Semester of Bridging Course Sequence	Course-Level Learning Objective	Course Module	Lecture-Level Learning Objective	Homework Problem Average Score	Quiz Average Score	Exam Problem Average Score	Final Exam Problem Average Score
		1.1	Describe the fundamental law of mass conservation in their own words	93.7			
			Write the general material balance equation and identify terms for a given system	90.8	57.9		
			Explain the meaning of the following terms: batch, semi-batch, continuous, transient, and steady-state processes	90.8	57.9		
			Perform a degree-of-freedom analysis for a series of equations	93.7		60.3	57.9
			Label a flowchart with the correct convention for mass (mass flow rate) or moles (molar flow rates) and compositions, ensuring that all streams are fully labeled	90.8	57.9	94.8	65.4
			Choose a convenient basis of calculation and, if necessary, scale the final values of stream amounts or flow rates based on a specified basis			44.2	
		1.2	Define a recycle stream and list at least four reasons why a recycle might be used in a chemical process				
			Define a bypass stream and list at least two reasons why a bypass stream might be used in a chemical process				
			Given a process description for a process involving a recycle and/or a bypass stream (a) draw and fully label a flowchart; (b) choose a convenient basis of calculation; (c) for a multiple-unit process, identify the subsystems for which balances might be written; (d) perform the degree-of-freedom analysis for the overall system and each possible subsystem; (e) write in order the equations you would use to calculate specified process variables; and (f) perform the calculations	91.2		44.2	54.5
			Draw and fully label a flow chart based on a description of a multiple- unit process	91.2		44.2	65.8

		1.3	Write independent material balances and equations based on “extra information”	91.2		71.0	
			Proceed through the entire process of drawing a flowchart for a multiple unit process without reaction, determine if the problem can be solved, and solve for particular unknowns	91.2		44.4	56.3
		1.4	Apply concepts and definitions of chemical reaction stoichiometry	80.4		52.7	
			Identify the limiting and excess reactants	80.4		56.0	
			Use fractional conversion of a reactant to calculate percentage conversion of others	83.7		48.7	
		1.5	Define what is meant by independent equations, independent species, and independent chemical				
			Explain the meaning of “extent of reaction” and define the equation used to calculate it	80.4		48.7	60.0
			Obtain degrees of freedom in each method used (molecular species, atomic species and extent of reaction) to determine if the problem is solvable or not	80.4		60.8	43.2
			Use molecular species balances, atomic species balances, and extent of reaction balances to determine unknown stream variables for a reactive process at steady state	80.4		48.7	60.0
			Determine which approach (molecular, atomic, extent of reaction) is best suited for the given process	80.4		44.4	
		1.6	Given a combustion reactor and information about the fuel composition and feed rate, calculate the feed rate of air from a given percent excess or vice versa				
			Given additional information about the conversion of the fuel and the absence or presence of partially oxidized species such as CO in the product gas, calculate the flow rate and composition of the product gas				
			Explain Le Chatelier’s Principle as applied to chemical equilibrium				
			Given an equilibrium constant, use it to calculate the final compositions of the reaction species				

		1.7	Explain the meaning of the following terms and define the equation used to calculate them: (a) yield; (b) selectivity				
			Explain the meaning of the following terms and define the equation used to calculate them: (a) single pass conversion; (b) overall conversion				
		2.1	Interpret PT and PV diagrams for a pure substance, identifying the solid, liquid, gas, and fluid regions; the fusion (melting), sublimation, and vaporization curves; and the critical and triple point		68.4		
		2.2	Given any of the three quantities P, V (or volumetric flowrate), n (or molar flowrate), and T for an ideal gas, calculate the fourth one directly from the ideal-gas equation of state	94.5	68.4	82.9	
			Define STP conditions				
			Use the sum of partial pressures and partial volumes to express the total pressure and total volume of a system	97.9			
		2.3	Describe the difference between a vapor and a gas				
			Carry out PVT calculations for a gas using the truncated virial equation of state	90.5			
			Carry out PVT calculations for a gas using the SRK equation of state	87.2			
		2.4	Explain what compressibility factor, z, represents and what its value indicates about the validity of the ideal-gas equation of state				
			Carry out PVT calculations for the compressibility factor equation of state with either tabulated compressibility factors or a generalized compressibility chart for a single species	92.8		71.7	
			Carry out PVT calculations for the compressibility factor equation of state with either tabulated compressibility factors or a generalized compressibility chart using Kay’s rule for a non-ideal mixture of gases				

		3.1	Estimate the vapor pressure of a pure substance at a specified T, or the boiling point at a given vapor pressure, using:				
			• the steam tables	80.8			
			• the Clausius-Clapeyron equation and known vapor pressures at two specified temperatures	90.0			
			• the Antoine equation	87.4		24.2	63.2
		3.2	Distinguish between intensive and extensive variables, giving examples of each	98.7			
			Use the Gibbs phase rule to determine the number of degrees of freedom for a multicomponent multiphase system at equilibrium	98.7			
			Specify a feasible set of intensive variables that will enable the remaining intensive variables to be calculated	98.7			
		3.3	In the context of a system containing a single condensable species and noncondensable gases, explain the terms saturated vapor, superheated vapor, dew point, degrees of superheat, and relative saturation		88.2	89.3	63.2
			Given an equilibrated gas-liquid system containing only a single condensable component, a correlation of pA*(T), and any two of the variables yA (mole fraction of A), temperature, total pressure, dew point, degrees of superheat, and relative/absolute saturation (or humidity if A is water and the condensable gas is air), use Raoult's law for a single condensable species to calculate the remaining variables	94.7			63.2
	lances (MEB)		Given vapor-liquid equilibrium compositions from tabulated data for a gas-liquid system that involves several components in each phase, draw and label the flowchart, carry out the degree-of- freedom analysis, and perform the required calculations	89.2		81.9	

		Mass and Energy Ba		Write and clearly explain the formulas for Raoult’s and Henry’s laws, state the conditions for which each relationship is most likely to be accurate, and applying the appropriate one to determine any of the variables t, P, xA, or yA (temperature, pressure, and mole fractions of A in the liquid and gas phases) from given values of the other three	94.7		66.3	
			3.4	Explain the terms bubble point, boiling point, and dew point of a mixture of condensable species, and the difference between vaporization and boiling		88.2		
				Use Raoult’s law to determine (a) the bubble-point temperature (or pressure) of a liquid mixture of known composition at a specified pressure (or temperature) and the composition of the first bubble that forms; (b) the dew-point temperature (or pressure) of a vapor mixture of known composition at a specified pressure (or temperature) and the composition of the first liquid drop that forms; (c) whether a mixture of known amount (moles) and composition (component mole fractions) at a given temperature and pressure is a liquid, a gas, or a gas-liquid mixture and, if the latter, the amounts and compositions of each phase; and (d) the boiling point temperature of liquid mixture of known composition at a specified total pressure	92.0		66.3	
				List and define in your own words the three components of the total energy of a process system and two forms of energy transfer between a system and its surroundings	93.7			
			4.1	State the conditions under which heat and work are positive	95.8			
				Define the terms closed process system, open process system, and isolated process system	95.8			

First Semester of Course Sequence		4.2	Write the first law of thermodynamics (the energy balance equation) for a closed process system and state the conditions under which each of the five terms in the balance can be neglected	95.8		73.6	57.1
			Define the term adiabatic process			100.0	
			Given a description of a closed process system, simplify the energy balance and solve it for whichever term is not specified in the process description	95.8	68.4		57.1
		4.3	Define the terms flow work and shaft work	86.1			
			Define the terms specific internal energy, specific volume, and specific enthalpy	86.1	68.4		
			Write the energy balance for an open process system in terms of enthalpy and shaft work and state the conditions under which each of the five terms can be neglected	86.1		98.9	
			Given a description of an open process system, simplify the energy balance and solve it for whichever term is not specified in the process description	86.1	68.4	73.6	
		4.4	Write the energy balance for an open process system in terms of enthalpy and shaft work and state the conditions under which each of the five terms can be neglected	86.1		66.3	
			Given a description of an open process system, simplify the energy balance and solve it for whichever term is not specified in the process description	86.1		66.3	47.9
			Define the concept of a reference state				47.9
			State why the actual values of specific internal energy and specific enthalpy can never be known for a given species in a specified state (temperature, pressure, and phase)				

			Given a process in which a specified mass m of a species goes from one state to another and tabulated values of specific internal energy or specific enthalpy for the species at the initial and final states are available, calculate the change in internal energy or the change in enthalpy	79.7		70.6	47.9
		4.5	Starting with the open system energy balance equation, derive the steady-state mechanical energy balance equation for an incompressible fluid and simplify the equation further to derive the Bernoulli equation. List all the assumptions made in the derivation of the latter equation	92.4			
			Given fluid conditions (pressure, flow rate, velocity, elevation) at the inlet and outlet of an open system and values of friction loss and shaft work within the system, substitute known quantities into the mechanical energy balance (or the Bernoulli equation if friction loss and shaft work can be neglected) and solve the equation for whichever variable is unknown	92.4			
		5.1	Describe the difference between a state function and a path function	86.6			
			List the five potential components that can be used to construct a process path from the initial state to the final state				
		5.2	Describe the effect on enthalpy and internal energy of pressure changes at constant temperature	81.8	81.6		
			Calculate sensible heat using the constant volume and constant pressure heat capacities	82.1			
			Calculate the change in specific internal energy and specific enthalpy for isobaric temperature changes	81.8			47.9

5.3	Define both formally (in terms of internal energies and enthalpies) and in words a high school senior could understand: heat of fusion, heat of melting, heat of vaporization, and standard heats of fusion and vaporization. State when the formulas you use for these calculations are exact, good approximations, and poor approximations		81.6		
	Estimate the heat of fusion and the heat of vaporization of a species	82.1	81.6		
	Perform energy balances on process involving phase changes	82.1	81.6		47.9
5.4	Use the heat of solution data in Table B.10 and solution heat capacity data to calculate the enthalpy of a hydrochloric acid, sulfuric acid, or sodium hydroxide solution of a known composition (solute mole fraction) relative to the pure solute and water at 25°C	77.6			
6.1	Explain in your own words the concepts of heat of reaction, exothermic and endothermic reactions, and standard heat of reaction	93.9	75.0	100.0	
6.2	Determine a heat of reaction from heats of other reactions using Hess's law	86.6			
	Determine standard enthalpies and internal energies of reaction from known standard heats of formation	88.9		96.5	60.0
6.3	Explain the concepts of heat of formation and standard heat of formation				60.0
	Explain the concepts of heat of combustion and standard heat of combustion		75.0		
	Determine the standard heat of reaction from known standard heats of combustion and from known standard heats of formation	88.9		96.5	60.0

		6.4	Write and solve an energy balance on a chemical reactor using either the heat of reaction method (taking reactant and product species as references for enthalpy calculations) or the heat of formation method (taking elemental species as references), and specify which method is preferable for a given process. Write the process path implicitly adopted when each method is used	80.0	75.0	89.6	70.8
		7.1	Describe why entropy is a state function and relate it to observable properties of a system, for which changes are computed from DSt = Q / T		44.7		
			State the second law of thermodynamics in words and as an inequality in terms of entropy		44.7		
		7.2	Apply the second law to heat engines	97.3			
			Draw schematics of a Carnot engine	99.2			
			Define the thermal efficiency of a heat engine	96.3			
		7.3	Draw schematics of a heat pump and explain the steps that make up the heat pump (refrigeration) cycle	94.2			
			Define the coefficient of performance of a heat pump and a Carnot heat pump	99.2	44.7		
		7.4	Write and solve an entropy balance for an open system	96.1		42.5	
		8.1	Write and apply the fundamental property relations for internal energy, enthalpy, Gibbs energy, and Helmholtz energy in both a general form applicable to any closed PVT system and the system for which n=1	92.2			47.9
			Write the Maxwell relations, and apply them to replace unmeasurable partial derivatives involving entropy with partial derivatives that can be determined from PVT data				
			Obtain any thermodynamic property from G/RT as a function of T and P				
		8.2	Define and apply residual properties and the relationships among them (e.g., the fundamental residual property relations)				
			Calculate enthalpy and entropy from residual properties				

Classical Thermodynamics	8.3	Construct multi-step computational paths to compute property changes for arbitrary changes of state of a pure substance, making use of data or correlation for residual properties, heat capacities and latent heat				
	8.4	Explain the origin of the Clapeyron equation and apply it to estimate the change in phase transition pressure with temperature from latent heat data and vice versa				
		Apply the Antoine equation and the Clapeyron equation to determine the vapor pressure at a given temperature and enthalpy of vaporization				
		Write an expression for the total molar value of an extensive property for a two-phase system	92.2			
		Explain how to read common thermodynamic diagrams (ln P-H, T-S, and H-S) and trace the paths of a given process using the appropriate diagram				
	9.1	Explain the purpose and function of a nozzle and apply relationships between thermodynamic quantities to flow processes such as flow through pipes and nozzles	88.8		49.6	
		Analyze a throttling process using the first law of thermodynamics	88.8		49.6	
	9.2	Compute the work produced by a turbine of given efficiency expanding a fluid from a known initial state to a known final pressure	94.7			
		Define and apply isentropic efficiencies for (1) processes that produce work and (2) processes that require work input	94.7	55.3	70.0	
	9.3	Compute the work required to compress a gas from a given initial state to a final pressure, using a compressor with known efficiency	91.9		70.0	
		Determine changes in all thermodynamic state variables for adiabatic, reversible compression or expansion of ideal gases	91.9	55.3	70.0	52.5
		Compute the work required to pump a liquid				

	9.4	Qualitatively describe the idealized Carnot and Rankine cycles and sketch each of them on a PV or TS diagram	95.6			
		Carry out the thermodynamic analysis of a steam power plant	95.6			
	9.5	Carry out a thermodynamic analysis of a vapor compression refrigeration cycle		55.3		
Momentum Transport	10.1	Define density, specific gravity, specific weight, and Reynolds number and calculate those quantities		83.6		
		Calculate pressure, volumetric flowrate and mass flowrate				
		Explain the difference between laminar and turbulent flow				
		Describe how pressure changes with elevation and calculate the pressure change		83.6		
		For a U-tube manometer, write the equation which equates the pressure at either leg and solve for the missing quantity				
	10.2	Describe the differences between macroscopic and microscopic balances				
		Explain dimensions of Cartesian, cylindrical and spherical coordinate systems	80.5			
	10.3	Explain the concepts of viscosity and shear stress	80.5	73.4		
		Describe the properties of a Newtonian fluid				
	10.4	Identify the factors (pressure and viscosity) which affect molecular momentum fluxes	80.5			
		Describe equations used to model effects of pressure and viscosity on momentum flux	80.5			
		Describe mechanism for convective momentum flux	80.5			
		Describe equations used to model momentum transport by convection	80.5	73.4		
		Describe a combined momentum flux which is the sum of molecular and convective momentum transport	80.5			

		10.5	Perform shell balances to solve for momentum flux distributions and velocity profiles for laminar flowing fluids	80.5			
		11.1	Derive the equation of continuity for a control volume	88.3	63.2		
		11.2	Derive the Navier-Stokes equations				
		11.3	Analyze and apply the continuity equation, equations of motion and Navier-Stokes equations to systems such as laminar flow through rectangular and circular conduits	91.1		68.3	77.6
			Analyze potential and boundary layer flows, development of laminar flow, and entrance length in pipes				
		12.1	Describe mechanism of heat transfer by conduction	87.9			
			Analyze conductive heat transfer in systems using Fourier's law of conduction for various geometries		70.0	84.6	85.1
		12.2	Identify the effect of temperature and pressure on thermal conductivity				
		12.3	Explain the impact of boundary layer flow on convective heat transfer		73.6		
			Describe mechanisms of heat transfer for free and forced convection	92.1	70.0		
			Analyze Newton's Law of Cooling	95.9	77.1	84.6	85.1
		12.4	Analyze the impact of thermal conductivities of composite materials (such as insulated walls) and convection on heat transfer	92.1	70.0	84.6	85.1
		12.5	Describe mechanism of heat transfer for radiation		70.0		
			Analyze heat transfer by radiation using the Stefan-Boltzmann equation		70.0		
		13.1	Describe the concept and procedure of shell momentum balances in solving energy balance problems		77.1		
			Derive the equation of energy for non-isothermal flow in terms of the transport properties	95.4		84.9	
			Identify boundary conditions for a given non-isothermal energy balance problem	95.9	77.1		
			Identify when to use special forms of the equation of energy	95.9		84.9	

	Heat/Mass Transport		Apply special forms of the equation of energy to solve differential steady-state heat transfer boundary value problems	95.9		84.9	
		13.2	Identify dimensionless groups important in heat transfer				
		13.3	Define function and describe construction of various types of heat exchangers		77.1		
			Determine overall heat transfer coefficients and log mean temperature difference for double-pipe heat exchanger operation	95.4			
			Analyze double-pipe heat exchangers	95.4	77.1		
		14.1	Describe mechanisms of mass transfer by diffusion		76.2		
			Analyze diffusive mass transfer in systems using Fick's law of diffusion for various geometries	92.9			
		14.2	Identify the effect of temperature and pressure on diffusivity				
		14.3	Define common terms and notation used in convective mass transport, including mass/mole concentrations, mass/mole fractions and mass/molar average velocities	94.3			
			Describe combined mass flux and molar flux vectors for diffusive and convective mass transport	94.3	84.5		
		15.1	Derive the general equation of continuity for mass transfer processes	99.6		88.1	78.6
			Identify boundary conditions for a given mass balance problem	96.3	92.9		
		15.2	Identify commonly-used specific forms of the equation of continuity for mass transfer and in which cases to apply them	96.3	92.9	88.1	78.6
			Analyze and apply specific forms of the equation of continuity for mass transfer to determine concentration profiles	96.3	92.9	79.0	78.6
		15.3	Define function, mechanism and applications of common types of industrial processes requiring mass transfer				
			Define mass fraction, mole fraction, and molar concentration	99.3			

Second Semester of Course Sequence	Solution Thermodynamics	16.1	Relate Gibbs energy to its canonical variables, temperature and pressure				
			Write down the fundamental property relation for a single-phase fluid systems of variable mass and composition which relates Gibbs energy to chemical potential	90.0		75.0	73.8
			Define, in words and in symbols, chemical potential				
			Define, in words and in symbols, chemical equilibrium				
		16.2	Define partial properties and write the equation relating molar and partial molar properties	99.3			
			Calculate partial properties from mixture properties	99.3	66.1		
			Apply the summability relation to compute mixture properties from partial properties	99.3			
			Calculate partial properties for a binary system	99.3	66.1		
		16.3	Compute partial properties of a mixture in the ideal-gas state	94.3			
		16.4	Define and use fugacity and fugacity coefficients for pure species and for pure species in a mixture	90.0	66.1		
			Compute the fugacity and fugacity coefficient of a pure species from PVT data or generalized correlation	90.0	66.1	75.0	
		16.5	Estimate the fugacity coefficient of a species in a gas or liquid mixture				
		16.6	Use the virial equation of state and the generalized correlation to calculate the fugacity coefficient				
		16.7	Relate partial properties in an ideal solution to corresponding pure species properties	91.8			
			Define the Lewis/Randall rule				
		16.8	Define and use excess properties of species in a mixture				
		17.1	Define, in words and in equations, standard property changes of mixing	92.2			
			Compute excess properties and partial excess properties from corresponding property changes of mixing				
		18.1	State and apply the phase rule and Duhem's theorem for non-reacting systems				

18.2	Identify dew point and bubble point surfaces, the critical locus, and pure species vapor-pressure curves that make up a vapor/liquid phase envelope when presented in a PTxy diagram	96.2	66.1	85.5	
18.3	Interpret and apply Pxy, Txy, P-T, and yx diagrams representing vapor/liquid equilibrium of binary mixtures	96.2	66.1	85.5	
18.4	Describe how the critical points of binary systems vary and the phenomenon of retrograde condensation				
18.5	Define an azeotrope and sketch examples of Pxy and Txy diagrams for an azeotropic system	96.2	66.1		
19.1	Describe the relationship between excess Gibbs energy and activity coefficients			75.0	73.8
19.2	Explain each term in the gamma/phi formulation for VLE				
19.3	Carry out VLE calculations using the Modified Raoult's law with activity coefficient	91.8	59.5		
	State and apply Henry's law		59.5		
19.4	Explain and interpret the P, T - flash calculation	97.9	59.5	76.9	
20.1	Describe and define the equation for rate of reaction	82.1	40.5	88.8	82.4
20.2	Derive the general mole balance equation		40.5	88.1	
	Apply the general mole balance equation to a batch reactor	85.4		85.7	
20.3	Apply the general mole balance equation to a CSTR, PFR and PBR	76.9	40.5	88.3	82.4
21.1	Define the term "conversion".				
	Write all balance equations for batch reactors in terms of conversion.	80.0			
21.2	Rewrite all balance equations for CSTR, PFR and PBR in terms of conversion, X	80.0		93.6	82.4
21.3	Decide the best configuration for reactors in series	80.0			
	In addition to being able to determine CSTR and PFR sizes given the rate of reaction as a function of conversion, calculate the overall conversion and reactor volume for reactors arranged in series	80.0		93.6	79.3
	Define the following terms:				

	Kinetics	22.1	• Homogeneous / Heterogeneous reaction				
			• Reversible / Irreversible reaction				
			• Molecularity (Unimolecular, Bimolecular, Termolecular)				
			• Relative / Net rates of chemical reaction				
			• Elementary reaction and elementary rate law		40.5		
			• Explain the power law model and define the order of reaction		40.5		
		22.2	Explain non-elementary rate laws:		57.1		
			• Homogenous reactions				
			• Heterogeneous reactions				
			Write rate law for reversible reactions	90.2	48.8		
		22.3	Define the rate constant and show how it could be calculated using the Arrhenius equation				
			Write the differential, algebraic and integral forms of the design equations for all four types of industrial reactors: Batch, CSTR, PFR and PBR	80.7			
		23.1	Define parameters δ and Θi in batch systems				
			Create a stoichiometry table for batch systems	99.6			
			Demonstrate how concentration can be related to conversion in batch reactors			85.7	
		23.2	Define parameters δ and Θi in flow systems				
			Write the general equation for concentration CA in terms of molar flow rate, conversion and volumetric flow rate in flow systems	80.7			
			Write the equation for concentration CA of the liquid phase	80.7			
			Write the equation for concentration CA of the gas phase in terms of the virial equation of state				
			Define parameter ε and show how it is related to δ	78.9			
		24.1	Describe the general isothermal-reaction design algorithm for conversion		40.5		
		24.2	Describe the algorithm to estimate reaction time in batch systems		40.5	85.7	

		24.3	Describe the algorithm to calculate conversion for a single CSTR for:				
			• first-order reactions	82.1		93.6	87.5
			• second-order reactions				
			Define the Damköhler number				
			Describe the algorithm to calculate conversion for CSTRs in series	85.0	40.5		
		24.4	Describe the algorithm to calculate conversion for a tubular reactor, PFR	85.0		93.6	
			Calculate and/or explain how ε affects conversion	85.0			
		25.1	Use molar flow rates in the mole balance to analyze a CSTR, PFR, PBR, and batch reactor	92.9			