28) Compounds that have the same molecular formula but different arrangements of atoms are called _____.

A) isomers
B) isotopes
C) indicators
D) isozymes
E) isometrics

29) Which of the following substances has the same molecular and structural formula, but different spatial arrangements?

A) structural positional isomers
B) optical isomers
C) functional isomers
D) cis-trans isomers
E) isotopes

30) Which of the following substances has the same molecular, but different chemical properties and behaviors?

A) structural positional isomers
B) optical isomers
C) functional isomers
D) cis-trans isomers
E) isotopes

## Solutions

31) In a solution, the solvent _____.

A) is a liquid.
B) can be a liquid or gas.
C) can be a solid, liquid, or gas.
D) is never a solid.
E) is the substance present in the smallest concentration.

32) Vinegar is a solution that contains approximately 4 g of acetic acid in 100 mL of water. Identify the solute and solvent in this solution of vinegar.

A) Vinegar is the solute; water is the solvent.
B) Water is the solute; vinegar is the solvent.
C) Acetic acid is the solute; water is the solvent.
D) Water is the solute; vinegar is the solvent.

33) Oil does not dissolve in water because _____.

A) oil is polar
B) oil is nonpolar
C) water is nonpolar
D) water is saturated
E) oil is hydrated

34) Water is a polar solvent and hexane ($C_6H_{14}$) is a nonpolar solvent.  Which of the following correctly describes the solubility of the solute in the given solvent?

A) mineral oil, soluble in water
B) $CaCl_2$, soluble in hexane
C) $NaHCO_3$, soluble in water
D) $CCl_4$, soluble in water
E) octane, soluble in water

35) If solid NaCl (inorganic) was placed in a methanol (organic) solution, the NaCl would _____.

A) dissolve completely
B) dissolve slightly
C) not dissolve at all

36) Organic solutes are soluble in _____ solvents.

A) inorganic
B) organic
C) ionic
D) nonpolar

E) polar

37) A substance that carries an electric current when dissolved in water is called a(n) _____.

A) weak acid
B) strong acid
C) weak base
D) strong base
E) electrolyte

38) A substance that produces only a small number of ions in solution is known as a _____ electrolyte.

A) strong
B) weak
C) semi
D) non

39) When $NH_4Cl$ (inorganic) is added to water (inorganic), the salt will be _____.

A) soluble
B) insoluble
C) independent
D) a non-electrolyte

40) Red litmus paper will turn blue in the presence of _____.

A) an acid
B) a base
C) NaCl (a salt)
D) any electrolyte
E) any nonelectrolyte

# DATA
## <mark>*Pre-test and Post-test Assessments and Gain Scores*</mark>

**Supplemental Table 1.** Descriptive Statistics for Pre-Test Scores in HOL and VTL, Overall and by Group

|  | *n* | *M* | *SD* | Min | Max | Range | *SE* |
|---|---|---|---|---|---|---|---|
| **High Prior Knowledge** | | | | | | | |
| HOL 1 | 20 | 4.58 | 2.83 | 1 | 9 | 8 | .94 |
| VTL 1 | 16 | 5.45 | 2.01 | 3 | 10 | 7 | .67 |
| HOL 2 | 16 | 6.00 | 2.00 | 3 | 9 | 6 | .67 |
| VTL 2 | 20 | 6.23 | 2.80 | 1 | 9 | 8 | .93 |
| HOL 3 | 20 | 4.45 | 1.88 | 0 | 6 | 6 | .63 |
| VTL 3 | 16 | 3.89 | 1.45 | 2 | 7 | 5 | .48 |
| HOL 4 | 16 | 4.44 | 2.19 | 1 | 7 | 6 | .73 |
| VTL 4 | 20 | 4.77 | 1.45 | 1 | 8 | 7 | .69 |
| HOL Comb | 36 | 4.57 | 1.95 | 0 | 9 | 9 | .89 |
| VTL Comb | 36 | 4.93 | 2.08 | 1 | 10 | 9 | .67 |
| **Low Prior Knowledge** | | | | | | | |
| HOL 1 | 16 | 4.80 | 1.31 | 0 | 7 | 7 | .52 |
| VTL 1 | 18 | 3.96 | 1.99 | 2 | 8 | 6 | .63 |
| HOL 2 | 18 | 4.88 | 1.60 | 1 | 5 | 4 | .50 |
| VTL 2 | 16 | 4.79 | 1.60 | 0 | 5 | 5 | .56 |
| HOL 3 | 16 | 2.99 | 1.31 | 1 | 5 | 4 | .46 |
| VTL 3 | 18 | 3.56 | 1.55 | 1 | 6 | 5 | .49 |
| HOL 4 | 18 | 3.00 | 2.46 | 0 | 9 | 9 | .78 |
| VTL 4 | 16 | 4.38 | 1.60 | 1 | 5 | 4 | .57 |
| HOL Comb | 34 | 4.22 | 1.96 | 0 | 9 | 9 | .80 |
| VTL Comb | 34 | 4.38 | 2.09 | 0 | 8 | 8 | .77 |
| **Overall** | | | | | | | |
| HOL 1 | 36 | 4.69 | 2.21 | 0 | 10 | 10 | .48 |
| VTL 1 | 34 | 4.70 | 1.56 | 0 | 10 | 10 | .69 |
| HOL 2 | 34 | 5.44 | 1.86 | 0 | 9 | 9 | .74 |
| VTL 2 | 36 | 5.61 | 1.99 | 0 | 9 | 9 | .81 |
| HOL 3 | 36 | 3.72 | 2.11 | 0 | 6 | 6 | .48 |
| VTL 3 | 34 | 3.73 | 2.06 | 1 | 7 | 6 | .66 |
| HOL 4 | 34 | 3.72 | 1.65 | 0 | 9 | 9 | .71 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| VTL 4 | 36 | 1.98 | 1.78 | 1 | 8 | 7 | .80 |

*Note.* HOL = Hands-on lab. VTL = Virtual lab. Comb = The combined HOL and VTL scores on all four experiments.

**Supplemental Table 2.** Descriptive Statistics for Post-Test Scores in HOL and VTL, Overall and by Group

| | *n* | *M* | *SD* | Min | Max | Range | *SE* |
|---|---|---|---|---|---|---|---|
| **High Prior Knowledge** | | | | | | | |
| HOL 1 | 20 | 8.78 | 1.20 | 7 | 10 | 3 | .40 |
| VTL 1 | 16 | 8.56 | 1.51 | 6 | 10 | 4 | .50 |
| HOL 2 | 16 | 8.22 | 1.79 | 4 | 10 | 6 | .60 |
| VTL 2 | 20 | 8.67 | 1.12 | 7 | 10 | 3 | .37 |
| HOL 3 | 20 | 7.56 | 1.01 | 6 | 9 | 3 | .34 |
| VTL 3 | 16 | 7.67 | 1.41 | 6 | 10 | 4 | .47 |
| HOL 4 | 16 | 7.22 | 1.20 | 5 | 9 | 4 | .40 |
| VTL 4 | 20 | 7.44 | .73 | 7 | 9 | 2 | .24 |
| HOL Comb | 36 | 7.95 | 1.67 | 4 | 10 | 6 | .78 |
| VTL Comb | 36 | 8.09 | 1.80 | 6 | 10 | 4 | .56 |
| **Low Prior Knowledge** | | | | | | | |
| HOL 1 | 16 | 8.00 | 1.31 | 6 | 10 | 4 | .46 |
| VTL 1 | 18 | 8.20 | .79 | 8 | 10 | 2 | .25 |
| HOL 2 | 18 | 7.79 | 1.10 | 6 | 10 | 4 | .35 |
| VTL 2 | 16 | 7.62 | 1.19 | 6 | 10 | 4 | .42 |
| HOL 3 | 16 | 6.00 | 2.39 | 1 | 9 | 8 | .85 |
| VTL 3 | 18 | 6.80 | 1.62 | 3 | 9 | 6 | .51 |
| HOL 4 | 18 | 7.40 | 1.90 | 3 | 9 | 6 | .60 |
| VTL 4 | 16 | 6.88 | 1.46 | 5 | 9 | 4 | .51 |
| HOL Comb | 34 | 7.30 | 1.97 | 1 | 10 | 9 | .81 |
| VTL Comb | 34 | 7.38 | 2.04 | 3 | 10 | 7 | .72 |
| **Overall** | | | | | | | |
| HOL 1 | 36 | 8.39 | 1.78 | 6 | 10 | 4 | .70 |
| VTL 1 | 34 | 8.38 | 1.90 | 6 | 10 | 4 | .65 |
| HOL 2 | 34 | 8.01 | 2.07 | 4 | 10 | 6 | .85 |
| VTL 2 | 36 | 8.15 | 2.14 | 6 | 10 | 4 | .62 |
| HOL 3 | 36 | 6.78 | 1.84 | 1 | 9 | 8 | .73 |
| VTL 3 | 34 | 7.24 | 1.94 | 3 | 10 | 7 | .88 |
| HOL 4 | 34 | 7.31 | 2.10 | 3 | 9 | 6 | .61 |
| VTL 4 | 36 | 7.16 | 1.59 | 5 | 9 | 4 | .71 |

*Note.* HOL = Hands-on lab. VTL = Virtual lab. Comb = The combined HOL and VTL scores on all four experiments.

**Supplemental Table 3.** Descriptive Statistics for Gain Scores in HOL and VTL, Overall and by Group

|  | *n* | *M* | *SD* | Min | Max | Range | *SE* |
|---|---|---|---|---|---|---|---|
| High Prior Knowledge |  |  |  |  |  |  |  |
| HOL 1 | 20 | 4.20 | 0.74 | 2 | 8 | 6 | .39 |
| VTL 1 | 16 | 3.11 | 2.31 | 0 | 7 | 7 | .77 |
| HOL 2 | 16 | 2.22 | 1.86 | 0 | 5 | 5 | .62 |
| VTL 2 | 20 | 2.44 | 2.19 | 0 | 6 | 6 | .73 |
| HOL 3 | 20 | 3.11 | 1.69 | 1 | 6 | 5 | .56 |
| VTL 3 | 16 | 3.78 | 1.79 | 1 | 6 | 5 | .60 |
| HOL 4 | 16 | 2.78 | 1.72 | 0 | 6 | 6 | .57 |
| VTL 4 | 20 | 2.67 | 2.00 | 0 | 6 | 6 | .67 |
| HOL Comb | 36 | 3.38 | 1.95 | 0 | 8 | 8 | .89 |
| VTL Comb | 36 | 3.16 | 2.08 | 0 | 7 | 7 | .67 |
| Low Prior Knowledge |  |  |  |  |  |  |  |
| HOL 1 | 16 | 3.20 | 2.31 | 0 | 7 | 7 | .52 |
| VTL 1 | 18 | 4.24 | 1.99 | 2 | 8 | 6 | .63 |
| HOL 2 | 18 | 2.91 | 1.60 | 1 | 5 | 4 | .50 |
| VTL 2 | 16 | 2.63 | 1.60 | 0 | 5 | 5 | .56 |
| HOL 3 | 16 | 3.01 | 1.31 | 1 | 5 | 4 | .46 |
| VTL 3 | 18 | 3.24 | 1.55 | 1 | 6 | 5 | .49 |
| HOL 4 | 18 | 4.40 | 2.46 | 0 | 9 | 9 | .78 |
| VTL 4 | 16 | 2.51 | 1.60 | 1 | 5 | 4 | .57 |
| HOL Comb | 34 | 3.08 | 1.96 | 0 | 9 | 9 | .80 |
| VTL Comb | 34 | 3.00 | 2.09 | 0 | 8 | 8 | .77 |
| Overall |  |  |  |  |  |  |  |
| HOL 1 | 36 | 3.70 | 2.21 | 0 | 8 | 8 | .48 |
| VTL 1 | 34 | 3.68 | 1.56 | 0 | 8 | 8 | .69 |
| HOL 2 | 34 | 2.57 | 1.86 | 0 | 6 | 6 | .74 |
| VTL 2 | 36 | 2.54 | 1.99 | 0 | 6 | 6 | .81 |
| HOL 3 | 36 | 3.06 | 2.11 | 1 | 6 | 5 | .48 |
| VTL 3 | 34 | 3.51 | 2.06 | 1 | 6 | 5 | .66 |
| HOL 4 | 34 | 3.59 | 1.65 | 0 | 9 | 9 | .71 |
| VTL 4 | 36 | 5.18 | 1.78 | 0 | 6 | 6 | .80 |

*Note.* HOL = Hands-on lab. VTL = Virtual lab. Comb = The combined HOL and VTL scores on all four experiments.

# DATA
## Pearson Correlations

**Supplemental Table 4.**

Pearson Correlations for Combined Performance Scores on Lab # 1 (DENSITY), by Lab Type and Group

|  | HOL Lab # 1: High Ach. | VTL Lab # 1: High Ach. | HOL Lab # 1: Low Ach. | VTL Lab # 1: Low Ach. |
|---|---|---|---|---|
| HOL Lab # 1: High Ach. | - | .47* | -.12 | -.20 |
| VTL Lab # 1: High Ach. |  | - | .25 | -.13 |
| HOL Lab # 1: Low Ach. |  |  | - | .30 |
| VTL Lab # 1: Low Ach. |  |  |  | - |

*Note.* HOL = hands-on laboratory experiments; VTL = virtual laboratory experiments; High Ach. = high-achieving students; Low Ach. = low-achieving students
*p < .01.

**Supplemental Table 5.**

Pearson Correlations for Combined Performance Scores on Lab # 2 (ACID-BASE), by Lab Type and Group

|  | HOL Lab # 2: High Ach. | VTL Lab # 2: High Ach. | HOL Lab # 2: Low Ach. | VTL Lab # 2: Low Ach. |
|---|---|---|---|---|
| HOL Lab # 2: High Ach. | - | .41 | .26* | -.33 |
| VTL Lab # 2: High Ach. |  | - | .29 | -.19 |
| HOL Lab # 2: Low Ach. |  |  | - | .30 |
| VTL Lab # 2: Low Ach. |  |  |  | - |

*Note.* HOL = hands-on laboratory experiments; VTL = virtual laboratory experiments; High Ach. = high-achieving students; Low Ach. = low-achieving students
*p < .01.

**Supplemental Table 6.**

Pearson Correlations for Combined Performance Scores on Lab # 3 (MODELS), by Lab Type and Group

| | HOL Lab # 3: High Ach. | VTL Lab # 3: High Ach. | HOL Lab # 3: Low Ach. | VTL Lab # 3: Low Ach. |
|---|---|---|---|---|
| HOL Lab # 3: High Ach. | - | .44* | .41 | .11* |
| VTL Lab # 3: High Ach. | | - | .30* | -.22 |
| HOL Lab # 3: Low Ach. | | | - | -.14 |
| VTL Lab # 3: Low Ach. | | | | - |

*Note.* HOL = hands-on laboratory experiments; VTL = virtual laboratory experiments; High Ach. = high-achieving students; Low Ach. = low-achieving students

*p < .01.

**Supplemental Table 7.**

Pearson Correlations for Combined Performance Scores on Lab # 4 (SOLUBILITY), by Lab Type and Group

| | HOL Lab # 4: High Ach. | VTL Lab # 4: High Ach. | HOL Lab # 4: Low Ach. | VTL Lab # 4: Low Ach. |
|---|---|---|---|---|
| HOL Lab # 4: High Ach. | - | .44 | .23* | .13 |
| VTL Lab # 4: High Ach. | | - | .32* | -.10 |
| HOL Lab # 4: Low Ach. | | | - | .28* |
| VTL Lab # 4: Low Ach. | | | | - |

*Note.* HOL = hands-on laboratory experiments; VTL = virtual laboratory experiments; High Ach. = high-achieving students; Low Ach. = low-achieving students

*p < .01.

**Supplemental Table 8.**

Pearson Correlations for Combined Performance Scores on Combined Labs # 1-4, by Lab Type and Group

| Group | HOL Combined: High Prior | VTL Combined: High Prior | HOL Combined: Low Prior | VTL Combined: Low Prior |
|---|---|---|---|---|
| HOL Combined: High Prior | - | .33 | .49* | .24 |
| VTL Combined: High Prior | - | - | −.28 | .29 |

| | | | | |
|---|---|---|---|---|
| HOL Combined: Low Prior | - | - | - | .34* |
| VTL Combined: Low Prior | - | - | - | - |

*Note.* HOL = hands-on laboratory experiments; VTL = virtual laboratory experiments; High Ach. = high-achieving students; Low Ach. = low-achieving students

*p < .01.