Assessment of General Chemistry Course

Samar Ayesh, Ph.D.
Unit Level Liaison for Dept. of Physical Science

Previous Assessment for Chemistry in the Department

I remember when I first joined the Physical Science department as an adjunct in fall of 2009, I was asked by the Chair at that time to use one of the ACS (American Chemical Society) Standardized Exam as a Final Assessment for my CHEM 201 course. I was told to leave the Scantrons and all the scratch paper in a folder in his office. I wasn't sure what, if anything, was done by the data collected.

Two years later, I joined as a full time and I kept using the same assessment. I was giving the exam, using the grades as a final exam and putting them aside. Unfortunately, I never examined the results in detail nor did the department. Sometimes I would quickly glance at the results to check which question was missed the most. I always wanted to dig deeply but never seemed to have the time.

Fast forward to 2017, when Allan Wilson became the first Assessment Liaison for the Physical Science Department. He was able to analyze the data of this ACS assessment from several semesters. The results showed that our students' scores are slightly lower than the national averages (our students answered, on average, 19 questions correctly out of 40, compared to 24 nationally). The results also showed us in detail the topics that students struggled in the most.

This led Allan to design a new assessment that focused on stoichiometry. It consisted of 3 stoichiometry questions with a range of difficulties. Results of this new assessment were not very encouraging since a big portion of students used the wrong algorithmic procedure to solve a "typical" question. It implied that students might benefit from more conceptual stoichiometry questions – questions that they cannot solve mathematically and must use a conceptual understanding instead.

Motivation for a New Plan, 2019-2020

In fall 2019, I took over the Assessment Liaison role for the Chemistry courses within the Physical Science department. Based on all the great work that Allan did, it was clear to me and others teaching CHEM 201 that student learning seems to be missing some important component. The results of the ACS assessment clearly indicated the areas that students are challenged. So I designed several "Learning Activities" which were meant to engage students in exploring the big ideas and concepts in order to develop the desired understandings, knowledge, and skills that they should come away knowing by taking CHEM 201. These activities were meant to be used in the classroom, so I am hoping to use them once we go back to face-to-face instruction. In the meantime, they will be share them with all faculty teaching CHEM 201 in order to use them in their classroom and get initial feedback.

Establishing Goals, 2020-2021

It is clear to us faculty teaching Chemistry 201, that student learning seems to be missing some important component. I decided to examine the course SLOs more closely. The first steps towards an effective assessment plan is to establish goals and develop specific measurable learning outcomes. It is very important to first determine what we faculty expect students to learn. The master syllabus for the course shows only 16 student learning outcomes. So this semester I used the survey that Allan designed earlier, in which he went through each chapter of our textbook, asking if this topic or that concept was being taught, and created a specific SLO for every topic that faculty taught. This came to 56 SLOs covering 13 chapters. I e-mailed the list to the faculty who typically teaches the course (a total of 6 faculty, both FT and adjuncts). I asked them to read the entire list and tell me which of those 56 they do not teach.

Using Wiggins and McTighe's "Understanding by Design", I asked the faculty to classify the SLOs as critical, important, or desirable, based on the following definitions.

- Critical outcomes (CRO) are considered to be vital and of fundamental importance. They are outcomes in which an enduring understanding is needed, such that students will remember them long after the details have faded.

- Important outcomes (IMO) are more specific and pertain to ideas or skills that the student must know or be able to do. Student learning is incomplete without mastery of these essentials.

- Desirable outcomes (DO) are recognized as worth knowing, but the aim is exposure, not mastery.

Designing and Conducting the Assessment (Spring 2021-Summer 2022)

Since we were able to classify our SLOs for CHEM 201, I wrote questions that should assess how much our students have learned during the semester for each of the SLOs. The initial assessment consisted of 25 multiple choice questions and was given online during spring/summer/fall of 2021. A total of 70 students in 4 different sections took this assessment. I revised the assessment in spring of 2022 and added 2 more questions. The revised assessment consisting now of 27 multiple choice questions was given in-person during the spring and summer of 2022. A total of 28 students in 3 different sections took this assessment. The data collected was studied and analyzed below.

Data Analysis

The following table summarizes the results for the studied SLOs. The table also shows the difference in the results between the online and the in-person groups.

SLO	Classification	Question(s) #	% Correct	
			Online	In-person
Understand the Nuclear Model of the Atom	CRO	4 5	81.4 50	60.7 75
Understand the nature and importance of isotopes.	DO	7	74.3	92.9
Apply derived units, such as volume and density, to perform calculations.	CRO	2	42.8	57.1
Apply Bohr's theory of the hydrogen atom to calculate energy levels.	CRO	8	42.9	46.4
Utilize rules of nomenclature to name the different types of compounds including: **ionic compounds**, covalent compounds, oxoacids, and hydrates.	CRO	1	75.7	53.6
Determine the empirical formula of a compound from **percent composition** or from combustion analysis data.	CRO	11	64.3	75
Identify the limiting reactant in a reaction.	CRO	12 13	68.6 44.3	35.7 71.4
Use the relationship between Avogadro's number, moles, molar mass, and grams to perform calculations.	CRO	9	67.1	60.7
Calculate the molarity of a solution and molarity of ions in solution.	CRO	16	62.9	75
Use the ideal gas equation to determine the pressure, volume, moles, or temperature of a given all of the other values.	CRO	25	42	57.1

Apply dimensional analysis toward solving problems with multiple steps or conversions.	CRO	26	N/A	85.7
Apply oxidation number rules toward determining the oxidation number of each element in a compound or polyatomic ion.	IMO	18	38.6	46.4
Define resonance and determine the resonance structures of a species.	CRO	19	34.3	3.57
Determine the Lewis structures of species that do not follow the octet rule, including radicals.	CRO	20	92.9	60.7
Use the valence-shell electron pair repulsion (VSEPR) model to determine the shape of a molecule.	CRO	21 22	41.4 84.3	50 32.1
Predict the hybridization of molecules to explain bonding in molecules.	CRO	24	65.7	78.6
Determine amounts of reactant required or product formed using stoichiometry.	CRO	14 **15**	68.6 **4.3**	85.7 **7.1**

Looking at the data collected, we can notice right away that there is a difference in the results of those students who took the assessment online compared to those who took it in-person.

I believe that there are significant differences whether the assessment tool was used online or in-person. However, moving forward and since all of the CHEM 201 sections are being taught in-person now, this tool will be used strictly in-person.

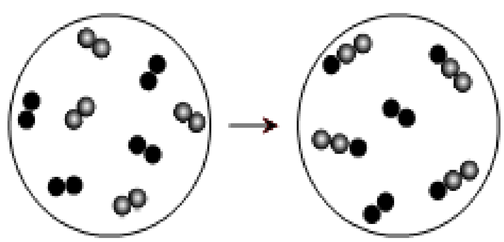
When looking at the date above, we can note that there is one question that showed very similar results. The following SLO was classified as a "Critical Outcome" (CRO):

Determine amounts of reactant required or product formed using stoichiometry.

The question that was written to test the students' knowledge concerning this SLO was the following (Question #14 in the Assessment Tool-see Appendix B):

> What mass of CCl_4 (153.81 g/mol) is needed to produce 2.00 g of CCl_2F_2 (molar mass = 120.91 g/mol)?
>
> $$3CCl_4 + 2SbF_3 \rightarrow 3CCl_2F_2 + 2SbCl_3$$
>
> A. 2.54 g B. 0.848 g C. 7.63 g D. 1.69 g

The data showed that more than 85% of the students who took this assessment in-person got it correct, while about 69% of the students who took this assessment online got it correct. Although, there is a significant difference between these 2 groups, both groups were not able to answer correctly another question that is significantly important when it comes to "determining amounts of reactant required or product formed using stoichiometry" which is balancing chemical equations. Although, balancing chemical equations was not an SLO that was specifically written, it is crucial to answer questions concerning stoichiometry. Question #15 in the assessment was written to test students' knowledge on how to balance chemical equations:

> What is a correct balanced equation for the reaction shown?
>
> 
>
> A. $N_2(g) + O_2(g) \rightarrow 2NO(g)$
>
> B. $2N_2(g) + O_2(g) \rightarrow 2N_2O(g)$
>
> C. $4N_2(g) + 4O_2(g) \rightarrow 4NO(g) + 2O_2(g)$
>
> D. $4N_2(g) + 4O_2(g) \rightarrow 4N_2O(g) + 2O_2(g)$

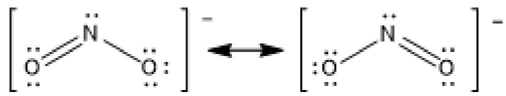
The data showed that **92.8%** of the students who took this assessment in-person got it **wrong**, while about **95.7%** of the students who took this assessment online got it **wrong**.

There was a very significant difference in the results of questions 19 and 20 between the Online and the In-person groups. These 2 questions cover topics concerning resonance and Lewis structures. For question #19, the online group got 34.3 % correct while the in-person where only able to 3.57% correct. This is more than 30% difference. The question covers the SLO below:

Define resonance and determine the resonance structures of a species.

Question #19:

Which statement best describes the bond length(s) in the nitrite ion (shown)? The bond length of N–O is 136 pm and N=O is 122 pm.



A. There is one bond length of 129 pm.
B. There is one bond length of 258 pm.
C. There are two bonds lengths where one bond is 136 pm, and the other is 122 pm.
D. There are two bonds lengths where the bonds oscillate between 122 pm and 136 pm.

For question #20, the online group got 92.9 % correct, while the in-person got only 60.7% correct. This is also more than 30% difference. The question covers the SLO below:

Determine the Lewis structures of species that do not follow the octet rule, including radicals.

Question #20:

Which is the best Lewis structure for nitrogen monoxide?

A. B. C. D.

Future Work

More work is still needed to further analyze the data. I was only able to collect data from 28 students in-person. This is a very small sample and I need to collect more data in the next few semesters. The results of this work will be discussed with other faculty in the Physical Science department who teaches Chem 201 and based on their recommendation few changes might be made on the assessment tool.

Appendix A:

The table below shows a few of these SLOs from different chapters. The first column is based on the survey conducted by Allan Wilson in 2017. It shows the number of faculty teaching a specific topic.

Topic	Student Learning Outcome	SLO Classification
Unit conversions involving units in the denominator (for instance, converting m/s to m/min)? **Yes__6__ No____** **Unit conversions involving units raised to a power (for instance, m^2 to cm^2)?** **Yes__6__ No____** **Do your students memorize SI prefixes *other than* kilo, centi, milli, and micro?** **Yes__3__ No__3__**	**1. Apply derived units, such as volume and density, to perform calculations.**	**CRO**
	2. Utilize conversion factors to conduct unit conversions.	**CRO**
	3. Apply dimensional analysis toward solving problems with multiple steps or conversions.	**CRO**
	4. Utilize SI unit prefixes.	**CRO**
Relating atomic weights to isotope abundances? **Yes__6__ No____**	**Calculate the average atomic mass of an element given the atomic mass and relative abundance of each of its naturally occurring isotopes.**	**DO**

Calculating empirical and molecular formulas? **Yes__6__ No____**	**1. Determine the empirical formula of a compound from percent composition or from combustion analysis data.**	**CRO**
If yes to the above, do your students learn to solve combustion analysis problems? **Yes__4__ No__2_**	**2. Determine the empirical formula of a compound using combustion analysis data.**	**DO**
	3. Utilize the empirical formula and molar mass to determine the molecular formula of a compound.	**IMO**
Do your students memorize strong/weak acids and bases? **Yes__4__ No__2__**	**Identify weak and strong acids and bases.**	**DO**
Calculating oxidation numbers? **Yes__5__ No__1__**	**Apply oxidation number rules toward determining the oxidation number of each element in a compound or polyatomic ion.**	**IMO**
Calculating the molarity of electrolytes (for instance, the sodium of sodium sulfate)? **Yes__6__ No____**	**Calculate the molarity of a solution and molarity of ions in solution.**	**CRO**

Bohr model of the hydrogen atom? **Yes__6__ No____**	**Apply Bohr's theory of the hydrogen atom to calculate energy levels.**	**CRO**
Do your students memorize the ideal gas law? **Yes__4__ No__2__** **If yes to the above, do your students memorize relationships such as Charles's Law, etc?**	**1. Use the ideal gas equation to determine the pressure, volume, moles, or temperature of a given all of the other values.**	**CRO**
Stoichiometry involving the ideal gas law? **Yes__6__ No____**	**2. Use the ideal gas equation in stoichiometric calculations.**	**IMO**

Appendix B: Assessment Tool

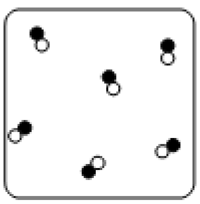
1. Which is NOT named correctly?
A. SnO_2 tin(II) oxide B. $CoSO_4$ cobalt(II) sulfate
C. K_3PO_4 potassium phosphate D. CaF_2 calcium fluoride

2. Which sample has the smallest volume? The density of aluminum is 2.70 g/cm^3, and the density of iron is 7.87 g/cm^3.

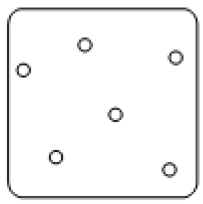
A. 1.0 g aluminum B. 5.0 g aluminum C. 1.0 g iron D. 5.0 g iron

3. Which microscopic representation best represents a diatomic gas only?

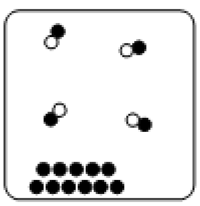
A.



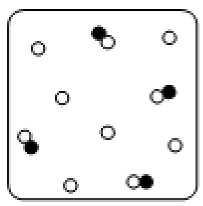
B.



C.



D.



4. Which statement regarding the nucleus of an atom is correct?
A. The nucleus contains protons and neutrons and has no charge.
B. The nucleus contains protons and neutrons and is positively charged.
C. The nucleus contains protons and electrons and has no charge.
D. The nucleus contains protons and electrons and is positively charged.

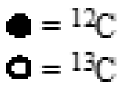
5. How many protons, neutrons, and electrons are in the following isotope: $^{131}I^{-}$?

A. 131 protons, 53 neutrons and 54 electrons
B. 53 protons, 78 neutrons and 53 electrons
C. 53 protons, 78 neutrons and 54 electrons
D. 53 protons, 131 neutrons and 52 electrons
E. 78 protons, 53 neutrons and 72 electrons

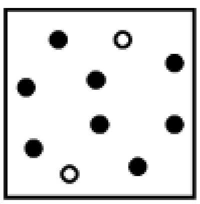
6. Which pair of particles has the same number of electrons?

A. O^{2-} , Na^{+} B. N^{3-} , P^{3-} C. $Br^{–}$, Se D. Al^{3+}, $P^{3–}$

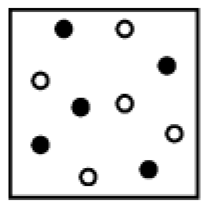
7. An enriched sample of carbon contains 20.0% ^{12}C and 80.0% ^{13}C. Which figure shows this sample?

Key: 

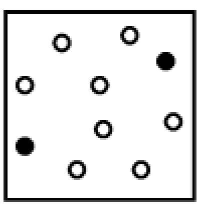
A.



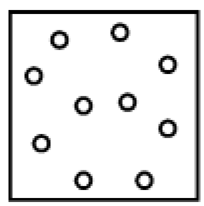
B.



C.



D.



8. Which electronic transition in a hydrogen atom is associated with the smallest *emission* of energy?

$$\Delta E = R_H\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right)$$

$R_H = 2.18\times10^{-18}$ J

A. n = 2 to n =1 B. n = 1 to n = 2 C. n = 2 to n = 3
D. n = 4 to n = 3 E. n = 3 to n = 2

9. What mass (in g) of oxygen is in 4.37×10^{-4} moles of $C_8H_{11}N_3O_3S$?

A. 2.10×10^{-2} g B. 3.12×10^{-2} g C. 4.20×10^{-2} g D. 1.84×10^{-2} g

10. What is the percent composition by mass of hydrogen in a 2.55 g sample of propanol, $CH_3CH_2CH_2OH$? The molar mass of propanol is 60.09 g·mol^{-1}.

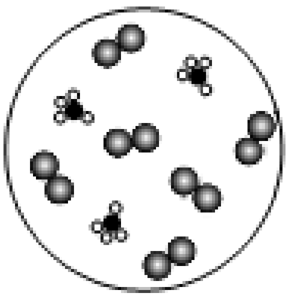
A. 11.7% H B. 33.9% H C. 13.4% H D. 60.0% H

11. A molecular compound is found to consist of 26.0% nitrogen and 74.0% oxygen. If the molecule contains 2 atoms of nitrogen, what is the molar mass of the molecule? (*Hint:* determine empirical formula of the compound)

A. 46 g/mol B. 92 g/mol C. 54 g/mol D. 108 g/mol

12. An initial state before reaction of CH_4 and Cl_2 is shown in the figure. Based on the balanced equation and the figure, what is the limiting reactant?

$$CH_4(g) + 4Cl_2(g) \rightarrow CCl_4(g) + 4HCl(g)$$



A. Cl_2 B. CCl_4 C. CH_4 D. not enough information is given.

13. What is the limiting reactant when 15.0 g of Fe and 15.0 g of carbon dioxide are allowed to react completely according to the following reaction:

$$2Fe(s) + 3CO_2(g) \rightarrow Fe_2O_3(s) + 3CO(g)$$

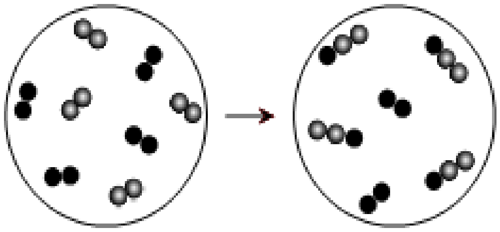
A. CO B. CO_2 C. Fe D. Fe_2O_3

14. What mass of CCl_4 (153.81 g/mol) is needed to produce 2.00 g of CCl_2F_2 (molar mass = 120.91 g/mol)?

$$3CCl_4 + 2SbF_3 \rightarrow 3CCl_2F_2 + 2SbCl_3$$

A. 2.54 g B. 0.848 g C. 7.63 g D. 1.69 g

15. What is a correct balanced equation for the reaction shown?



C. $N_2(g) + O_2(g) \text{-->} 2NO(g)$

B. $2N_2(g) + O_2(g) \text{-->} 2N_2O(g)$

C. $4N_2(g) + 4O_2(g) \text{-->} 4NO(g) + 2O_2(g)$

D. $4N_2(g) + 4O_2(g) \text{-->} 4N_2O(g) + 2O_2(g)$

16. What is the best procedure to prepare 0.750 L of a 0.500 M solution of Na_2SO_4? The molar mass of Na_2SO_4 is 142.05 g/mol.

A. Weigh 53.3 g of solute and add 0.750 L of water.
B. Weigh 142.05 g of solute and add sufficient water to obtain a final volume of 0.750 L.
C. Weigh 53.3 g of solute and add sufficient water to obtain a final volume of 0.750 L.
D. We do not have sufficient information.

17. What volume of 0.200 M $K_2C_2O_4$ is required to react completely with 30.0 mL of 0.100 M $Fe(NO_3)_3$?

$$2Fe(NO_3)_3 + 3K_2C_2O_4 \rightarrow Fe_2(C_2O_4)_3 + 6KNO_3$$

A. 10.0 mL B. 15.0 mL C. 22.5 mL D. 30.0 mL

18. In which reaction is carbon oxidized?

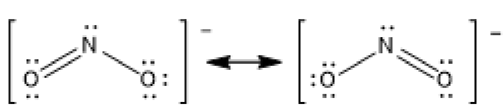
A. $CO_2(g) \rightarrow CO(g) + O_2(g)$

B. $H_2CO_3(aq) \rightarrow CO_2(g) + H_2O(l)$

C. $CO_2(g) + 2H_2O(l) \rightarrow CH_4(g) + 2O_2(g)$

D. $C_2H_4(g) \rightarrow C_2H_2(g) + H_2(g)$

19. Which statement best describes the bond length(s) in the nitrite ion (shown)? The bond length of N–O is 136 pm and N=O is 122 pm.



E. There is one bond length of 129 pm.
F. There is one bond length of 258 pm.
G. There are two bonds lengths where one bond is 136 pm, and the other is 122 pm.
H. There are two bonds lengths where the bonds oscillate between 122 pm and 136 pm.

20. Which is the best Lewis structure for nitrogen monoxide?

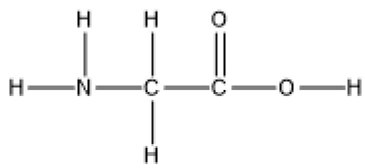
A. 

B. 

C. 

D. 

21. What is the molecular geometry around the N atom in the molecule depicted (lone pairs are not shown)?



A. t-shaped B. tetrahedral C. trigonal planar D. trigonal pyramidal

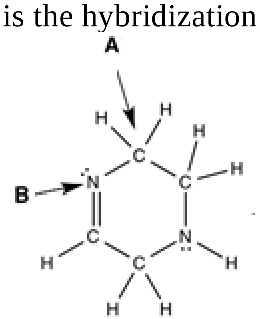
22. Which molecule has the smallest bond angle?

A. H_2O B. SO_4^{2-} C. SO_2 D. SO_3

23. Which molecule has polar bonds but is overall nonpolar?

A. SF_4 B. O_3 C. SO_2 D. NO_3^-

24. What is the hybridization of the indicated atoms below?



A. **A** is sp^3; **B** is sp^2 B. **A** is sp^2; **B** is sp^3

C. **A** is sp^2; **B** is sp^2 D. **A** is sp^3; **B** is sp^3

25. A 10.00 g sample of an unknown gas in a 20.0 L container at 75.0 ^{o}C exerted a pressure of 0.476 atm. What is the gas? R = 0.08206 (L·atm)/(mol·K)

A. NH_3 B. HCN C. NO D. NO_2

26. The average distance between the Earth and the Moon is 240,000 miles. Express this distance in kilometers. (1 mi = 1609 m)

A. 6.1×10^5 km B. 5.3×10^5 km C. 3.9×10^5 km D. 1.5×10^5 km

27. Given the following thermochemical reaction, how many grams of CaO must react in order to liberate 525 kJ of heat?

$$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s) \qquad \Delta H^\circ_{rxn} = -64.8 \text{ kJ/mol}$$

A. 6.92 g B. 56.1 g C. 454 g D. 606 g E. 3.40×10^4 g