This two-part series describes the structure of the stoichiometry course at North Carolina State University. The course has a variety of learning objectives, and several nontraditional pedagogies are used in the course delivery. This first paper outlines the course structure and policies, the preparation given to the teaching assistants (who play an integral part in the course delivery), and the course assignments. The next one describes the methods used for classroom instruction and assessment.

A Student-Centered Approach To Teaching MATERIAL AND ENERGY BALANCES

1. Course Design

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Like most chemical engineering curricula, the chemical and biomolecular engineering curriculum at North Carolina State University begins with a course on material and energy balances, historically designated the "stoichiometry course." For much of its history, the course was generally feared and despised by students, with their descriptions of it invariably including the term "weed-out." They were put off by the fragmented nature of the subject matter, which appeared to be a hodgepodge of loosely related concepts from physical chemistry. Test grades were low, failure rates were high, and student course ratings were routinely the lowest of any course in the curriculum.

Beginning in the late 1970s with the publication of *Elementary Principles of Chemical Processes*,[1] a new approach to the stoichiometry course was adopted at N.C. State. Individual topics from physical chemistry were no longer presented on a stand-alone basis, but were introduced and applied in the context of chemical process engineering. The traditional homework problems related to chemical and petroleum processes were supplemented by problems from the growing range of fields that employ chemical engineers, including environmental engineering, biochemistry and biomedicine,

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and microelectronics. Most lectures included brief activities that provided practice and feedback in the methods that would be required on homework and tests. A 1990 paper outlined the new instructional approach and described the turnaround in student performance and evaluations that resulted from its adoption.[2]

The stoichiometry course has continued to evolve. Since the early 1990s, it has been taught using cooperative (team-based) learning, with measures being taken to hold all team members individually accountable for the entire content of team assignments. Instructional technology has played an increasingly important role in the course, with a variety of software tools supplementing traditional instruction. Assignments include traditional closed-ended problems as well as open-ended problems that call for creative or critical thinking or both.

A goal of the N.C. State Chemical and Biomolecular Engineering (CBE) Department is to equip students to be self-directed learners by the time they graduate. Our premise is that they are a very long way from that status when they enter the engineering curriculum and the best way to get them there is to use what educational theorists call *scaffolding*—initially providing a great deal of structure and support, and gradually withdrawing it over the course of the curriculum. Since the stoichiometry course is the gateway to the CBE curriculum, we set a high level of challenge in the course to give the students a realistic picture of the intellectual demands that await them in the next three years, but we also provide higher levels of structure and support than most of them have ever encountered.

In the fall 2005 semester, 110 students enrolled in two sections of the stoichiometry course. Although each of the authors was primarily responsible for one lecture section, we worked together closely to generate common course materials, assignments, and tests, and we periodically guest-lectured in each other's sections. This two-part series of papers outlines the structure of the course and our approach to teaching it and offers suggestions to faculty who might wish to adapt the approach to their own teaching. Part 1 describes the course design, and Part 2 summarizes the course delivery.

COURSE STRUCTURE AND POLICIES

The stoichiometry course at N.C. State, designated CHE 205, is a four-credit, one-semester course, structured as three 50-minute or two 75-minute interactive lecture classes per week taught by a faculty member plus a two-hour weekly problem session (recitation) conducted by a graduate teaching assistant. Prerequisites for the course include two semesters of calculus, two semesters of general chemistry, and one semester of physics. The text is the 2005 edition of *Elementary Principles of Chemical Processes*,[1] which comes bundled with a CD containing several instructional resources and a workbook that guides students through the solution of selected chapter-end problems. The course covers Chapters 1–9 of the text.

In the fall 2005 offering of CHE 205, handouts and worksheets that guided students through problem solutions were used extensively in lectures, problem sessions, and homework assignments. In the problem sessions, the TAs provided a modest amount of formal instruction in Excel and E-Z Solve (a program on the text CD that solves algebraic and differential equations numerically); carried out active exercises that guided students through the solution of unassigned text problems and problems from old tests; and answered questions.

The syllabus, course policies, assignment schedule, handouts, study guides, sample tests, and other course materials may be viewed at <www.ncsu.edu/felder-public/cbe205site/cbe205.html>, and the course policies are also listed in Appendix 1A of this paper. Features of the course structure that departed from traditional practice were as follows:

- *After the first four weeks of the course, most of the homework was done by instructor-assigned student teams, with measures taken to satisfy the five defining conditions for cooperative learning* (individual accountability, positive interdependence, face-to-face interaction, development and appropriate use of teamwork skills, and regular self-assessment of team functioning).[3] We will say more about those measures in Part 2 of this paper.
- *Late assignments (*i.e.*, assignments turned in after the start of class on the due date) were accepted and graded with a 40% penalty, but a team or individual was only allowed two late assignments in the semester.*
- *Homework problem solutions were not posted, although final answers were given so that students reworking problems would know when their solutions were correct.* When solutions are posted, many students just copy them verbatim without trying to understand them; copies find their way into file cabinets in fraternity and sorority houses; and the frequency of perfect solutions achieved without understanding steadily rises from one semester to the next.
- *The students could refer to their texts on the midterm and final exams, but not to their course notes or graded homework.* Our rationale for this policy is that the students work through a number of examples in the course notes in active learning group exercises and do most of their homework in groups. We make it clear to them that they each need to understand the complete solutions regardless of who in the group took the lead on each part, tell them that we will be testing that understanding on the exams, and do so with some explicit questions about both the in-class exercises and the homework.
- *Students who missed a midterm exam without a certified medical excuse or prior approval took a comprehensive makeup exam late in the semester.* This policy enables the instructor to write one makeup test instead of one for each midterm, and the number of students who miss

tests because of faulty alarm clocks and getting stuck in traffic goes down dramatically. Individual arrangements are made with students who had legitimate and verifiable excuses for missing tests.

- *Study guides were posted on the course Web site one to two weeks before each of the three midterm tests and the final exam*. The study guide for a test contains a comprehensive list of learning objectives for that test—statements of all the terms, phenomena, and concepts the students might be asked to define or explain and the kinds of problems they might be asked to solve, including but not limited to the problems they had solved in homework assignments. Study guides for all tests and the final exam are posted at <*www.ncsu.edu/felder-public/cbe205site/guides.html*>. The study guide for the second test is shown in Appendix 1B.
- *Students could appeal their homework and test grades within a week of the time the graded assignments were handed back. To do so, they had to justify their request for additional points in writing*. The one-week limit prevents a flood of requests for regrading at the end of the semester when students traditionally scramble for more points wherever they can get them, and requiring written justification cuts down significantly on frivolous requests.
- *An absolute grading system was used—no curving*. This feature of the course encourages cooperation among the students on homework (one of our primary course goals), but it also puts a burden on the instructors to construct tests that are appropriately challenging without being unfair. The tests are taken individually, and students must earn an average grade of 60 or better on tests for the team homework grades to count toward the final course grade. This policy precludes students moving on in the curriculum (which requires a C– or better in CHE 205) solely because they were on a good homework team.
- *A considerable amount of external support was available to the students*. The two instructors and the three lead teaching assistants each maintained three office hours per week, and the instructors were also open to e-mailed questions, although they made it clear that they were not on call 24/7 and that e-mail messages sent at 11 p.m. the night before an assignment was due would almost certainly not be replied to until sometime the next day.

TEACHING ASSISTANT PREPARATION

We had an enrollment of 110 students in the two sections of CHE 205 and six teaching assistants. Three of the TAs (all graduate students) took responsibility for the problem sessions (facilitating them and writing, administering, and grading computer proficiency tests), and the other three (all seniors) graded homework assignments. The TAs and course instructors all held weekly office hours and worked together to grade the midterm and final exams. We designated one of the graduate students who had previously helped with the course as TA captain, in which capacity he coordinated grading and worked with the instructors to develop the weekly problem session content.

The graduate student TAs had 10 hr/wk commitments including 3 hr/wk office hours, and the undergraduate graders had 6-8 hr/wk commitments. The fact that most homework assignments were submitted by groups of three to four instead of by individual students kept the requirement for graders from being excessive. The course instructors spent three hours each week in class and another three hours holding office hours.

In the first week of class, we met with the TAs and gave them a five-page memo that spelled out their roles and responsibilities. The memo included the following instructions:

- **Tips on office hours:** When students come to you for help on homework problems, don't just give them answers or let them look at the solution key. Your first response should be, "Show me what you've done so far." If it's a material or energy balance problem, ask them to show you their flowchart and degree-of-freedom analysis, get them to explain the problem and outline the solution strategy, and try to lead them to the solution by asking questions. Let them do all the writing rather than just watching you do it, and don't do any algebra or number crunching—they can do that on their own time once they understand how to derive the system equations.
- **Tips on grading:** Use a grading key that specifies in detail how much credit is given for each part of every problem, and make sure the same mistakes get the same deductions on every paper. A given problem or portion of a problem on an assignment or test should only be graded by one individual. Penalize careless errors enough so that it stings, but don't slaughter students who basically understand what they're doing. Try to figure out what the students did wrong and make legible comments on their papers to help them understand their mistakes. (It takes time to do that, but if you don't spend it when you're grading you'll have to spend it less productively in office hours explaining the grades.) Avoid sarcastic comments about mistakes and compliment good work. Make sure the homework is collected when it is due on Friday and the graded papers are returned to the instructors' mailboxes by Monday morning before the class.

TEXT, CD, AND WORKBOOK

Instruction in the course closely followed Chapters 2–9 of *Elementary Principles of Chemical Processes* (*EPCP*). The students were required to bring the text with them to every lecture class, among other reasons so that when working through problems in class they would get practice in finding the information (physical properties, conversion factors, graphical correlations, etc.) they would need to look up on the open-book tests to come.

The latest edition of *EPCP* contains a CD with tools including E-Z Solve (a user-friendly equation-solving program), a physical property database that includes a program to evaluate sensible heats by integrating tabulated heat capacity formulas, the *Visual Encyclopedia of Chemical Engineering Equipment* created by Susan Montgomery of the University of Michigan, and a set of six interactive instructional tutorials that lead the students through most of the basic problem-solving techniques needed in the course. E-Z Solve and the physical property database enable students to solve problems involving many simultaneous material and energy balance calculations with relative ease (although we require some manual solutions of system equations and integrations of heat capacity formulas before the students are allowed to use the software tools); the *Visual Encyclopedia* gives students realistic views of the unit operations and processes they analyze in the homework problems; and the tutorials provide practice and immediate feedback in the analytical methods at the heart of the course.

When we first began to use this edition of the text, the students virtually ignored the software tools we had been so sure they would find invaluable. When we later required them to use the tools in several early assignments, however, they overcame their inertia and discovered how helpful the tools could be. Their subsequent use of the software increased by an order of magnitude over what it had been without those initial assignments, and their end-of-course evaluations reflected a strong appreciation of the CD's usefulness.[4]

A common student complaint in the stoichiometry course is that the examples presented in class tend to be much simpler than many of the chapter-end problems that show up on homework assignments. The 2005 edition of the course text comes with a workbook that guides students through the solutions of several of the more complex text problems. We asked the students to bring the workbooks to the problem session each week, and the TAs chose relevant problems for the students to work through individually or in groups. We also included at least one workbook problem in each week's homework assignment to be completed and submitted individually, and we encouraged students to solve unassigned workbook problems when studying for exams. In their end-of-course evaluations, many students reacted positively to having the workbook as a resource.

ASSIGNMENTS

Homework

Problem sets were assigned weekly. Most of the assigned problems were taken from the end of the textbook chapters, sometimes with added parts calling for reflection on the meaning of calculated results or speculation about possible explanations for differences between the calculated results and results that might be measured. Every three or four assignments the teams were asked to assess their performance as a team. The assignments can be seen at <*www.ncsu.edu/felder-public/cbe205site/homework.html*>.

Creativity Exercises

The text includes several creativity exercises that call on students to brainstorm responses to open-ended questions related to the course content. We assigned several of those exercises and gave an even more general assignment toward the end of the semester:

> ***Creativity Exercise – Extra Credit***
>
> *You may earn up to 10 points of extra credit on your final homework assignment by submitting a creative expression of your experience in CHE 205. It might be a poem, song, puzzle, artwork—the sky's the limit! The only constraints are that your work must be original and your submission must be in good taste (something that could be shared with the rest of the class). You may work in groups if your idea requires multiple people to execute or is too big for one person to complete individually (but group projects will have a higher bar for grading).*

In the three years in which we've given this assignment, we've gotten a remarkable collection of products, including crossword puzzles, cartoons, haiku and other poems, paintings, a murder mystery, a crocheted doll holding a tiny model of the textbook, a music video, and a live rap song with costumes and choreography. Some of the students kept doing the same sort of thing in other courses: two who did a music video in the stoichiometry course went on to do sequels in subsequent courses on process simulation and thermodynamics, and another student who submitted a personal course journal in CHE 205 continued the journal through her senior year, documenting her entire experience in chemical engineering. We spend the last day of class allowing students to share their contributions, which are generally received with lots of laughter and cheering. It's a great way to end the semester.

Information Literacy

One of us has worked for several years with N.C. State librarians to incorporate information literacy concepts throughout the CBE curriculum, starting with the freshman engineering course and continuing through the sophomore stoichiometry course, the junior professional development seminar, and the senior capstone design course.[5] In CHE 205, librarians visit during a problem session to introduce students to important discipline-specific resources that chemical engineers typically use, including *Perry's Chemical Engineers Handbook*, the *Chemical Economics Handbook*, the *Kirk-Othmer Encyclopedia of Chemical Technology*, and the *Chemical Market Reporter*, as well as databases including Compendex and SciFinder Scholar. The presenters stress the importance of proper literature citation and give students brief practice citation exercises, and they discuss the idea that the credibility of information depends strongly on the source, with *Perry's Handbook* and a MySpace blog representing extremes of trustworthiness.

The following assignment is given to students following the information literacy presentation. Typically they are given two to three weeks to complete it. By linking information competencies to assignments related to class material, we move beyond decoupled instruction that is quickly forgotten to "just-in-time" need-based instruction.

Library Assignment

1. *Select a chemical substance from Table B.1 in your text that begins with the same letter as your first name or the nearest possible letter (for example Angie → Aniline). Find and report the information listed below for this substance in references other than the course text or CD, and properly cite the references. Organize your report neatly and show all units.*
    - (a) *Specific gravity, molecular weight, normal melting and boiling points, Antoine constants, heats of fusion and vaporization at the normal melting and boiling points, and heat capacity as a function of temperature. If some of these properties are missing for your chosen species, choose a different species with complete physical properties.*
    - (b) *Several examples of industrial uses of the species.*
    - (c) *Toxicity data and environmental hazards associated with the species.*
    - (d) *At least three companies that manufacture the species.*
    - (e) *Worldwide demand and/or sales.*
    - (f) *Unit pricing ($/kg, $/gal, etc.) Your figure should reflect bulk pricing, not pricing of small units from laboratory supply firms such as Fisher Scientific.*
2. *From the textbook index, select a topic that begins with the same letter as your last name or the nearest possible letter (for example Brent → Bubble point). Identify three published articles (not Web sites) that deal with this topic and list their full bibliographic citations. Then find the articles and photocopy or print out their first pages and abstracts (if the abstracts are not included in the first pages).*

SUMMARY OF PART 1

The two-part series of papers of which this is the first part describes the structure of the stoichiometry course at North Carolina State University in the fall of 2005. The course had a variety of learning objectives, including traditional objectives related to the course content and also objectives involving creative thinking skills, communications and teamwork, and information literacy. Several nontraditional pedagogies were used in the course delivery, including active, cooperative, and inquiry-based learning, and a number of different applications of instructional technology. This paper outlines the course structure and policies, the preparation given to the teaching assistants who played an integral part in the course delivery, and the course assignments. The next paper summarizes the methods used in the course instruction and assessment.

ACKNOWLEDGMENTS

We acknowledge with gratitude the numerous and significant contributions to CHE 205 of the TAs (especially Adam Melvin). Our thanks also go to Honora Nerz Eskridge for her invaluable assistance with the information literacy segment of the course.

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APPENDIX 1A

ChE 205 Policies And Procedures

- **Academic integrity.** Students should refer to the university policy on academic integrity found in the Code of Student Conduct (found in *Appendix L of the Handbook for Advising and Teaching*). It is the instructor's understanding and expectation that the student's signature on any test or assignment means that the student contributed to the assignment in question (if a group assignment) and that the student neither gave nor received unauthorized aid (if an individual assignment). Authorized aid on an individual assignment includes discussing the interpretation of the problem statement, sharing ideas or approaches for solving the problem, and explaining concepts involved in the problem. Any other aid would be unauthorized and a violation of the academic integrity policy. All cases of academic misconduct will be submitted to the Office of Student Conduct. If you are found guilty of academic misconduct in the course, you will be on academic integrity probation for the remainder of your years at NCSU and may be required to report your violation on future professional school applications. It's not worth it!
- **Homework.** Students will submit homework individually for the first few homework assignments. Early in the semester, the instructors will designate teams of three to four individuals, and all subsequent assignments should be submitted by those teams unless otherwise specified. The assignment schedule will be posted on the course Web site.
- **Homework format.** Use engineering paper (available in the Student Supply Store), one side of each page; begin each problem on a new page; and box the final answers. Each completed assignment should be in one person's handwriting (the recorder's). Staple the pages and fold them vertically when you hand them in, putting your name (individual assignments) or the names and roles (coordinator, recorder, checker, and

monitor) of the *participating* team members (team assignment), and the problem set number and date on the outside. *If a student's name appears on a solution set, it certifies that he/she has participated in solving the problems. If this turns out not to be the case, both the nonparticipating student and the recorder will get zeros for that assignment.*

- **Late homework.** Completed assignments should be turned in at the beginning of class on the due date (Bullard's section) or to the homework box in the CHE lounge (Felder's section) between 5 p.m. on Thursday (day before the due date) and 9:30 a.m. on Friday (the due date). If it's your job to turn in the homework and you're late, so is the homework. Late assignments will receive a maximum grade of 60. Late solution sets will be accepted up to 8 a.m. on the Monday after the due date, turned in to your instructor's mailbox in the CHE office, 2001 EB1. *Once an individual or a group hands in two late assignments, however, no more will be accepted.*
- **Posted solutions.** *Problem set solutions will not be posted.* It is your responsibility to make sure you find out how to solve the problems by asking about them in class, during office hours, or in the problem session after they have been handed in.
- **Individual effort assessments for team homework.** Teams will periodically be asked to submit individual effort assessments with completed assignments. These assessments will be incorporated into the assignment of homework grades. *If repeated efforts to improve team functioning (including faculty intervention) fail, a nonparticipant may be fired by unanimous consent of the rest of the team, and a team member doing essentially all the work may quit.* (Details of the required procedures are given in the handout on team policies and expectations.) Individuals who quit or are fired must find a team unanimously willing to accept them; otherwise they will receive zeros for the remainder of the homework.
- **Tests.** There will be three tests during the semester and a comprehensive final exam. *All tests will be open-book, closed-notes.* Each student's lowest test grade will count half as much as the other two. Tests will be given as a common exam for both sections on scheduled Fridays from 3-5 p.m. (see detailed course schedule for dates). Students who are unable to take the test at those times (with a documented excuse—not just that you don't want to) will schedule an alternate time to take the exam. To make up for the additional test time required out of class, the class period before the exam will be an optional review session conducted by the instructor or a TA.
- **Test and homework grading.** The responsibility for grading tests and homework assignments resides with the graders. If you believe an error has been made in grading on a problem set, bring it to the grader who did the grading during his or her office hours. If you believe that you should have gotten more points than you got for any reason other than a simple addition error, write a statement making your case and take it to the grader. If you are not satisfied with the grader's decision, bring the statement to your course instructor, who will make the final decision.
- **Missed tests.** If you miss a test without either a certified medical excuse or prior instructor approval, you will take a makeup test at a designated time during the last week of the semester. The makeup exam will be fair but comprehensive (covering all the course material) and challenging. Tests missed with certified medical excuses or prior instructor approval will be dealt with individually. Only one missed test can be made up.
- **Problem session.** *All 205 students must be registered for one of the weekly problem sessions* (205P). Several computer applications will be taught during the problem sessions. Ten percent of your grade is based on problem session quizzes and in-class exercises. Attendance is expected. You should not float between problem sessions; stay in the one in which you are registered. If it is necessary to miss a problem session, however, you may attend another session to make up the time as long as you notify the TA of the problem session you attend so that your attendance can be recorded.
- **Attendance.** Students who miss class due to an excused absence should work with the instructor or problem session TA to make up any missed work. Documented medical excuses should be presented to the instructor. Examples of <u>anticipated</u> situations where a student would qualify for an excused absence are:
  a. The student is away from campus representing an official university function, *e.g.*, participating in a professional meeting, as part of a judging team, or athletic team. These students would typically be accompanied by a university faculty or staff member.
  b. Required court attendance as certified by the Clerk of Court.
  c. Religious observances as verified by Parents & Constituent Services (515-2441). For more information about a variety of religious observances, visit the Diversity Calendar.
  d. Required military duty as certified by the student's commanding officer.

  For a full statement of the university attendance policy, see <*www.ncsu.edu/provost/academic_regulations/attend/reg.htm*>.
- **Calculation of course grade.** A weighted average grade will be calculated as follows:
  - ► Midterm tests = 40% (Lowest grade counts 1/2 of each of the other two)
  - ► Final examination = 30%
  - ► Homework = 20%
  - ► Problem session quizzes and in-class exercises = 10%.

Weighted average	>97	93-96.9	90–92.9	87–89.9	83–86.9	80–82.9	77–79.9	73-76.9	70–72.9	67–69.9	63-66.9	60–62.9	< 60
Letter grade	A+	A	A-	B+	B	B-	C+	C	C-	D+	D	D-	F

The homework grades will only count if the average grade on class tests and the final exam is 60 or above—in other words, if you can't pass the individual tests, then you can't pass the course.

Note: We do not curve grades in this course. It is theoretically possible for everyone in the class to get an A (or an F). Your performance depends only on how you do, not on how everyone else in the class does. It is therefore in your best interests to help your classmates, while keeping the academic integrity policy in mind.

- **Instructors' commitment.** You can expect your instructors to be courteous, punctual, well organized, and prepared for lecture and other class activities; to answer questions clearly and in a non-negative fashion; to be available during office hours or to notify you beforehand if they are unable to keep them; to provide a suitable guest lecturer when they are traveling; and to grade uniformly and consistently according to the posted guidelines.
- **Consulting with faculty.** We strongly encourage you to discuss academic or personal questions with either of the CHE 205 course instructors during their office hours or by e-mail.
- **Disabled students.** North Carolina State is subject to the Department of Health, Education, and Welfare regulations implementing Section 504 of the Rehabilitation Act of 1973. Section 504 provides that: "No otherwise qualified handicapped individual in the United States. . . shall, solely by reason of his handicap be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any program or activity receiving Federal financial assistance." This regulation includes students with hearing, visual, motor, or learning disabilities and states that colleges and universities must make "reasonable adjustments" to ensure that academic requirements are not discriminatory. Modifications may require rescheduling classes from inaccessible to accessible buildings, providing access to auxiliary aids such as tape recorders, special lab equipment, or other services such as readers, note takers, or interpreters. It further requires that exams actually evaluate students' progress and achievement rather than reflect their impaired skills. This may require oral or taped tests, readers, scribes, separate testing rooms, or extension of time limits.

Team Policies and Expectations

Your team will have a number of responsibilities as it completes problem and project assignments.

- *Designate a coordinator, recorder, and checker for each assignment*. Rotate these roles for every assignment.
- *Agree on a common meeting time and what each member should have done before the meeting* (readings, taking the first cut at some or all of the assigned work, etc.)
- *Do the required individual preparation.*
- *Coordinator checks with other team members before the meeting to remind them of when and where they will meet and what they are supposed to do*.
- *Meet and work*. Coordinator keeps everyone on task and makes sure everyone is involved, recorder prepares final solution to be turned in, monitor checks to makes sure everyone understands both the solution and the strategy used to get it, and checker double-checks it before it is handed in. Agree on next meeting time and roles for next assignment. For teams of three, the same person should cover the monitor and checker roles.
- *Checker turns in the assignment, with the names on it of every team member who participated actively in completing it.* If the checker anticipates a problem getting to class on time on the due date of the assignment, it is his/her responsibility to make sure someone turns it in.
- *Review returned assignments*. Make sure everyone understands why points were lost and how to correct errors.
- *Consult with your instructor if a conflict arises that can't be worked through by the team.*
- ***If a team member refuses to cooperate on an assignment, his/her name should not be included on the completed work.*** If the noncooperation continues, the team should meet with the instructor so that the problem can be resolved, if possible. If no resolution is achieved, the cooperating team members may notify the uncooperative member in writing that he/she is in danger of being fired, sending a copy of the memo to the instructor. If there is no subsequent improvement, they should notify the individual in writing (copy to the instructor) that he/she is no longer with the team. The fired student should meet with his/her instructor to discuss options. Similarly, students who are consistently doing all the work for their team may issue a warning memo that they will quit unless they start getting cooperation, and a second memo quitting the team if the cooperation is not forthcoming. Students who get fired or quit must find a team of three willing to accept them as a member, otherwise they get zeros for the remaining assignments.

As you will find out, group work isn't always easy—team members sometimes cannot prepare for or attend group sessions because of other responsibilities, and conflicts often result from differing skill levels and work ethics. When teams work and communicate well, however, the benefits more than compensate for the difficulties. One way to improve the chances that a team will work well is to agree beforehand on what everyone on the team expects from everyone else. Reaching this agreement is the goal of the assignment on the last part of this handout.

Team Expectations Assignment

On a single sheet of paper, put your names and list the rules and expectations you agree as a team to adopt. You can deal with any or all aspects of the responsibilities outlined above—preparation for and attendance at group meetings, making sure everyone understands all the solutions, communicating frankly but with respect when conflicts arise, etc. Each team member should sign the sheet, indicating acceptance of these expectations and intention to fulfill them.

These expectations are for your use and benefit—we won't grade them or even comment on them unless you ask us to. Note, however, that if you make the list fairly thorough without being unrealistic you'll be giving yourselves the best chance. For example, "We will each solve every problem in every assignment completely before we get together" or "We will get 100 on every assignment" or "We will never miss a meeting" are probably unrealistic, but "We will try to set up the problems individually before meeting" and "We will make sure that anyone who misses a meeting for good cause gets caught up on the work" are realistic.

APPENDIX 1B

*Study Guide For Midterm Test 2**

To do well on the next test, you should be able to do the following:

1. Explain in your own words the terms *separation process, distillation, absorption, scrubbing, extraction, crystallization, adsorption*, and *leaching*. (What are they and how do they work?)
2. Sketch a phase diagram (P vs. T) for a single species and label the regions (solid, liquid, vapor, gas). Explain the difference between a vapor and a gas. Use the phase diagram to define (a) the vapor pressure at a specified temperature, (b) the boiling point at a specified pressure, (c) the normal boiling point, (d) the melting point at a specified pressure, (e) the sublimation point at a specified pressure, (f) the triple point, (g) the critical temperature and pressure. Explain how the melting and boiling point temperatures vary with pressure and how P and T vary with time (increase, decrease, or remain constant) as a specified path on the diagram is followed.
3. Estimate the vapor pressure of a pure substance at a specified temperature or the boiling point at a specified pressure using (a) the Antoine equation, (b) the Cox chart, (c) the Clausius-Clapeyron equation and vapor pressures at two specified temperatures, (d) Table B.3 for water.
4. Use data in the text to speculate on whether distillation and/or crystallization might be a reasonable separation process for a mixture of two given species. List the additional information you would need to confirm your speculation.
5. Distinguish between intensive and extensive variables, giving examples of each. Use the Gibbs phase rule to determine the number of degrees of freedom for a multicomponent multiphase system at equilibrium, and state the meaning of the value you calculate in terms of the system's intensive variables. Identify a feasible set of intensive variables to specify that will enable the remaining intensive variables to be calculated.
6. In the context of a system containing a single condensable species and other noncondensable gases, explain in your own words the terms *saturated vapor, superheated vapor, dew point, degrees of superheat,* and *relative saturation*. Explain the following statement from a weather report in terms a first-year engineering student could understand: "The temperature is 75 °F, barometric pressure is 29.87 inches of mercury and falling, the relative humidity is 50%, and the dew point is 54°F."
7. Given an equilibrium gas-liquid system with a single condensable component (A) and liquid A present, a correlation for p_A*(T), and any two of the variables y_A (mole fraction of A(v) in the gas phase), temperature, and total pressure, calculate the third variable using Raoult's law.
8. Given a mixture of a single condensable vapor, A, and one or more noncondensable gases, a correlation for p_A*(T), and any two of the variables y_A (mole fraction of A), temperature, total pressure, dew point, degrees of superheat, and relative, molal, absolute, and percentage saturation (or humidity), use Raoult's law for a single condensable species to calculate the remaining variables.
9. For a process system that involves a gas phase containing a single condensable component and specified or requested values of feed or product stream saturation parameters (temperature, pressure, dew point, relative saturation or humidity, degrees of superheat, etc.), draw and label the flowchart, carry out the degree-of-freedom analysis, and perform the required calculations.
10. After completing your analysis of a vapor-liquid phase change process, identify as many possible reasons as you can for discrepancies between what you calculated and what would be measured in a real process. Include any assumptions made in the calculation.
11. Explain the meaning of the term "ideal solution behavior" in the context of a liquid mixture of several volatile species. Write and clearly explain the formulas for Raoult's law and Henry's law, state the conditions for which each correlation is most likely to be accurate, and apply each one to determine any of the variables T, P, x_A, or y_A (temperature, pressure, and mole fractions of A in the liquid and gas phases) from given values of the other three.
12. Explain in your own words the terms *bubble point, boiling point,* and *dew point* of a mixture of condensable species, and the difference between *vaporization* and *boiling*. 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; (d) the boiling point temperature of a liquid mixture of known composition at a specified total pressure.
13. Use a Txy or Pxy diagram to determine bubble and dew point temperatures and pressures, compositions and relative amounts of each phase in a two-phase mixture, and the effects of varying temperature and pressure on bubble points, dew points, and phase amounts and compositions. Outline how the diagrams are constructed for mixtures of components that obey Raoult's law. Construct a diagram using a spreadsheet.
14. For a process system that involves liquid and gas streams in equilibrium and vapor-liquid equilibrium relations for distributed components, draw and label the flowchart, carry out the degree-of-freedom analysis, and perform the required calculations.
15. Explain in your own words the terms *solubility of a solid in a liquid, saturated solution*, and *hydrated salt*. Given solubility data, determine the saturation temperature of a feed solution of given composition and the quantity of solid crystals that precipitate if the solution is cooled to a specified temperature below the saturation point. Perform material and energy balance calculations on a crystallizer, and identify sources of error in your calculation.
16. Given a liquid solution of a nonvolatile solute, estimate the solvent vapor pressure lowering, the boiling point elevation, and the freezing point depression, and list the assumptions required for your estimate to be accurate. Give several practical applications of these phenomena. Identify sources of error in your calculation.
17. Given the description of a familiar phenomenon involving more than one phase, explain it in terms of concepts discussed in this chapter. Given an explanation of such a phenomenon, evaluate its scientific soundness. ❐

* *This test covered through Chapter 6 of the text.*