AC 2011-2605: BIOLOGY ACROSS THE CURRICULUM: PREPARING STUDENTS FOR A CAREER IN THE LIFE SCIENCES

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Biology across the curriculum: Preparing students for a career in the life sciences

Abstract

Addition of biological applications into the chemical engineering undergraduate curriculum is becoming more common now, in a response to the pervasive use of biology in more and more aspects of modern technology. Likewise, as recommended in the National Academy of Engineering's, "Educating the Engineer of 2020", "*Engineering schools should introduce interdisciplinary learning in the undergraduate environment, rather than having it as an exclusive feature of the graduate programs.*" Thus, including biological problems in undergraduate courses serves two purposes, namely, to teach students to apply their fundamental engineering principles to new and different fields and also to help prepare more students for eventual careers in the life sciences.

The Bioengineering Educational Materials Bank (BioEMB) has been in operation since early in 2007 with problems for the Material and Energy Balance Course. With continuing funding, five additional core courses have been added: Kinetics and Reactor Design; Process Dynamics and Control; Heat and Mass Transfer; Fluid Dynamics; and Thermodynamics. Workshops were held for faculty to learn basic principles of biology and how engineering principles are applied in many different aspects of modern biotechnology, from kinetics of biological reactions to fluid transfer and process dynamics problems in whole organisms. Problems are organized by textbook sections relevant for each course. There are over 300 problems posted on the website and the solutions to the problems are available only to registered faculty. The problems have been created by chemical engineering faculty with research and teaching expertise in the subject areas of the problems. To date the website has had over 1200 registrations by students and faculty, including faculty from chemical engineering departments from around the world.

Beta testing is in progress for the newly posted course materials. To date, the data has been analyzed only for the material and energy balance course problems. For that study, 199 students from six universities were tested with a set of simple bio and non-bio concept questions, in addition to questions about familiarity with the material. Data showed that students from classes that included the BioEMB problems were able to perform better on the bio-based problems than students whose teachers did not include the BioEMB problems in their course. Additionally, the performance on the non-bio questions did not show statistical differences in performance across the intervention and comparison sites. It can thus be inferred that inclusion of the additional BioEMB problems did not distract the students from learning the fundamental chemical engineering principles.

Introduction

There is expected to be a growing need for chemical engineers trained in the life sciences. As summarized in a special section article of Chemical Engineering Progress, a 2005 AIChE survey reported 12.8% of chemical engineers who responded were employed in a combination of pharmaceutical, biological and medical industries, and this total nearly equaled the number employed in the oil/gas industries[1]. The article also listed biotechnology as one of the sectors driving innovation in the chemical industry, along with micro- and nanotechnology and alternative energy. It is known that the traditional chemical industries house research and development groups that focus on the life sciences as potential process strategies. Most notably, these industries include several major chemical producers[2]. DuPont has developed and commercialized a process together with Tate & Lyle for the production of 1,3 propanediol for making Sorona^{TM} polymer. DuPont has also entered a new joint venture with Genencor for the production of cellulose-based ethanol. Archer Daniels Midland has joined with Metabolix for the commercialization of a polyhydroxy-alkanoic acid-based polymer called Mirel^{TM}. Other chemical producers with bioengineering research and development personnel include Dow, DSM, W. R. Grace and BASF. Fuel producers with a leg into biofuels include Chevron, BP and Iogen. Numerous smaller companies also host research and development efforts into biofuels. While overall the chemical industry has suffered a 20% job loss, or about 200,000 jobs, since 1990, it is expected that the development of bio-based chemicals would require the addition of tens of thousands of jobs in the next five years in the US alone[3].

To prepare students for a highly varied portfolio of industries is a new challenge for chemical engineering faculty. The ability of an engineer to apply the fundamental concepts to new problems is necessary for their effectiveness (see ABET Outcomes a and e), but it is difficult to teach using lecture-only teaching methods. In addition to mastering an effective strategy for teaching students to solve problems[4, 5], faculty must coach them in applying their problem solving skills to different areas in which they, both faculty and students, may be unfamiliar [6].

Engineering educators have been challenged with the need to include interdisciplinary learning in the undergraduate curriculum[7]. A recent article identifies that students have difficulty transferring their knowledge from one technical area to another, and they also lack the vision to recognize the involvement of multiple disciplines in solving modern engineering problems[8]. To include biology or other non-traditional discipline in a course, a professor must develop or have access to a variety of different case studies, modules or problems. The motivational barriers to problem development may not be as high as the lack of time. Developing quality problems that have a basis in real industrial and relevant scientific subjects is challenging and time consuming and faculty may not be sufficiently rewarded to undertake such a task.

The BioEMB project mainly consists of a website (http://www.bioemb.net) that was developed to address the need to include biological applications in the core chemical engineering curriculum. The goals of the project as outlined in the proposal include

1. Develop approximately 250 homework-type problems that can be seamlessly incorporated into the undergraduate ChE core curriculum.
2. Offer workshops tailored to each of the core courses to facilitate that faculty who do not have formal training in biology can incorporate the problems in their courses.
3. Evaluate student achievement of the learning objectives through testing after a select set of problems have been used in courses at several different universities.
4. Evaluate student attitudes about biotechnology after having learned some material from the BioEMB website.

The website is organized by course and each course is organized by popular textbook. Each course lists at least two textbooks and there is no limit to the number of textbooks. Additional textbooks can be added upon request by the authors. Each textbook page lists problems that require the application of chemical engineering fundamentals to solve and the problems are organized by chapter to facilitate that faculty can easily recognize when to assign them. Students can also register for the website and download their own problems as Word^{TM} files. Only activated faculty accounts enable the problem solutions to be viewed, however, to prevent that students are simply regurgitating published solutions. Problem statements include context that help students understand the significance of the calculation. Some words in problem statements are linked to a pop-up dictionary designed to make the problems easier to understand for students who have not had the biological background to understand them as written. The website is still under development but many, if not most, of the problems are posted and ready for use. The opportunity to post comments by faculty is also available on the website. This feature has been relatively unused but is designed to serve as a mechanism for faculty to rate problems and add suggestions for improvement, if needed.

Material & Energy Balances

This section was the first to be posted and beta testing results have been reported[9]. Problem topics include separations by ultrafiltration, chromatography and aqueous two-phase extraction. Reaction problems include biofuel, commodity chemical and protein production. Problems explore typical material balance calculations that biochemical engineers would need to make in industry, such as determining the oxygen uptake and carbon dioxide evolution rates in a fermentation, approximating the tank fill rate in a fed-batch fermentation, as well as using optical density measurements to determine the amount of bacteria produced and completing a carbon balance on a fermentation process. Separation calculations include determining the purity of a sample after a chromatography run and calculating the protein yield after a protein purification. Fewer problems are posted for the energy balance portion, but include calculation of heat effects in a fermentation comparing the effects of different substrates, and other problems.

Heat & Mass Transfer

Problems included in this section cover both steady state and unsteady state heat and mass transfer, although there are very few heat transfer problems. Biological systems generate chemical energy by combustion of substrates and only a portion of this energy is used for carrying out life functions so heat is likewise given off. The mechanisms of heat transfer are identical to those of non-living bodies. On the other hand, the complex chemical nature of living systems involves numerous mass transfer situations. Biological systems take advantage of chemical gradients but often they need to move compounds against the chemical gradient through active transport. Active transport is coupled to energy utilization. Significant to bioprocess applications, there is a need to transfer oxygen from sparged air to the aqueous fermentation broth where the biocatalysts thrive. Effective mass transfer of oxygen was a critical development in the advancement of bioprocess engineering.

Fluids

All biological systems require an aqueous environment to sustain life. Water is found both inside and outside of living systems and the role of water is often key to the ability of biological moieties at all levels – from microscopic to macroscopic – to function. The presence of densely packed biopolymers inside cells creates a non-newtonian fluidic space which complicates the convective mass transfer of species. Likewise, both the cells themselves and intracellular contents spilled out into bioreactors can also create a non-newtonian media for the transfer of oxygen and nutrients to living cells in the bioreactor. Fluids in higher organisms, such as blood and mucous, also have unique properties. The fluids problems on the BioEMB website encompass a wide selection of these environments for students to explore the application of traditional fluid equations to biological systems.

Thermodynamics

Because of the complexity of biological systems, thermodynamic analyses of their properties and processes have often been omitted from undergraduate curricula. The problems created for the BioEMB website attempt to demonstrate clear connections of typical thermodynamics course content to the phenomena and properties of biosystems. Thus, they include evaluations of energy effects, pure and mixed system properties, and phase and reaction equilibria for both simplified and complex systems. For example, one problem finds the work done by the heart, another asks for the equations to obtain energy and power expended on a treadmill, while a third utilizes thermodynamics to rationalize elastomer behavior where thermal stress responses are opposite those of normal fluids. Mixture problems involve such topics as the effects of dilution on the work of purification, hemoglobin osmotics, supercritical extraction of a biochemical, and design of polymer/solvent systems for microencapsulation of drugs. Treatment of reaction equilibria includes protein stability and dimerization, coupling of chemical reactions to produce substances and energy via unfavorable reactions, and speculation about the origins of life on earth. Initially the site has 21 problems keyed to the two most popular texts for one or two undergraduate thermodynamics courses.

Reactor Design & Kinetics

The variety of kinetic functions in biological systems is daunting, but at the same time makes for exciting applications for the students. Beyond calculations for chemical reactors, that include antibody production, protein synthesis, immobilized enzymes, and others, a number of kinetic calculations are included based on biomolecules in living systems. Among these is an analysis of the G protein mechanism, which is a key membrane protein involved in numerous cell signaling processes. The kinetics of insulin secretion is covered, that involves cell signaling, active transport by means of membrane protein action and other enzyme catalyzed reactions. The toxicity of β-amyloid oligomers in Alzeimer's patients is also explored. Other calculations include in vitro diagnostics such as molecular beacons, which are DNA probes for identifying pathogens in food and medical applications. Students will be able to learn about important new biotechnologies in addition to understanding how chemical engineering kinetics applies to many interesting and unique systems.

Process Dynamics & Control

Bioprocesses include chemical reactors, components of higher ordered systems such as organs of the body and complete organisms ranging from single cells to multicellular organisms. In essence each type of process could be viewed as a chemical reactor with control mechanisms necessary for efficient function. The problems on the BioEMB site for this course include chemical reactors for waste-water treatment, ethanol, general enzyme-catalyzed reactions and generic bioreactors. The processes of living organisms include bone regeneration, DNA monomer recycling, flow of current through the membrane of a nerve axon, kinetics of lead in the body, and others. The effects of insect outbreak in a forest are covered in the section on linearization of non-linear systems. As with all of the courses, the problems are neatly categorized into a typical undergraduate course that addresses fundamental student learning outcomes.

Summary of workshop content

In the summer of 2007 a workshop for the instructors of Material & Energy Balances was given to faculty from 19 different universities. The workshop included lectures on basic biology and biochemistry, and also time was allotted for the participants to solve problems that could be included in their courses for the coming school year. Based on feedback from that event, workshops were designed for the five additional courses. Three workshops were held in the summer of 2009 on Heat & Mass Transfer, Fluids, and Reactor Design & Kinetics. Then, in the summer of 2010, two more workshops were held on Thermodynamics and Process Dynamics & Control. The faculty who gave the instruction prepared their BioEMB problems ahead of the workshops to provide the participants with a quality problem solving session and the solutions. As with the first year meeting, lectures on biology and biochemistry were given by a chemical engineering professor who could deliver the information in a meaningful way for his fellow faculty from an engineering perspective.

Each workshop included lectures on cells, enzymes and protein structure, primary metabolic pathways and respiration, and relevant bioreactor processes. Other biological topics were included as appropriate to the specific courses. Chemical coupling and energy storage was included for the thermodynamics faculty, as well as bioseparations. The kinetics workshop included detail on enzymatic reactions of various types, including cascade reactions that are used for signal amplification in higher organisms. The process control workshop included some higher organism control mechanisms, such as insulin and the body's strategy for blood glucose control. The object was to tailor the workshop content to enable the faculty to understand the biology needed for incorporating the problems in their courses. The sustainability of the project depends, in part, on enabling new faculty to feel comfortable assigning the problems in their courses. While there will not be additional workshops offered through the grant funds, other opportunities may be available at conferences or other venues where interested faculty are gathered.

Review of beta-test outcomes

The beta testing of the Material & Energy Balance (MEB) problems has been completed as part of the initial phase of funding[9]. The strategy for the testing involved requesting faculty at different universities to include a set of the MEB problems in the course as part of their regular instruction. Eleven problems were provided for the course that could be used as homework or in-class problems. The project team did not request that the problems be added to midterm examinations for the students. The problems covered learning objectives that are normally part of the MEB course but additionally, some "bio learning objectives" were also identified that the problems also covered. The bio learning objectives for the problems included:

1. Work with common biological units
2. Learn and use basic bioprocess terminology just as MEB students now learn chemical process terminology.
3. Use chemical formulas to represent cellular composition and cellular transformations.
4. Explain why there will be CO_2 among the products of a whole cell bioprocess.
5. Explain the significance of respiratory quotient.
6. Demonstrate MEB-level familiarity with bioprocess unit operations.

The second part of the beta testing assignment included administering a test to the students in the MEB course. Two attempts at testing were undertaken. A primary factor in the test design was simplicity for the beta-test faculty. It was necessary to minimize the time input on the part of the participating faculty because they were volunteers and they were taking time from their course to administer the test. Faculty volunteers were not compensated for their contributions, but we hope to compensate faculty who help with the additional courses of BioEMB.

The first attempt included giving students two material balance problems to solve – one covering a traditional chemical engineering problem and the second covering an analogous calculation but with a biological application. Students performed very poorly overall and no conclusions could be drawn from the exercise. Part of the complication is that material balance questions that include several calculation steps involve multiple learning objectives, such as unit conversions, selection of appropriate relationships between unknown variables, incorporation of thermodynamic data, and the like. It became clear that it was not reasonable to extract from the soup of a student's calculation whether confusion in interpreting the problem statement, difficulties in setting up the calculation, unfamiliarity with the bio terminology, or other issues were the obstacle to solving the whole problem. Likewise, few students completed both calculations and the survey questions in the allotted 50 minute testing period.

The second attempt involved a multiple choice test with eight questions on it. Four of the questions covered biological applications and the other four covered analogous material balance questions based on familiar chemical moieties. The idea was to compare how the students performed on the bio and non-bio questions. Two of the problems included simple calculations to determine the correct answer. While one-step multiple choice questions do not mimic the solution of a real, complex problem, they allow an analysis of exactly what the student does and does not know related to specific learning objectives.

The outcome of the tests confirmed that students performed better on the bio questions who had taken the course where the problems were included. Likewise, the students who had the BioEMB problems in their course felt more confident to answer the bio questions than those who did not have the intervention, based on questions about their level of confidence. There was no difference in the average amount of time students spent answering each question, as measured across the intervention and comparison sites. Interestingly, an analysis of the survey results that accompanied the test showed that the students' levels of interest in biotechnology increased by having the BioEMB problems in their course, but only in the case that they were already considering a career in the life sciences. This one analysis of the intervention did not show that students who were not interested in biotechnology as a career from the outset then became interested after exposure to the materials. It can be concluded from this result that the students career interests were somehow confirmed by adding the problems in the courses.

Conclusion

A website has been developed for faculty as a resource of problems addressing biological applications that can be included in the undergraduate chemical engineering curriculum. The problems address current applications of bioprocessing and biotechnology research. Workshops were held to facilitate faculty to use the problems in their courses. Beta testing is complete for the Material & Energy Balance course and will be carried out in the next year for the remaining courses. Initial beta testing results suggest that students showed improved performance on test questions related to biological systems who had some of the problems assigned in the undergraduate course.

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Appendix: Student Test

Key: Blue colors were included on the actual test, purple is the solutions and additional information that was not on the actual test given to the students.

Please use a watch to help you estimate the approximate amount of time it takes you to answer each of the 8 technical questions.

Instructions: Please answer all of the following questions. Circle one answer for each question. If you have no idea how to do it please choose the option for "I don't know how to do this problem." Note there are 3 parts to each question. Parts A and B following each problem are for the purpose of understanding your level of familiarity with the subject of the numbered questions. **Note: you are asked to estimate the time to complete the problems so please check your watch before you start.**

Questions 1 and 2 – Learning objective: conversion of units.

1) What is the concentration in mM of a 20 g/L stock solution of fructose (MW = 180) in water (MW = 18)?
a) 0.111 mM
b) 111 mM
c) 90 mM
d) 90000 mM
e) none of the above
f) I don't know how to do this problem

Question 1 – Solution and Answer: $$20\frac{g}{L}\cdot\frac{1\,mol}{180\,g}\cdot\frac{1000\,mmol}{1\,mol}=111\,mM$$

1A) About how long did it take you to either determine an answer for or give up on question 1? (circle one time)
- a) 1 min or less
- b) 1-2 min
- c) 2-3 min
- d) 3-4 min
- e) more than 4 minutes

1B) Upon reading question 1 and during trying to answer it, how confident did you feel about being able to work towards finding the correct answer?
- a) I don't know how to do this problem
- b) Low level of confidence - enough to try
- c) Reasonably confident
- d) Absolutely Confident

2) What is the mass of benzene in 240 grams of a liquid mixture that has a mass fraction of benzene (MW = 78) of 0.10?
a) 7.80 grams
b) 10.0 grams
c) 24.0 grams
d) 78.0 grams
e) none of the above
f) I don't know how to do this problem

Question 2 – Solution and Answer: $$240\text{grams mixture}\cdot 0.10\,\frac{\text{grams benzene}}{\text{gram mixture}}=24.0\text{ grams}$$

2A) About how long did it take you to determine an answer for or give up on question 2?
- a) 1 min or less
- b) 1-2 min

c) 2-3 min
d) 3-4 min
e) more than 4 minutes

2B) Upon reading question 2 and during trying to answer it, how confident did you feel about being able to work towards finding the correct answer?
a) I don't know how to do this problem
b) Low level of confidence - enough to try
c) Reasonably confident
d) Absolutely Confident

Questions 3 and 4 – Learning objective: Familiarity with expected products of a reaction or bioconversion

ChE problem – key concepts are (1) not all the reactants are consumed when there is excess air, (2) that atomic species C, N, S may end up partially or completely oxidized, and (3) hydrogen typically is fully oxidized to water.

BioEMB problem – key concepts are (1) unused glucose remains in the liquid phase, (2) CO is not formed, (3) some organic molecule like ethanol or lactate may be formed, and (4) CO2 is formed for aerobic systems, (5) water in the offgas may be evaporate or product water (not clear which is the source).

3) Which of the following species are expected to be present in the bioreactor liquid and gaseous product stream(s) at the end of an aerobic bacterial fermentation producing a recombinant protein. Assume all the offgas is collected and the liquid remains in the bioreactor. The bioreactor was originally charged with fructose-containing medium and supplied with 1.0 volume air/volume medium per minute.
a) there is only liquid product containing H_2O, protein, and bacteria

b) vapor product contains H_2O, CO, CO_2 , O_2, and N_2, while the liquid product contains any unreacted fructose, protein, H_2O, and some additional byproducts may also be present

c) the vapor product contains H_2O, CO_2 , O_2, and N_2, and the liquid product contains H_2O, any unreacted fructose, protein, and some additional byproducts may also be present

d) the vapor product contains H_2O, CO_2 , O_2, and N_2, and the liquid product contains H_2O, any unreacted fructose, bacteria, protein, and some additional byproducts may also be present

e) the vapor contains only CO_2 and N_2, and the liquid contains protein and unreacted fructose only

f) there is only vapor product containing H_2O, unreacted fructose, bacteria, protein, CO_2, O_2, and N_2

g) I don't know how to answer this question

Question 3 – Solution and Answer
Best answer is (d). gas phase has O_2 and N_2 (unused oxygen and N_2 from air), CO_2 (from respiration), and H_2O from evaporation of medium and reaction-produced water.
Pitfalls: Fructose or protein in offgas. Production of CO (as if it were a combustion). Water would be mainly in the liquid phase, but it also evaporates and there is not mention of drying the offgas. Don't forget about the bugs produced...

3A) About how long did it take you to determine an answer for or give up on question 3?

a) 1 min or less
b) 1-2 min
c) 2-3 min
d) 3-4 min
e) more than 4 minutes

3B) Upon reading question 3 and during trying to answer it, how confident did you feel about being able to work towards finding the correct answer?

a) I don't know how to do this problem
b) Low level of confidence - enough to try
c) Reasonably confident
d) Absolutely Confident

4) Which of the following species are expected to be present in the flue gas of the furnace of a continuous boiler? The furnace is supplied with a hydrocarbon fuel containing C and H and supplied excess air to achieve 100% conversion, but the combustion is not complete.

a) H_2O, CO, CO_2 , O_2, N_2, CO, fuel
b) H_2O, CO_2 , O_2, N_2, fuel
c) H_2O, CO_2 , O_2, N_2
d) H_2O, CO, O_2, N_2
e) H_2O, CO, CO_2, O_2, N_2
f) I don't know how to do this problem

Question 4 – Solution and Answer

Correct answer is (e). O_2 and N_2 (unused oxygen and N_2 from air), CO and CO_2 from incomplemet and combustion. H_2O from combustion.
Pitfalls: No fuel left since conversion = 100%. CO is present since combustion is not complete.

4A) About how long did it take you to determine an answer for or give up on question 4?

a) 1 min or less
b) 1-2 min
c) 2-3 min
d) 3-4 min
e) more than 4 minutes

4B) Upon reading question 4 and during trying to answer it, how confident did you feel about being able to work towards finding the correct answer?

a) I don't know how to do this problem
b) Low level of confidence - enough to try
c) Reasonably confident
d) Absolutely Confident

Question 5 and 6 – Learning objective: terminology

5) What is the respiratory quotient in a fermentation?

a) The molar ratio of CO_2 produced divided by the sugar substrate consumed
b) The molar ratio of CO_2 produced divided by the O_2 consumed
c) The molar ratio of bug produced divided by the sugar substrate consumed

d) The molar ratio of bug produced divided by the nitrogen consumed
e) I don't know how to answer this question

Answer for Question 5: (b)

5A) About how long did it take you to determine an answer for or give up on question 5?
   a) 1 min or less
   b) 1-2 min
   c) 2-3 min
   d) 3-4 min
   e) more than 4 minutes

5B) Upon reading question 5 and during trying to answer it, how confident did you feel about being able to work towards finding the correct answer?
   a) Not confident
   b) Somewhat confident
   c) Confident
   d) Very Confident
   e) Absolutely Confident

6) What is meant by "theoretical oxygen" in the combustion of a hydrocarbon?
a) The oxygen needed to completely react with the reactants (100% conversion)
b) The oxygen needed to completely react with the reactants to yield complete combustion
c) The oxygen needed to completely react with the reactants to yield complete combustion plus the amount of excess oxygen added with the reactants
d) Theoretical oxygen does not exist in reality
e) I don't know how to answer this question

Answer for Question 6: b

6A) About how long did it take you to determine an answer for or give up on question 6?
   a) 1 min or less
   b) 1-2 min
   c) 2-3 min
   d) 3-4 min
   e) more than 4 minutes

6B) Upon reading question 6 and during trying to answer it, how confident did you feel about being able to work towards finding the correct answer?
   a) I don't know how to do this problem
   b) Low level of confidence - enough to try
   c) Reasonably confident
   d) Absolutely Confident

Problems 7 and 8 - Learning objective: material balance with chemical reaction

Info for problem (7): An aerobic bacterial process has the following overall reaction stoichiometry:

$C_6H_{12}O_6 + \alpha\ NH_3 + \beta\ O_2 \text{-->} \gamma\ C_4H_7O_2N + \pi\ C_2H_6O + \delta\ CO_2 + \varepsilon\ H_2O$

(MW=180) (MW = 101)

The conversion of glucose is 100% and 0.51 g CO_2 are produced per g of glucose consumed. Also, the biomass-to-glucose yield ($Y_{X/S}$) is 0.1 mol biomass/mol substrate.

7) How many moles of product (C_2H_6O) per mole glucose consumed are produced?
a) 3.5 moles of product
b) 2.8 moles of product
c) 1.8 moles of product
d) 1 mole of product
e) I don't know how to do this problem

Solution and Answer:
The answer being sought is pi. Pi is found in molecular species balance as n_{prod} = pi*x, where x = 1. Pi is also found in a atomic species balance as 6 = 4*gamma+2*pi+delta. Gamma and delta are given in the specifications: gamma = 0.1 and delta = 0.51 g/g = 2.1 mol/mol. Hence, pi = 1.75 and n_{prod} = 1.75 moles..

7A) About how long did it take you to determine an answer for or give up on problem 7?
a) 3 min or less
b) 3-5 min
c) 5-7 min
d) 7-9 min
e) more than 9 minutes

7B) Upon reading problem 7 and during trying to answer it, how confident did you feel about being able to work towards finding the correct answer?
a) I don't know how to do this problem
b) Low level of confidence - enough to try
c) Reasonably confident
d) Absolutely Confident

Info for problem (8): Ethylene oxide is produced by the catalytic oxidation of ethylene. CO and CO_2 are also produced by undesirable side reactions. The overall reaction is:

$$C_2H_4(g) + \alpha\, O_2(g) \longrightarrow \pi\, C_2H_4O(g) + \beta\, CO(g) + \gamma\, CO_2(g) + \delta\, H_2O(g)$$

The conversion of ethylene is 25% and 0.1 g CO_2 is produced per g of ethylene consumed. The molar yield of ethylene oxide is 80%.

8) How many moles of CO are produced in this process per mole of ethylene consumed?
a) 0.336 mol
b) 0.25 mol
c) 0.168 mol
d) 0.084 mol
e) I don't know how to do this problem

Solution and Answer:
The answer being sought is beta. Beta is found in a molecular species balance as n_{CO} = beta*x, where x = 1 as a basis (1 mole of ethylene reacting). Beta is also found in a atomic species balance as 2 = 2*pi + beta + gamma. Pi and gamma are given in the specifications: pi = 0.8 and gamma = 0.1 g/g * 28/44 = 0.064 mol/mol. Hence, beta = 2 – 2*0.8 – 0.064 = 0.336 and n_{CO} = 0.336 for x = 1.

8A) About how long did it take you to determine an answer for or give up on problem 8? (circle one time)

a) 3 min or less
b) 3-5 min
c) 5-7 min
d) 7-9 min
e) more than 9 minutes

8B) Upon reading problem 8 and during trying to answer it, how confident did you feel about being able to work towards finding the correct answer?

a) I don't know how to do this problem
b) Low level of confidence - enough to try
c) Reasonably confident
d) Absolutely Confident