Supporting Information for "Implementing Mastery Grading in Large Enrollment General Chemistry: Improving Outcomes and Reducing Equity Gaps

S1 Syllabus Language

This section provides the language used in the course syllabus to explain the grading system, as well as a tentative course outline.

S1.1 Grading Policy

Grading Policy: Below is a breakdown of the grading distribution used to calculate your final grade. The Canvas point totals will be weighted to accurately represent the final grade. However, your grade on Canvas may not be accurate if you have missing or ungraded assignments.

	Points
In-class polls and Discussions	5%
OLI Homework	15%
Unit 1: Gases	10%
Unit 2: Thermochemistry	10%
Midterm	10%
Unit 3: Intermolecular Forces	10%
Unit 4: Colligative Properties	10%
Unit 5: Thermodynamics	10%
Unit 6: Kinetics	10%
Final Exam	10%
Total:	100%

Exams will be given on the dates provided in the syllabus. **Missed exams cannot be made-up** unless arrangement are made with the instructor **prior** to the exam date. The exams will be completed in class using Canvas. Note, if you miss the midterm exam due to an excused absence, the final exam will act as the makeup exam for the missed midterm exam. In addition, if you perform better on the final exam, then your score on the final exam will replace your midterm score.

Mastery Grading Scheme: Six unit mastery assessments will be administered during discussion throughout the quarter. Each mastery assignment will consist of 10 questions valued at 10 points each. You will have 25 minutes to complete the unit assessment, and you will be given three chances to demonstrate mastery for the content in each unit. A separate mastery grading scale will be used for the unit mastery assessments:

		Points
Well below mastery	<50%	0 points
Below mastery	50-60%	50/100 points
Mastery	= 60%	60/100 points
Above Mastery	70%	70/100 points
Above Mastery	80%	80/100 points
Well above mastery	> 90%	100 points

If the midterm score is higher than the Unit 1–2 mastery score, the midterm score will replace those scores; if the final exam score is higher than any of the Unit 1–6 scores and/or midterm score, the final exam score will replace those scores.

S1.2 Tentative Course Outline

		Subject	OLI Module
Week 1			
Jan 09		Unit 1: Ideal Gases	
	T	Introduction to Ideal Gases	1
	Th	Gas Laws	2
Discussion		OLI Survey	
Week 2			
Jan 16		Unit 1: Ideal Gases	
	T	Stoichiometry of Gases	3
	Th	Kinetic Molecular Theory	4
Discussion		Mastery Assessment: Unit 1	
Week 3			
Jan 23		Unit 2: Thermochemistry	
	T	Introduction to Energy	6,7
	Th	Calorimetry	8
Discussion		Mastery Assessment: Unit 1 and 2	
Week 4			
Jan 30		Unit 2: Thermochemistry	
	T	Enthalpy	9
	Th	Review Dipoles	
Discussion		Mastery Assessment: Unit 1 and 2	
Week 5			
Feb 06		Unit 3: Solids and Liquids	
	T	Intermolecular Forces	14,15
	Th	Phase Changes	16
Discussion		Midterm Exam (Units 1 and 2)	

Week 6			
Feb 13		Unit 3: Solids and Liquids and Unit 4: Solutions	
	T	The Solid State of Matter (Unit 3)	17
	Th	Solubility (Unit 4)	20
Discussion		Mastery Assessment: Unit 3	
Week 7			
Feb 20		Units 4 Solutions and Unit 5 Thermodynamics	
	T	Colligative Properties (Unit 4)	21
	Th	Intro to Thermodynamics (Unit 5)	22
Discussion		Mastery Assessment: Unit 3 and 4	
Week 8			
Feb 27		Unit 5: Thermodynamics	
	T	The Second Law of Thermodynamics	23
	Th	Free Energy	24
Discussion		Mastery Assessment: Unit 3, 4, and 5	
Week 9			
Mar 06		Unit 6: Chemical Kinetics	
	T	Introduction to Kinetics	27
	Th	Reaction Rates	28
Discussion		Mastery Assessment: Unit 4, 5, and 6	
Week 10			
Mar 13		Unit 6: Chemical Kinetics	
	T	Reaction Mechanisms	29
	Th	Rates Laws	30
Discussion		Mastery Assessment: Unit 5 and 6	
Finals Week			
Mar 24		Final Exam[1] 8:00 am to 11:00 am	

S2 Pair-wise Comparison Statistics

Analysis of variance (ANOVA) was used to compare average scores on the common final exam questions between the three study groups. The analyses were carried out for the entire class populations (Tables S2 and S3) and for specific demographic groups. The demographic groups examined include URM students (Tables S4 and S5), first-generation students (Tables S6 and S7), students receiving financial aid (Tables S8 and S9), and students who belong to all three of these categories (Tables S10 and S11). Post hoc pair-wise tests were used to determine where significant differences in final exam scores were observed for cases when the omnibus ANOVA was found to be

[1] An additional Unit 6 mastery exam attempt was provided during the final exam block.

statistically significant. Effect sizes [**?**] were calculated using the partial eta-squared statistic (η^2) from the omnibus ANOVA according to Eq. 1,

$$\text{Cohen's f} = \sqrt{\frac{\eta^2}{1-\eta^2}}. \tag{1}$$

and all calculations were carried out using the IBM SPSS software program version 28.0.0.0.[**?**]

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η^2	Noncent. Parameter	Observed Power[b]
Corrected Model	6152.322[a]	2	3076.161	8.847	0.000	0.024	17.695	0.972
Intercept	3348396.192	1	3348396.192	9630.294	0.000	0.931	9630.294	1.000
Class Group	6152.322	2	3076.161	**8.847**	**0.000**	**0.024**	17.695	0.972
Error	249992.033	719	347.694					
Total	3605425.000	722						
Corrected Total	256144.356	721						

Table S2: Statistical data for all demographics. [a] $R^2 = 0.024$ (Adjusted R^2=0.021). [b] computed using $\alpha = 0.05$. Cohen's $f = \sqrt{0.024/(1-0.024)} = 0.157$.

Class Group		Mean difference	Standard Error	Sig.	**95% Confidence** Lower Bound	Upper Bound
Mastery+OLI	Control	7.0757*	1.7022	0	2.9911	11.1603
	Mastery	4.4709*	1.6969	0.026	0.399	8.5427
Control	Mastery+OLI	-7.0757*	1.7022	0	-11.1603	-2.9911
	Mastery	-2.6049	1.70045	0.378	-6.6853	1.4755
Mastery	Mastery+OLI	-4.4709*	1.6969	0.026	-8.5427	-0.399
	Control	2.6049	1.70045	0.378	-1.4755	6.6853

Table S3: Multiple comparisons data for all demographics based on the observed means. The mean square error is 347.694. *: the mean difference is significant at the 0.05 level.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η^2	Noncent. Parameter	Observed Power[b]
Corrected Model	3364.654[a]	2	1682.327	4.19	0.016	0.032	8.38	0.733
Intercept	973135.676	1	973135.676	2423.695	0.000	0.905	2423.695	1
Class Group	3364.654	2	1682.327	**4.19**	**0.016**	**0.032**	8.38	0.733
Error	101581.831	253	401.509					
Total	1108700	256						
Corrected Total	104946.484	255						

Table S4: Statistical data for URM students. [a] $R^2 = 0.032$ (Adjusted R^2=0.024). [b] computed using $\alpha = 0.05$. Cohen's $f = \sqrt{0.032/(1-0.032)} = 0.181$.

Class Group		Mean difference	Standard Error	Sig.	95% Confidence Lower Bound	95% Confidence Upper Bound
Mastery+OLI	Control	7.0984*	2.93098	0.048	0.0347	14.1621
	Mastery	7.9680*	3.16945	0.038	0.3296	15.6063
Control	Mastery+OLI	-7.0984*	2.93098	0.048	-14.1621	-0.0347
	Mastery	0.8696	3.19111	1.000	-6.821	8.5602
Mastery	Mastery+OLI	-7.9680*	3.16945	0.038	-15.6063	-0.3296
	Control	-0.8696	3.19111	1.000	-8.5602	6.821

Table S5: Multiple comparisons data for URM students based on the observed means. The mean square error is 401.509. *: the mean difference is significant at the 0.05 level.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η^2	Noncent. Parameter	Observed Power[b]
Corrected Model	6262.550[a]	2	3131.275	8.361	0.000	0.069	16.721	0.962
Intercept	817078.772	1	817078.772	2181.645	0.000	0.907	2181.645	1
Class Group	6262.55	2	3131.275	**8.361**	**0.000**	**0.069**	16.721	0.962
Error	83893.397	224	374.524					
Total	919400	227						
Corrected Total	90155.947	226						

Table S6: Statistical data for first-generation students. [a]$R^2 = 0.069$ (Adjusted R^2=0.061). [b]Computed using $\alpha = 0.05$. Cohen's $f = \sqrt{0.069/(1-0.069)} = 0.272$.

Class Group		Mean difference	Standard Error	Sig.	95% Confidence Lower Bound	95% Confidence Upper Bound
Mastery+OLI	Control	12.3934*	3.0941	0.000	4.9301	19.8566
	Mastery	8.1308*	3.14049	0.031	0.5557	15.706
Control	Mastery+OLI	-12.3934*	3.0941	0.000	-19.8566	-4.9301
	Mastery	-4.2625	3.22668	0.564	-12.0456	3.5205
Mastery	Mastery+OLI	-8.1308*	3.14049	0.031	-15.706	-0.5557
	Control	4.2625	3.22668	0.564	-3.5205	12.0456

Table S7: Multiple comparisons data for first-generation students based on the observed means. The mean square error is 374.524. *: the mean difference is significant at the 0.05 level.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η^2	Noncent. Parameter	Observed Power[b]
Corrected Model	5594.116[a]	2	2797.058	7.804	0.000	0.026	15.608	0.951
Intercept	2675524.752	1	2675524.752	7464.777	0.000	0.927	7464.777	1
Class Group	5594.116	2	2797.058	7.804	0.000	0.026	15.608	0.951
Error	210034.067	586	358.42					
Total	2893525	589						
Corrected Total	215628.183	588						

Table S8: Statistical data for students receiving financial aid. [a] $R^2 = 0.026$ (Adjusted R^2=0.023). [b] computed using $\alpha = 0.05$.

Class Group		Mean difference	Standard Error	Sig.	**95% Confidence** Lower Bound	Upper Bound
Mastery+OLI	Control	7.4007*	1.92733	0.000	2.7735	12.028
	Mastery	5.1868*	1.89833	0.019	0.6292	9.7445
Control	Mastery+OLI	-7.4007*	1.92733	0.000	-12.028	-2.7735
	Mastery	-2.2139	1.90844	0.739	-6.7958	2.368
Mastery	Mastery+OLI	-5.1868*	1.89833	0.019	-9.7445	-0.6292
	Control	2.2139	1.90844	0.739	-2.368	6.7958

Table S9: Multiple comparisons data for students receiving financial aid based on the observed means. The mean square error is 358.420. *: the mean difference is significant at the 0.05 level.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η^2	Noncent. Parameter	Observed Power[b]
Corrected Model	3281.147[a]	2	1640.574	3.967	0.021	0.058	7.934	0.703
Intercept	415910.514	1	415910.514	1005.646	0.000	0.886	1005.646	1
Class Group	3281.147	2	1640.574	3.967	0.021	0.058	7.934	0.703
Error	53351.239	129	413.575					
Total	484475	132						
Corrected Total	56632.386	131						

Table S10: Statistical data for first-generation URM students financial aid. [a] $R^2 = 0.058$ (Adjusted $R^2 = 0.043$). [b] computed using $\alpha = 0.05$.

Class	Group	Mean difference	Standard Error	Sig.	95% Confidence Lower Bound	95% Confidence Upper Bound
Mastery+OLI	Control	11.5957*	4.15479	0.018	1.5178	21.6735
	Mastery	7.0667	4.44519	0.343	-3.7156	17.8489
Control	Mastery+OLI	-11.5957*	4.15479	0.018	-21.6735	-1.5178
	Mastery	-4.529	4.52537	0.956	-15.5057	6.4478
Mastery	Mastery+OLI	-7.0667	4.44519	0.343	-17.8489	3.7156
	Control	4.529	4.52537	0.956	-6.4478	15.5057

Table S11: Multiple comparisons data for first-generation URM students receiving financial aid based on the observed means. The mean square error is 413.575. *: the mean difference is significant at the 0.05 level.

S3 Student Feedback

Anonymous course evaluation data for the Mastery and Mastery+OLI sections were separated by sentence, providing 397 responses for the Mastery+OLI section and 95 responses for the Mastery grading section. Each sentence was processed using Google's Natural Language API to identify keywords with a corresponding salience ranking. The following keywords were used in the salience ranking: retakes, quizzes, assessments, weekly, mastery, mini quizzes, grading structure, grading format, test, and multiple chances. These keywords were selected following review of the student responses. Selecting sentences containing the above keywords with a salience score greater than or equal to 0.1 resulted in 103 student comments related to the mastery grading model across both sections. The main text reports the sentiment analysis results using Google's Natural Language Processing tools. Here, we compare the Google Cloud Sentiment Analysis (GCSA) results with two other commonly used sentiment analysis algorithms: TextBlob and VADER.[**?**]

The TextBlob is a Python library for text processing, and it uses the Natural Language ToolKit (NLTK) for natural language processing. VADER is a simple rule-based model for general sentiment analysis, which is also provided in the NLTK libraries. The TextBlob and VADER algorithms return a polarity (sentiment) score between -1 and +1, with larger scores corresponding to more positive sentiment. Figure S1 illustrates the sentiment analysis results for both algorithms. For ease of interpretation, scores below -0.25 are classified as negative (red), between -0.25 and +0.25 as neutral (yellow), and above +0.25 as positive (green). The TextBlob and VADER algorithms provideed similar findings when compared to the GCSA results in the main text.

These sentiment analysis results did not separate the data based on the different aspects of the mastery grading system.

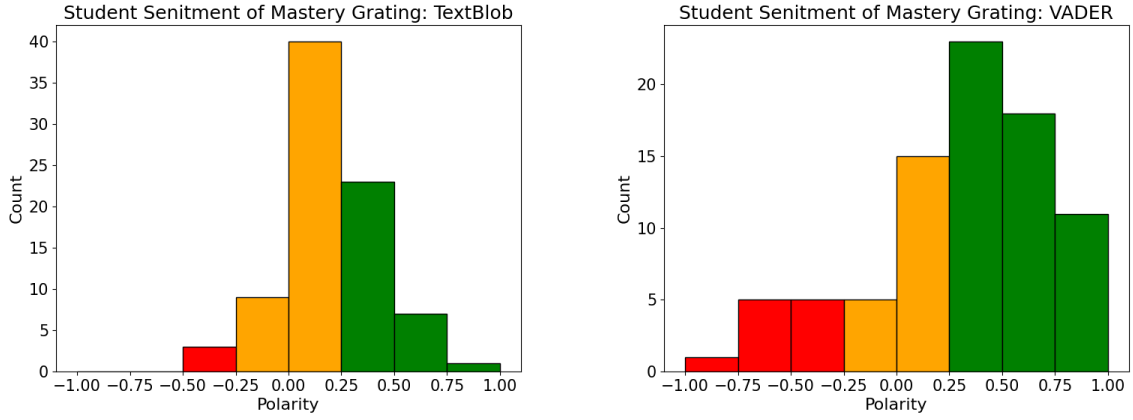
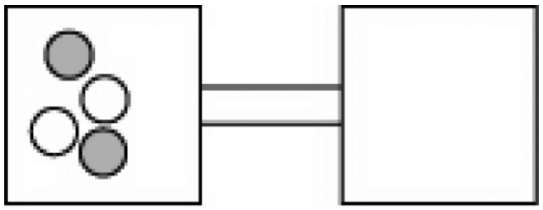


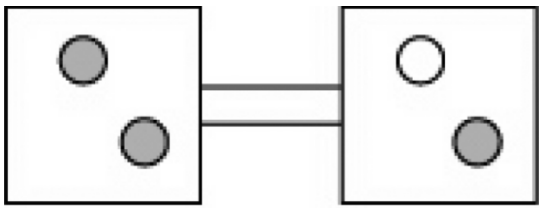
Figure S1: Student sentiment analysis for mastery grading using the TextBlob (left) and VADER (right) sentiment analysis algorithms.

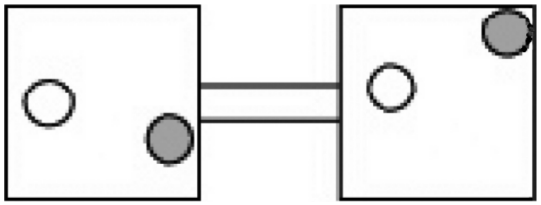
S4 Common Test Questions

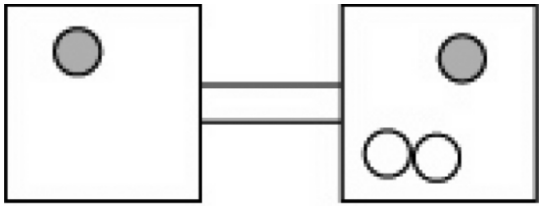
The common test questions as they appeared on the student exams, along with the average student student performance (Mean Score) and discrimination index for the Mastery and Mastery+OLI sections, are depicted:

(1) The following figures represent distributions of two types of gas molecules between two containers connected by an open tube. In which figure is the entropy of the system maximized?

(a)


(b)


(c)


(d)


(e) These are equal entropy systems.

	Mean Score	Discrimination Index
Mastery	0.44	0.17
Mastery+OLI	0.60	0.44

(2) Indicate which of the following has the lowest standard molar entropy (S°).

(a) $CH_4(g)$
(b) $CH_3CH_2OH(l)$
(c) $H_2O(l)$
(d) $Na(s)$
(e) $He(g)$

	Mean Score	Discrimination Index
Mastery	0.81	0.52
Mastery+OLI	0.67	0.45

(3) Determine ΔS° for the reaction $N_2O_4(g) \rightarrow 2NO_2(g)$ given the following information.

Substance	S° **(J/mol $\times$ k)**
$N_2O_4(g)$	304.3
$NO_2(g)$	240.45

(a) +176.6 J/mol $\times$ K

(b) -63.8 J/mol $\times$ K

(c) +63.8 J/mol $\times$ K

(d) -50.7 J/mol $\times$ K

(e) -176.7 J/mol $\times$ K

	Mean Score	Discrimination Index
Mastery	0.86	0.54
Mastery+OLI	0.93	0.16

1. Methane and water vapor can react to form carbon monoxide and hydrogen gas according to the reaction $CH_4(g) + H_2O(g) \rightarrow CO(g) + 3H_2(g)$. If $\Delta H^\circ = 206.1$ kJ/mol and $\Delta S^\circ = 214.5$ J/mol $\times$ K, what is the ΔG° for this reaction at 25.00°C?

(a) -6.375×10^4 kJ/mol

(b) -8.400 kJ/mol

(c) 142.1 kJ/mol

(d) 205.9 kJ/mol

(e) -5156 kJ/mol

	Mean Score	Discrimination Index
Mastery	0.88	0.52
Mastery+OLI	0.90	0.26

(5) Estimate the standard free energy change at 800.00°C for the reaction $2SO_3(g) \rightarrow 2SO_2(g) + O_2(g)$ given the following information.

Substance	ΔH_f° (kJ/mol)	S° (J/mol $\times$ K)
$SO_3(g)$	-395.7	256.8
$SO_2(g)$	-296.8	248.2
$O_2(g)$		205.0

(a) -3.70 kJ

(b) +47.6 kJ

(c) -399.3 kJ
(d) +348.0 kJ
(e) +399.3 kJ

	Mean Score	Discrimination Index
Mastery	0.77	0.65
Mastery+OLI	0.83	0.41

(6) For the reaction $2SO_3(g) \rightarrow 2SO_2(g) + O_2(g)$, the rate of the reaction in terms of the change in oxygen concentration would be written as

(a) $-1/2\Delta[O_2]/\Delta t$
(b) $1/2/\Delta[O_2]/\Delta t$
(c) $-\Delta[O_2]/\Delta t$
(d) $\Delta[O_2]/\Delta t$
(e) $2\Delta[O_2]/\Delta t$

	Mean Score	Discrimination Index
Mastery	0.61	0.50
Mastery+OLI	0.60	0.50

(7) Given the following data, determine the rate law for the following reaction:

$$NH_4^+(aq) + NO_2^-(aq) \rightarrow N_2(g) + 2H_2O(l)$$

Experiment	$[NH_4^+](M)$	$[NO_2^-](M)$	Rate (M/s)
1	0.2500	0.2500	1.25×10^{-3}
2	0.5000	0.2500	2.50×10^{-3}
3	0.2500	0.1250	6.25×10^{-4}

(a) $k[NH_4^+][NO_2^-]$
(b) $k[NH_4^+]^2[NO_2^-]$
(c) $k[NH_4^+][NO_2^-]^{1/2}$
(d) $k[NH_4^+]^{1/2}[NO_2^-]^2$
(e) $k[NH_4^+][NO_2^-]^2$

	Mean Score	Discrimination Index
Mastery	0.60	0.51
Mastery+OLI	0.75	0.42

(8) Which statement below regarding rate laws and rate constants is true?

(a) The rate constant is independent of temperature.
(b) The units of the rate constant depend on the stoichiometry of the reaction.

(c) The rate constant typically depends on concentration of reactant(s).

(d) The rate typically depends on concentration of reactant(s).

(e) The rate constant does not change when a catalyst is introduced.

	Mean Score	Discrimination Index
Mastery	0.58	0.30
Mastery+OLI	0.58	0.38

(9) The initial rate data for the reaction $2N_2O_5(g) \rightarrow 4NO_2(g)+O_2(g)$ are shown in the following table. Determine the value of the rate constant for this reaction.

Experiment	$[N_2O_5](M)$	Rate(M/s)
1	2.56×10^3	450.
2	1.28×10^2	22.5

(a) 4.09 1/s

(b) 0.176 1/s

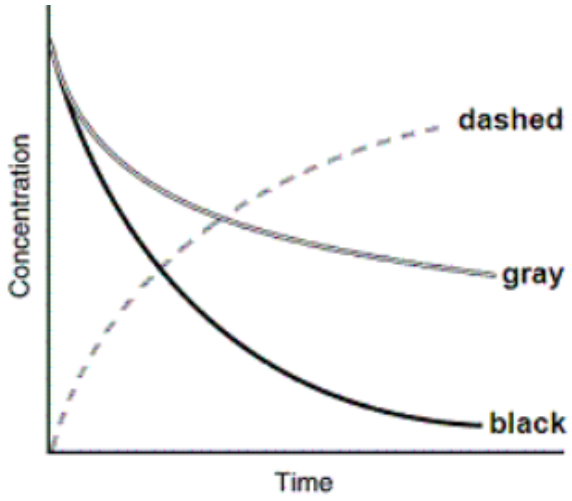
(c) 0.0569 1/s

(d) 0.255 1/s

(e) 80.1 1/s

	Mean Score	Discrimination Index
Mastery	0.80	0.59
Mastery+OLI	0.84	0.35

(10) The following graph shows the kinetics curves for the reaction of oxygen with hydrogen to form water: $O_2(g) + 2H_2(g) \rightarrow 2H_2O(g)$. Which curve is hydrogen?



(a) The dashed curve

(b) The gray curve

(c) The black curve

(d) Either the gray or the black curve

(e) Any of these curves could be hydrogen.

	Mean Score	Discrimination Index
Mastery	0.52	0.53
Mastery+OLI	0.52	0.54

(11) In an experiment, 0.250 kg water at 95.0°C is quickly transferred to a 0.500 kg alumina crucible at 25°C. The final temperature of the water and crucible comes to 61.8°C. What is the approximate specific heat capacity of alumina? [c_p(water) = 4.18 J/(g × °C)]

(a) 7.94 $J/(g \times^\circ C)$

(b) 5.17 $J/(g \times^\circ C)$

(c) 1.89 $J/(g \times^\circ C)$

(d) 0.664 $J/(g \times^\circ C)$

(e) 2.32 $J/(g \times^\circ C)$

	Mean Score	Discrimination Index
Mastery	0.89	0.56
Mastery+OLI	0.89	0.30

(12) A 65.0 g piece of chromium [c_p = 0.449 $J/(g \times^\circ C)$)] is heated to a temperature of 120.0°C and then placed in contact with a 95.0 g piece of zinc at 20.0°C [cp = 0.387 $J/(g \times^\circ C)$)]. What is the final temperature of the two pieces of metal?

(a) 70°C

(b) 42°C

(c) 64°C

(d) 47°C

(e) 83°C

	Mean Score	Discrimination Index
Mastery	0.67	0.57
Mastery+OLI	0.81	0.37

(13) Hydrogen gas (2.02 g/mol) can be produced from the reaction of methane (16.05 g/mol) and water vapor (18.02 g/mol) according to the following reaction equation:

$$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3H_2(g)$$

If 262 grams of CH_4 reacts with excess H2O at 423 K and 0.862 atm, what volume of H_2 gas will form?

(a) 342 L
(b) 1970 L
(c) 98.9 L
(d) 657 L
(e) 70,800 L

	Mean Score	Discrimination Index
Mastery	0.76	0.60
Mastery+OLI	0.75	0.43

(14) A solution is prepared by adding 1.50 mol of glucose, which is not volatile, to 3.50 mol of water. What is the vapor pressure of this solution at 25°C given that the vapor pressure of pure water is 23.8 torr?

(a) 7.00 torr
(b) 16.7 torr
(c) 10.2 torr
(d) 7.14 torr
(e) 34.0 torr

	Mean Score	Discrimination Index
Mastery	0.49	0.44
Mastery+OLI	0.53	0.53

(15) Which statement below regarding the liquid–gas phase transition and boiling is NOT correct?

(a) More molecules have sufficient energy to escape the liquid phase at higher temperatures.
(b) The vapor pressure of a liquid increases with temperature.
(c) Boiling occurs only when the vapor pressure of a liquid equals 1 standard atm.
(d) Compared to less volatile liquids, more volatile liquids tend to have lower boiling points.
(e) Liquids with stronger intermolecular forces typically have higher boiling points.

	Mean Score	Discrimination Index
Mastery	0.46	0.35
Mastery+OLI	0.72	0.22

(16) What is the boiling point of a solution prepared by dissolving 157.0 g of urea (CH_4N_2O, 60.06 g/mol) in 750.0 g of water? ($K_b = 0.512°C/m$ for water)

(a) 98.22°C
(b) 101.00°C
(c) 99.00°C
(d) 101.78°C

(e) 100.26°C

	Mean Score	Discrimination Index
Mastery	0.79	0.56
Mastery+OLI	0.78	0.29

(17) A scientist conducts an experiment to determine the rate of the following reaction:

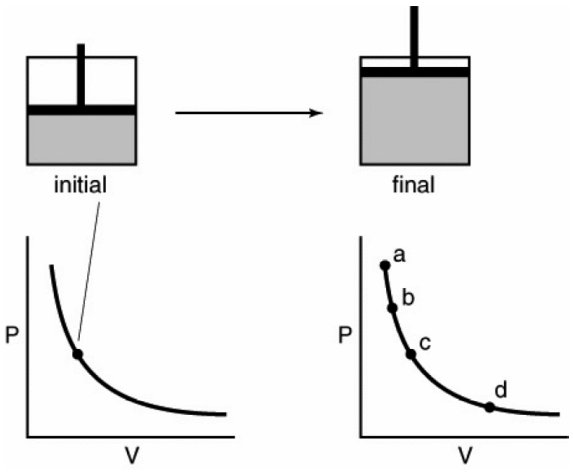
$$2N_2O_5(g) \rightarrow 4NO_2(g) + O_2(g)$$

If the initial concentration of NO_2 was 0.000 M and the concentration of NO_2 was 0.0500 M after 0.100s, what is the average rate of reaction over the first 0.100s?

(a) 0.125 M/s
(b) 0.500 M/s
(c) 1.25 M/s
(d) 2.00 M/s
(e) 5.25 M/s

	Mean Score	Discrimination Index
Mastery	0.34	0.32
Mastery+OLI	0.67	0.02

(18) A gas is contained in the piston assembly and allowed to expand as in the following figure. Which point on the graph shows the correct final pressure and volume? (assume that the temperature of the gas did not change in this experiment)



(a) A
(b) B
(c) C
(d) D

	Mean Score	Discrimination Index
Mastery	0.92	0.35
Mastery+OLI	0.93	0.10

(19) You wish to de-ice your driveway, so you consider buying 10 lb of $NaCl$, 10 lb of $CaCl_2$, or 10.0 lb of $MgCl_2$. Which of these would de-ice your driveway most effectively? Assume that the van't Hoff factor is based on the number of ions formed in solution, the three salts would evenly mix with the same amount of ice/water, and that colligative properties are the only consideration.
1 pound = 454 grams
(hint: to answer this question, determine how many moles of each salt are present in 10 pounds)

(a) 10.0 lb of $NaCl$ will de-ice best.

(b) 10.0 lb of $CaCl_2$ will de-ice best.

(c) 10.0 lb of $MgCl_2$ will de-ice best.

(d) The three driveways will de-ice to the same extent.

	Mean Score	Discrimination Index
Mastery	0.64	0.30
Mastery+OLI	0.61	0.15

(20) Isopropyl alcohol, $(CH_3)_2CH-OH$, is a liquid that has a boiling point of 82.3°C. Solutions of isopropyl alcohol in water have boiling points less than 100°C. How is it possible for a solution of isopropyl alcohol to have a lower boiling point than pure water?

$$\Delta T_b = iK_b m$$

(a) Isopropyl alcohol forms hydrogen bonds with water, thus lowering the boiling point.

(b) Since isopropyl alcohol is a volatile liquid, this will not increase the boiling point of water.

(c) Isopropyl alcohol undergoes reverse osmosis, which lowers the boiling point.

(d) The boiling point depression constant changes for water when isopropyl alcohol is mixed.

	Mean Score	Discrimination Index
Mastery	0.85	0.17
Mastery+OLI	0.52	0.45