ASYNCHRONOUS LEARNING OF CHEMICAL REACTION ENGINEERING

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With the emergence and widespread use of computers during the past twenty years, technology has advanced further than most people ever thought possible. This progression has had a significant impact on education. Through ever-increasing technological advancements, education has been able to expand to better meet the diverse needs of students. An excellent review of the literature by Kadiyala and Crynes[1] provides evidence that instructional technology enhances learning. With these advances, a variety of student learning styles described by the Felder and Soloman Inventory[2] (*e.g.,* active, reflective, global, sequential) can be addressed, thereby reducing the need for a synchronous course with a lecture. Wallace and Mutooni[3] and Felder and Brent[4] discuss these advantages.

Asynchronous Learning (AL) is the concept that students can learn at different locations and at different times. AL is opposite to synchronous learning, where students learn at the same time and in the same place in traditional activities such as classroom lecture and laboratory sessions. Recently, Dutton, *et al.,*[5] showed that on-line AL students in their course performed better than the lecture students. The asynchronous learning environment provides students with interactive teaching materials and tools for registration, instruction, and discussion. Student-to-student interaction is provided by a common "conference room," (either an online chat room, a bulletin board, or an e-mail group) that allows everyone to post a message, read a message, or respond to a message, all within the same shared space. Student-faculty/teaching assistant interactions are primarily through e-mail.

Technology has facilitated the use of AL and has now made it a viable alternative to synchronous learning. Today, with widespread Internet use, as well as faster connections and more powerful computers, it is easy to provide interactive lessons. Students can communicate with other students, read and interact with the course summary notes on the web, and even check their own grades.

Because AL involves the ability to maintain communication without the necessity of having to meet at the same place and at the same time as their classmates, students who work during the day or who have family responsibilities at home can easily take a class without having to commute to a college or university at night. Another benefit is that because AL involves self-paced study, students who have more important priorities in one week can easily move their coursework to a more convenient time. Because of these benefits, AL has emerged as a popular and effective alternative for many students.

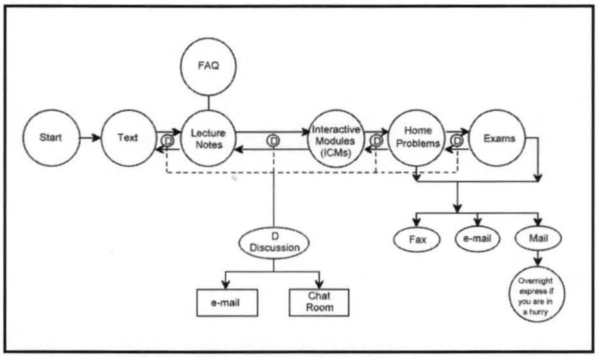

Figure 1. *Organizational structure of the course.*

COURSE CONTENT

The course, "Principles of Chemical Reaction Engineering," covers the fundamentals of chemical reaction engineering and includes rate laws, kinetics, mechanisms of homogeneous and heterogeneous reactions, analysis of rate data, multiple reactions, adiabatic and non-adiabatic reactors, safety, and multiple reactions with heat effects. Emphasis is placed on logic rather than memorization of equations and the conditions to which they apply.

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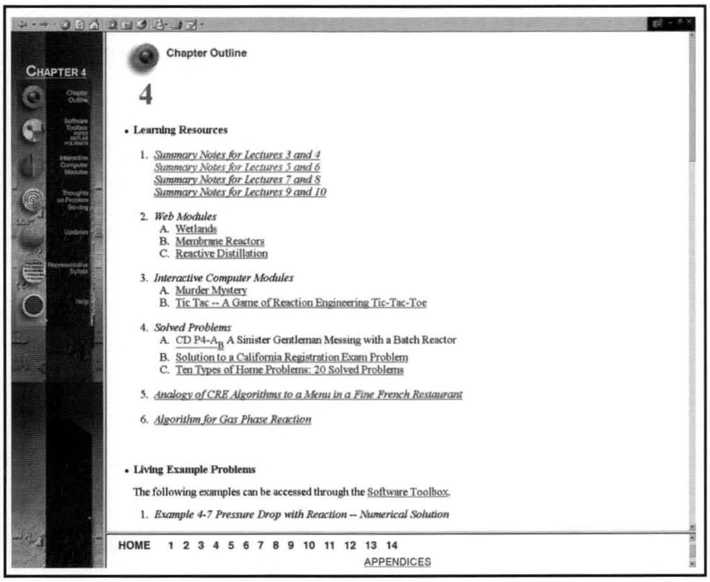

Figure 2. *Chapter outlines.*

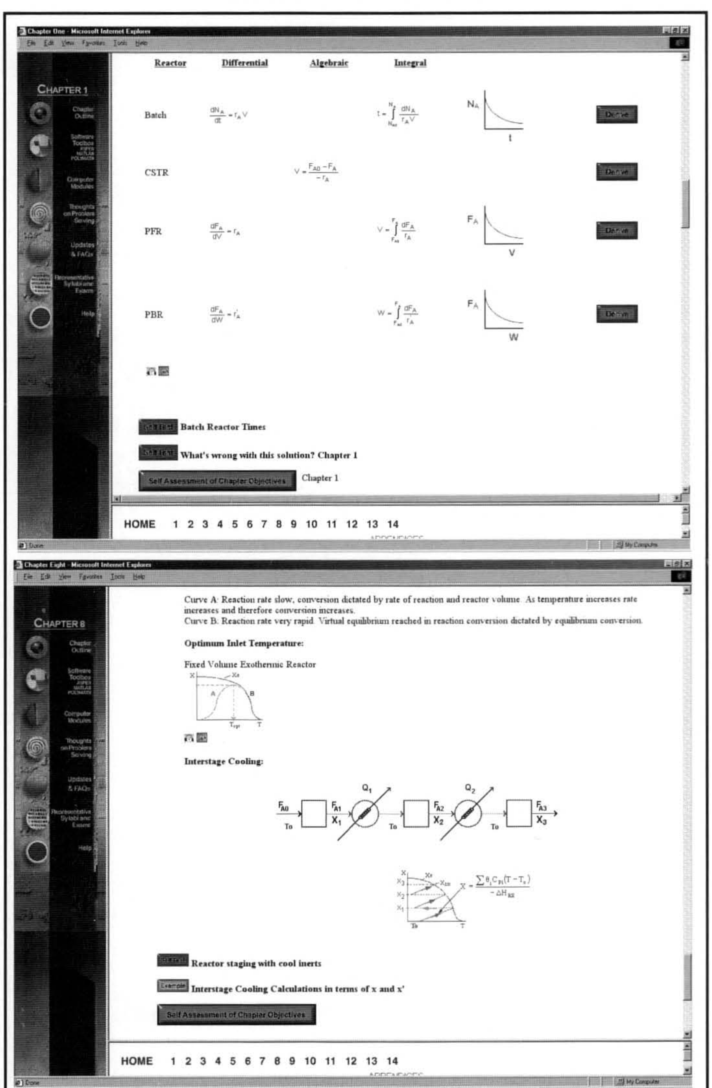

Figure 3. *Lecture notes.*

COURSE STRUCTURE

The class, normally a four-credit course for junior students, is divided into 21 self-paced units. Each unit contains a textbook and a CD reading assignment, mandatory homework problems, recommended study problems, and solved problems. In addition to the 21 units, students must take two tests and a final exam, and complete an open-ended project (OEP). Figure 1 shows an organizational structure of the course.

CLASS RESOURCES

Because of the enormous resources associated with the course that had been built up over the years,"Principles of Chemical Reaction Engineering" was the first class chosen in the Department of Chemical Engineering to be offered through asynchronous learning. In addition to the textbook, *Elements of Chemical Reaction Engineering,*[6] each student is provided with an interactive CD and the class web page (<URL: http://www.engin.umich.edu/~cre/asyLearn> or <CRE URL: http://www.engin.umich.edu/~cre>). The interactive CD includes:

- *Chapter outlines*
- *Web modules*
- *Summary notes with audio clips*
- *Equation derivations*
- *Self tests*
- *Video clips*
- *Living example problems*
- *FAQs*
- *Interactive computer modules*

The Chapter Outlines (see Figure 2) give the user an easy index to "surf" the CD ROM.The Summary Notes, which are interactive (see Figure 3), with their numerous derivations, examples, links, self-tests (Figure 4), and audio clips (in both wave and mp3 format) are a nice supplement to the text material and are ideal not only for the global learner, but also for the active and sequential learners.

Because questions asked by the students from year-to-year are very similar (if not the same), one of the key ingredients for a successful AL course is the collection and display of these frequently asked questions (FAQs). The FAQs (see Figure 5) section provides answers to the most commonly asked questions in previous classes.

Simulations are also a major component of the CD, as web modules, interactive computer modules (ICMs) (see Figure 6) and living-example problems are also included. The web modules (Figure 7) are stand-alone lessons that show novel applications of the chemical reaction engineering principles. Each ICM has a description of the module, a review of the fundamentals, and an interactive scenario on which the students are graded by the computer (Figure 8).

The living-example problems are a new concept. The examples in the textbook are also on the CD ROM, so they can easily be loaded onto the student's computer. They are designed so that students can easily vary parameters in the text example problems in order to understand real-life problems and ask "what if" questions that will allow them to develop their creative and critical thinking skills. The eight ICMs and six Web Modules are well suited for active and sequential learners. The ICMs allow students to ask "what if" questions as well as enjoy practicing reaction engineering concepts, while the Web Modules enable students to learn how reaction engineering principles can be applied to a variety of real-world situations. The CD also features a Professional Reference Shelf that includes material important to the practicing engineer, which is typically not included in most chemical reaction engineering courses.

ADDRESSING DIFFERENT LEARNING STYLES

Research has shown that not everyone learns the same way. One of the more cited ways to classify the different learners is given by Felder and Soloman[2]

- *Active Learners vs. Reflective Learners*
- *Global Learners vs. Sequential Learners*
- *Visual Learners vs. Verbal Learners*
- *Sensing Learners vs. Intuitive Learners*

Virtually all the different learning styles are addressed in the resources available for the AL course. For example, the global learner can obtain an overview of the material from the web summary notes before diving into the text for the details. The sequential learner can interact with the "Derive" hot buttons to see the details of the derivation of an equation. Owing to the large number of hot buttons ("Derive," "Self-Test," "Example," and "Link"), the active learner is continually able to participate in the learning process. The reflective learner style is addressed through the self-tests and the ICMs multiple-choice quizzes where the student has a chance to pause and think about an answer before proceeding further. The visual learner is able to follow the trends through plotting the variables from the solutions to the Polymath living-example problems. The audio clips in the summary notes, which are more like short "sound bytes" than reading the text material, are a welcome resource to the verbal learner, as is the textbook material.

DEVELOPING CRITICAL THINKING SKILLS

Thoughts on critical thinking were taken from R.W. Paul's book, *Critical Thinking,*[7] and from the Oklahoma State University Phillips Lecture of April, 1997.[8] A number of assignments asked the students to write a question about the homework problem that required critical thinking and to explain why it involved critical thinking. Specifically, Paul's six types of Socratic questions were used. The questions were then collected and e-mailed back to the students—they were asked to vote on the best critical-thinking question and to make a statement as to why they felt it was the best. Seeing, judging, and comparing other students' questions further develop their critical-thinking skills.

In accordance with ABET requirements, there is an open-ended project involved in the class. The purpose of the project is to give each member of the class a chance to practice and develop their creative-thinking skills. To do this, students need to learn and bring creative-thinking skills (Osborn's Vertical Thinking, Futuring, Analogy, DeBono's Lateral Thinking) to bear on a specific problem.[9] The specific topics chosen were researched independently in groups of two. These topics represent situations that can be modeled using the principles of chemical reaction engineering learned in this course. The type of modeling includes reactor schemes, math-

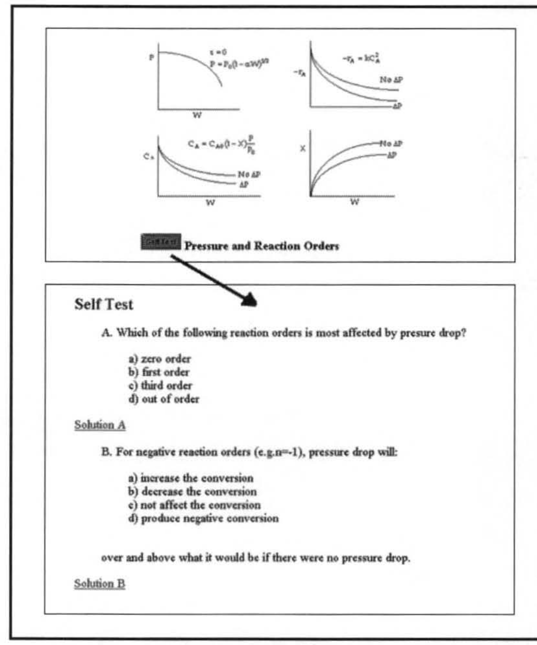

Figure 4. *Self-tests.*

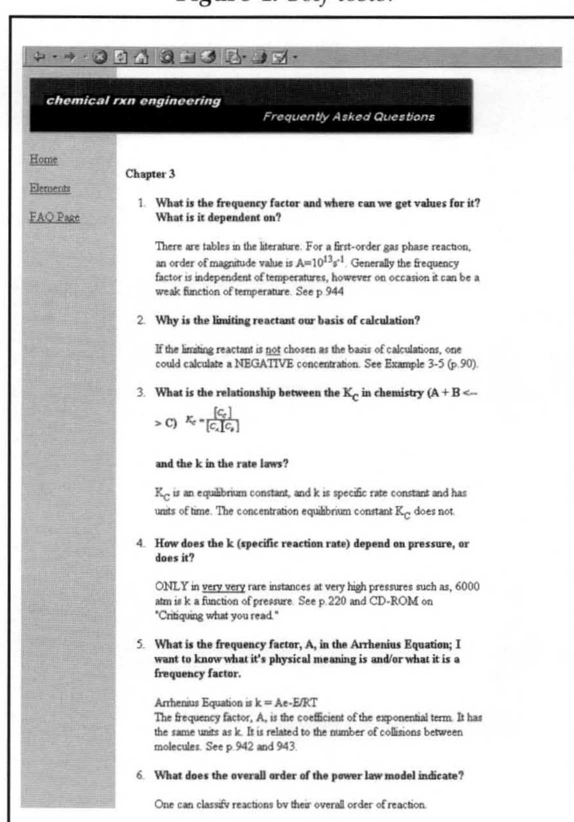

Figure 5. *FAQs*

ematical models, evaluation of constants, analysis of assumptions, etc. Resources that can be used include web sites, journals, books, and class materials. The topics for the summer 2000 OEP included

- *Drinking and Driving* (a study of alcohol uptake by body)
- *The Poison Bite Problem* (a study of venom and anti-venom effect of a poisonous snake)
- *The Antibiotic Model* (a study concerning antibiotic concentration in blood with bacterial growth and death)

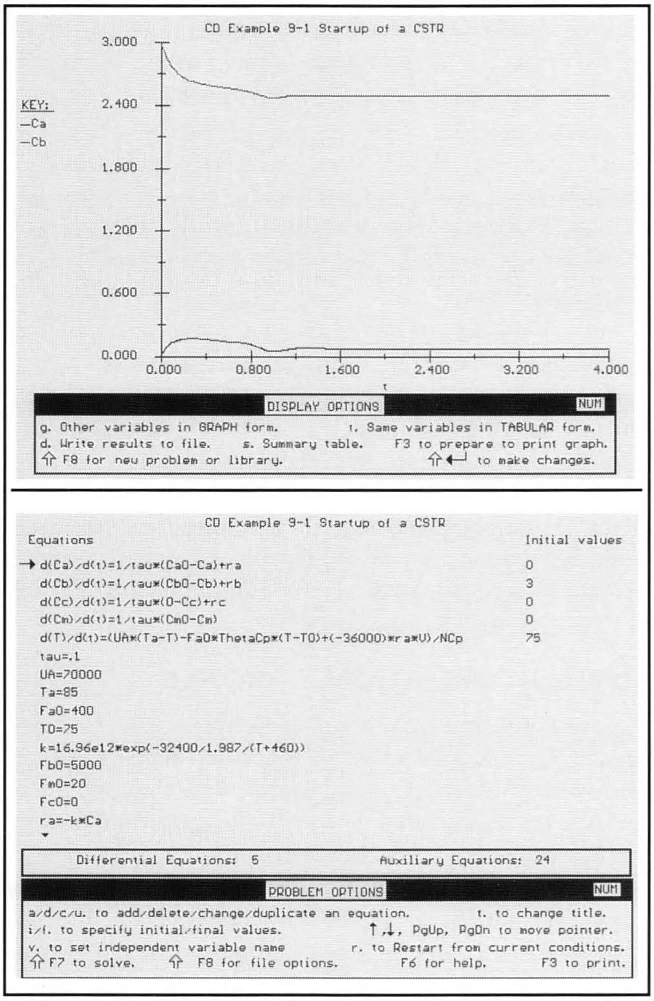

Figure 6. Living-example problems.

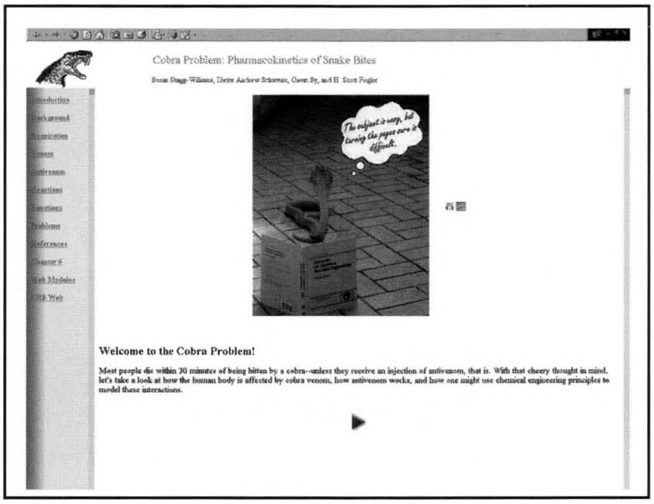

Figure 7. Web modules.

The students divided almost equally between the "Drinking and Driving" and "The Poison Bite Problem." The "Drinking and Driving Problem" is currently being developed into a full web module.

STUDENT PERSPECTIVE

AL is also advantageous from the students' perspective. Course structure in the chemical engineering department is oriented so that certain required classes are only offered every other semester. Because of this arrangement, a student who accepts a co-op job assignment is often at a disadvantage, having to take an extra semester to a year to graduate. There are also students who barely fail a course and want to take it again immediately. AL fulfills this need, recognizing that a student who is fresh with the material is more likely to do better than a student who has been away from the subject for a while. Finally, we realized that some students have obligations (family, work, etc.) that do not allow them to regularly meet for a class. With AL, these students can study when they have free time—they don't have to worry about missing an important lecture or lab session.

For students taking the course asynchronously, many aspects of the class have to be logistically considered, including: submission of assignments, taking exams, getting answers to questions, and the nature of the open-ended project. Assignment submission and home-problem assignments were submitted in three ways: by fax, mail, or e-mail as a graphics attachment (a gif or jpeg image file). The most popular choice for turning in assignments was e-mail submission. The handwritten homework solutions were scanned and attached to an e-mail message to the teaching assistant (TA). The assignments

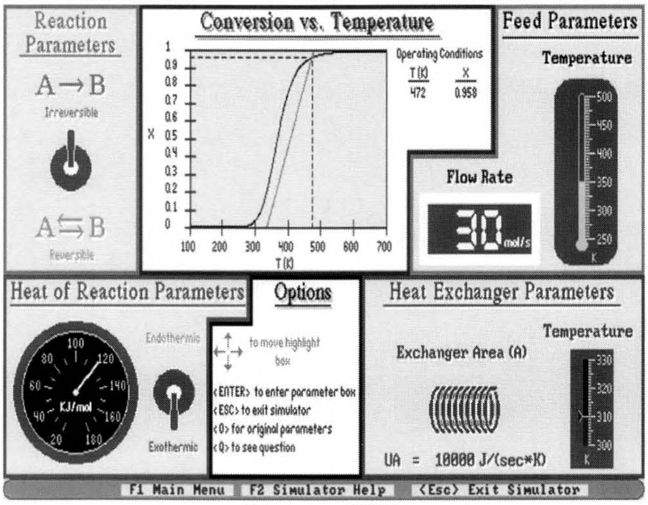

Figure 8. ICMs.

were graded in the normal way and returned to the students. Once the homework assignment is turned in, the student is given an assignment-specific *password* for each problem set to view the solution on the web.

Two exams and a final were required for the class. Because students were scattered throughout the United States, a proctor system was developed. Students were allowed to take exams only under the supervision of a proctor, who had to be either a supervisor at work, another college professor, or a high school teacher. The exams were mailed to the proctor and returned by the proctor to the TA or the professor. The proctor had to sign a statement indicating that he/she monitored the test at all times and had not observed any violations of the University of Michigan College of Engineering's honor code.

Students will inevitably have questions regarding homework assignments and conceptual understanding of course material. (They are asked to read through the FAQs related to the chapter first.) A teaching assistant is "on e-mail call" for most of the day, so questions can be answered with a minimum amount of turn-around time, usually less than a day. On the average, the TA received about 10-15 e-mails a week. Students also have the opportunity to send questions to the class e-mail list.

Grading in this course, whether synchronous or ashynchronous, has always been on the following straight scale basis:

A	90-100
B	80-89
C	70-79
D	66-70
E	Below 66

The weighting of each component is

Homework	20%
OEP	5%
Comprehensive Problem	5%
Exam I	20%
Exam II	25%
Final Exam	25%
Total	***100%***

The comprehensive problem is a specific problem in the textbook, encompassing one of the main goals of the class, to solve a chemical reaction engineering problem involving *multiple reactions with heat effects*. Usually either problem P8-29, P8-30, or similar ones, are assigned as the comprehensive problem.

BARRIERS

There are many advantages of an asynchronous class, but there are many barriers as well. We were able to remedy a few of these barriers, but others have no apparent solution.

One easily solved barrier was related to the web page. The course web page has links to the overall chemical reaction engineering home page, which we initially suggested the students visit frequently. Students using a modem were having difficulty listening to the audio files—they were rather large to download (about one megabyte each). To compensate for this and solve the problem, we supplied an updated CD containing the audio files, which effectively removed the bottleneck (download time) from the studying and learning process. We also made the asynchronous-learning course home page very easy to download, with no large image files.

Another potential barrier we were able to solve had to do with students asking questions and getting quick answers. When students encountered a frustrating concept or question, we knew that if they they could e-mail the TA and get a quick response, they would be more likely to keep working on it that same period.

Perhaps the biggest barrier that is common in AL courses is student self-discipline. Without specific deadlines, it is human nature to put off studying and learning until the last possible moment. We found that after only one month, just two students out of seven were keeping pace with homework submission. To combat this in the next AL offering of this course, we will implement three or four deadlines for homework. We have already placed deadlines for taking the first test and believe that a few more deadlines would help students stay on track for the course.

SUMMER 2000 STUDENT PROFILE

Seven students were enrolled in the course: all seven passed. Six were University of Michigan students and one was a junior ChE student from Northwestern University. Five students were off campus at their co-op work or summer internship and only two students were on the Ann Arbor campus. Four students from Winter Term 2000 were required to repeat the course because of their winter-term grade. The final grades in the AL course coincided with the students' GPA's from previous courses at the university. The final grade for the course was a 3.04 (two As, one B+, two B-s, and two C+s).

SUMMER 2001

Eleven students were enrolled in the course, one of whom was out of the country. Based on the progress of the students in the summer 2000 course, the time lines for completing the various units were revised, an additional exam was set, and the window for taking the exams was specified.

OUTCOMES

At the end of the course the students were asked to fill out a questionnaire/evaluation of the course. In addition, one-on-one interviews were carried out during the fall term a month or so after the course had been completed. Based on the interviews, questionnaires, exams, and exam scores, there appeared to be no significant difference between the seven students who took the course asynchronously during the summer of 2000 and the 135 students who took the course synchronously during winter term 2000.

One major discovery by the AL students was a realization that responsibility for learning the material was transferred from the instructor to themselves. Recognition of this fact is desirable in every course, not just courses offered asynchronously, as it helps the student develop life-long learning skills.

Many AL students said their self-confidence increased as a result of successfully completing the course. All students liked the flexibility of the AL course and that it was offered during the summer. Two students commented that when they were in cooperative learning groups during the winter term, they felt rushed by the other group members and were under stress to understand the material, in contrast to the summer 2000 course, which was virtually self-paced.

The next time the course is offered we plan to place deadlines for taking the exams at specified times during the term. In addition, to help the students proceed at a reasonable pace two or three cumulative deadlines may be imposed.

All of the students appreciated the resources available to them, namely the Interactive Computer Modules, the Summary Notes with "Derive" hot buttons, extra examples, audios, and self tests. The key activities of a successful AL course are to:

- *Provide a variety of learning resources to accommodate the various learning styles described by Felder and Soloman.*[2]
- *Keep the student involved through interacting with the computer and the material (hot buttons, simulations).*
- *Provide a number of FAQs collected from previous courses since the AL instructor is not immediately available and a number of the same questions come up year after year.*
- *Help the student come to a realization that the responsibility of learning material is on his/her shoulders. There is no instructor around to answer questions after class*
- *Provide incentives that will keep the students on the time line.*

The principle negative of the course is the lack of face-to-face interaction between student, faculty, graduate student instructors, and other students. Also, the chat room/bulletin board was not effective, perhaps in part because of the small number of students. Future AL courses may use professional software to facilitate a "real time" chat room.

With respect to the open-ended problems, generating and developing ideas proved to be quite difficult solely through e-mail and telephone conversations. Only one or two of the open-ended problems were of above-average quality. Also, if students could not find the answer to a question in the FAQ's, they sometimes they had to wait for the TA to respond if, for example, the TA had checked his e-mail just before they signed on. Another drawback was that some of the questions were difficult to explain by just using e-mail—especially those where sketches were required.

A teacher can make every effort to motivate students to learn, but in the end it is the student who is responsible for learning the course material. AL places a greater responsibility on the student to learn as compared with a traditional class, but we believe it is good practice for the workplace. When students move into industrial jobs, there will be many times when they will have to assume the full responsibility for learning. The AL course prepares them for this environment in addition to giving them confidence that they can learn on their own. In the exit survey, most of the students cited increased self-confidence as one of the preatest positives in the AL course.

SUMMARY

Chemical reaction engineering was taught asynchronously using e-mail, the web, texts, and CD-ROMs. The wide variety of resources given to the students allowed for most of the learning styles described by Felder and Soloman. The students in the course performed well in the AL course and enjoyed it. Two major advantages of the chemical reaction course were that it addressed a number of the learning styles identified in Felder/Soloman's inventory and that it provided great flexibility in time and location for learning the subject. The students developed a greater sense of self-confidence and gained a realization that the responsibility for learning was transferred from the professor to the student.

The major drawback was a lack of face-to-face communication between student, GSIs, and faculty. After reviewing the course structure and outcomes from summer 2000, the chemical engineering department's curriculum committee voted to accept the asynchronous learning version of the chemical reaction engineering course as equivalent to the synchronous version of the course offered during the academic year.

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