A WEB-BASED COURSE

*In the Fundamentals of Microelectronics Processing**

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The ability to instantly communicate and exchange information with anyone at anytime, anywhere in the world, *i.e.,* the Internet, has helped eliminate many of the distances that once kept people apart. In this paper, we focus on the course "Fundamentals and Design of Microelectronics Processing," which was offered for the first time on the Web in the spring of 2000. It is the first course ever to be offered on the Web by the Chemical Engineering Department at UIC; to our knowledge, this is also the first chemical engineering (ChE) microelectronics course ever offered on the Web.

Through this Web-based dual-level ChE course, we will present and discuss our experiences on the impact the Internet is having in the field of engineering education. We will also examine the Internet's potential benefits for learning and what it means to teach a graduate/advanced undergraduate engineering course on the Web.

THE DUAL-LEVEL GRADUATE/UNDERGRADUATE COURSE

Increasingly more chemical engineers are entering the field of microelectronic materials and processing, in part because basic knowledge of this fast-growing field lies in chemical engineering. Novel ultra-thin dielectric materials, passivation of silicon and silicon germanium, surface and gas-phase reaction chemistry in microfabrication techniques, diffusion of impurities through the films, and process-structure-function relationships in micro- and nano-electronics processing are some representative example systems.[1-11] Chemical, electrical, and material engineering principles in the fundamental understanding and design of microelectronics processing are bringing about great changes in integrated circuits, micro-electro-mechanical systems (MEMS), and other fields in which data acquisition, computation, or controls are necessary. Several chemical engineering departments (worldwide) have either offered courses in microelectronic materials and processing or incorporated several examples and case studies in core curriculum chemical engineering courses.[e.g., 12-14]

In the spring of 1997, UIC started a dual-level class (offered to graduate and advanced undergraduate students) titled "Fundamentals and Design of Microelectronics Processing." The objective of the course was to provide participants and students with the basic principles and practical aspects of the most advanced state of electronics and MEMS processing. The emphasis of the course was on basic aspects of thin film growth, substrate doping and passivation, ion implantation, lithography, and etching coupled with chemical kinetics, reactor design, thermodynamics, optimization and other engineering concepts as they apply to fundamental processes useful for feature sizes down to the order of about 0.01 - 1 μm. Therefore, the principles and philosophy underlying the selection of topics and their ordering focused mainly on fundamental notions of transport, reaction kinetics, thermodynamics, and reactor design, along with process-struc-

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* *Found at (http://www.uic.edu/eng/meng/che_494.htm)*

ture-function relationships in electronic materials and microfabrication.

In the Spring semester of 1998, the scope and effectiveness of this course was substantially enhanced and augmented with the introduction and implementation of two Web-based semiconductor simulation tools:[15-16] ThermoEMP and TSUPREM-4. Table 1 shows the outline of the Web course, which consisted of 41 lectures; the number of lectures listed for each heading in the course outline is not meant to be related, however, to the number of bulleted subjects below it. Further, in the Course Information section of the class there are several additional items, including (i) two lectures introducing those two Web-based simulation tools along with step-by-step instructions and working examples, and (ii) extensive external links.

WEB-BASED INSTRUCTION OF THE CHE COURSE

Instead of attending classes in a centralized institution or location, students can sit in front of a computer monitor anywhere in the world, viewing, listening, and interacting with class materials that have been designed for Internet use. In order to design effective class material for all students, we needed to take into account a number of different learning styles: visual, audio, reading and writing, and interactive (examples are provided at http://www.uic.edu/eng/meng). We had to prepare materials with the different learning styles in mind.

Various components were incorporated into the class materials so as to mimic and enhance the real live experience of a classroom. For example, there were extensive audio segments of the professor lecturing and discussing specific issues and topics in depth in the first Web offering of the course. In a classroom, when a student has a question, (s)he raises his(er) hand, immediately attracting the professor's attention. On the Web, there were also several effective ways to communicate with the professor, teaching assistant, and/or classmates. By means of "asynchronous and synchronous" communication tools such as e-mail, bulletin boards and chat rooms, the students and participants in the class could maintain contact with the instructor and fellow class-

TABLE 1
Outline of the Course on the Web

Introduction (3 Lectures)
- Introduction to Microelectronics Processing, Yield
- Overview of Electronic Materials

Crystal Growth (4 Lectures)
- Fundamentals of Crystal Growth Processes
- Energy and Mass Transfer, Modeling
- Doping, Design of Crystal Growth Processes
- Modeling and Simulation, Examples

Thin Film Deposition (14 Lectures)
- Chemical Vapor Deposition (CVD)
- Silicon Epitaxy, Thermodynamics
- ThermoEMP as a Simulation Tool
  (*Thermo*dynamics of *E*lectronic *M*aterials *P*rocessing)
- A Priori Process - Property Relationships
- Surface and Gas-Phase Chemical Kinetics
- Kinetics and Mass Transfer of Epitaxial Growth
- Transport Phenomena, Reactor Design, Modeling
- Silicon-Germanium, Silicon Carbide
- Metal Organic CVD (MOCVD)
- Doping of Epilayers, Autodoping, Diffusion
- Three-Dimensional Integration
  A Priori Process - Property Relationships, Reactor
  Analysis and Design, Selective Epitaxial Growth
  Three-Dimensional Integration and Microfabrication - Examples
- Epitaxial Evaluation, Thin Film Characterization,
  Physical Vapor Deposition, Molecular Beam Epitaxy
- Plasma - Assisted/Enhanced CVD (PACVD or PECVD)
  Design of Plasma CVD Reactors, Modeling - Examples
- CVD of Polysilicon, Amorphous Silicon, SiO_2 and Si_3N_4

Passivation of Electronic Materials (4 Lectures)
- Thermal Oxidation of Silicon
  Kinetics, Reactor Design, Modeling
- TSUPREM-4 as a Simulation Tool
- Oxynitridation of Silicon
  Kinetics, Reactor Design, Modeling, Simulation, Examples
  Degradation and Characterization of Dielectric Thin Films
- Redistribution of Impurities during Thermal Oxidation

Ion Implantation (3 Lectures)
- Fundamentals, Kinetics
- Design and Process Considerations
- Analysis and Design of Masking Films for Ion Implantation
- Mathematical Modeling - Examples

Advanced Lithography (5 Lectures)
- Chemistry and Physics of Lithographic Materials
- Fundamentals of Surface Preparation
- Positive and Negative Resists, Multi-Level Resists
- Design and Control of Lithographic Materials
- Advanced Lift-off Techniques, Problem Areas - Examples

Dry Etching (4 Lectures)
- Low-Pressure Discharges, Physical and Chemical Phenomena
- Selectivity - Feature and Pattern Size Control
- Fundamentals of Dry Etching
- Design and Process Considerations
- Modeling - Simulation - Examples

Wet Etching (2 Lectures)
- Chemistry - Physics, Thermodynamic and Kinetic Considerations
- Analysis and Design of Wet Etching Processes
- Characterization of Etched Substrate Surfaces, Modeling - Examples

Design of Experiments (2 Lectures)
- How to Use Statistical Techniques, General Factorial Design
- Factorial Design at Two Levels, Interaction Effects, Example
- Analysis of Data, Minimum Significant Factor and Curvature Effects
- Example

mates. Bulletin boards and e-mail turned out to be the preferred communication tools.

Text is the easiest material to prepare for computer-based learning. Text on a computer can be easily improved by taking advantage, for example, of HyperText Markup Language (HTML) and hyperlinks since it could be prepared to look like a book or a set of slides. Further, any document already existing in electronic format could be easily transferred and presented on the Web. In our course, an electronic set of extensive written notes was included as the core reference material. This was in no way a substitute for the traditional textbook(s) and/or other references, however. In fact, several references and relevant journal articles, as well as other reading assignments, were used with every 3-5 lectures.

The entire set of electronic notes was created with an HTML editor. HTML also helped in incorporating rich media such as photos, drawings, audio, interaction and, more importantly, hyperlinks. Hyperlinks allowed students to click on an area of the document and to immediately be transported to either a previous or a following chapter, to additional references published worldwide on the Internet, to bookmarked pages, to an audio explanation by the professor, to a graphical representation of the problem being discussed, or to other relevant sites.

We did not have to learn HTML since current text-editors (Word, etc.) have the capability to translate to HTML. HTML can be considered as an encoder, a universal container in which to put information. It is the universal language of the Web, enabling anybody to see any information of interest with a simple Web browser, without the use of specialized tools. Such electronic sets of written notes can be updated and published on the Web immediately. This is a significant benefit since current research and development requires that material be frequently updated. Yet, overall preparation of the first electronic set of written notes, coupled with photos, audio, interaction, hyperlinks and drawings, turned out to be a substantially higher-than-anticipated commitment of time, effort, and resources. We estimate that the course took about three times more time and effort in its initial Web preparation compared to the preparation required for a well-run

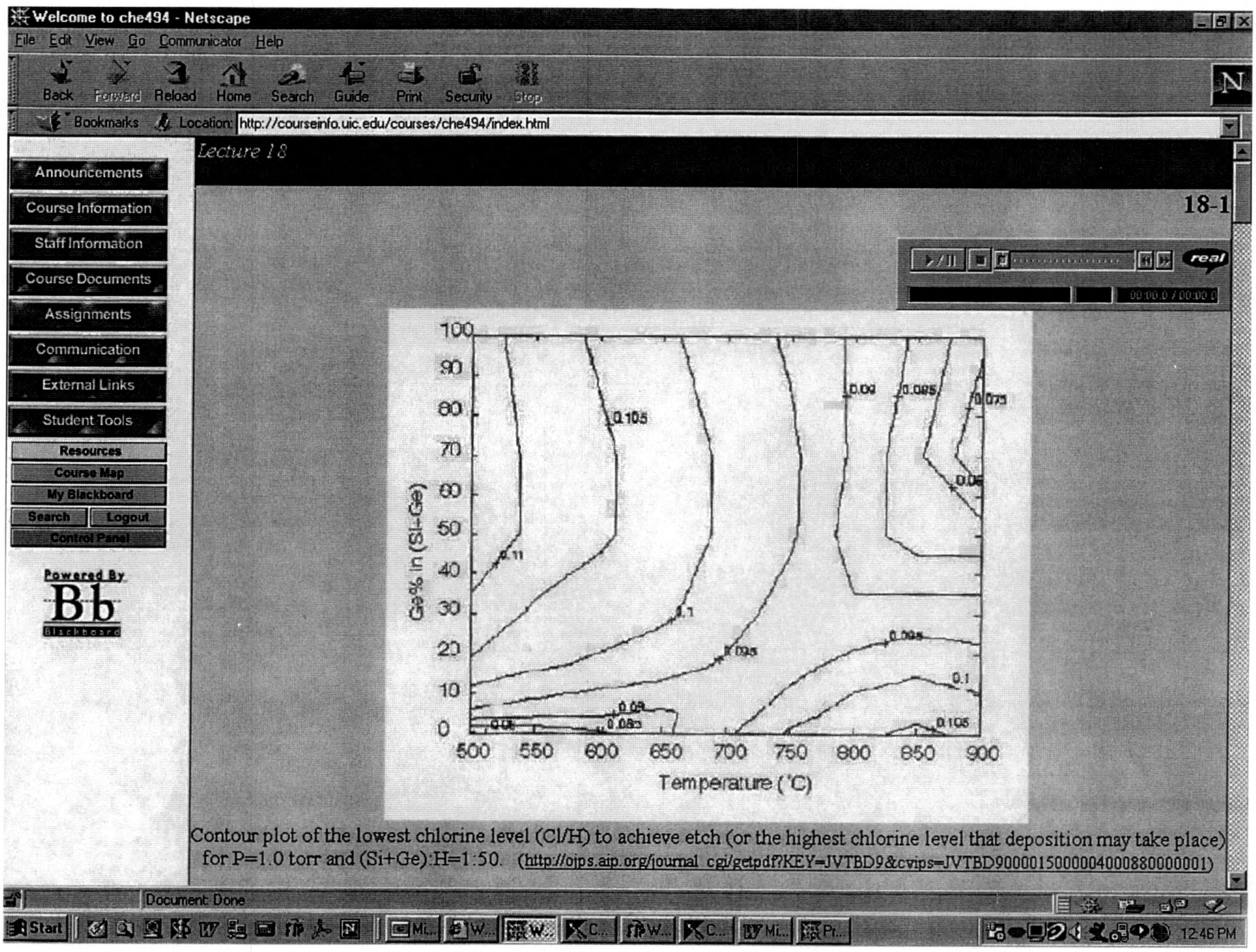

Figure 1. Example of an actual Web page of the class; it demonstrates the use of different media.

traditional course. The lead time needed to get this course set up was about 6-8 months, and financial and personnel resources from the university were critically important and extremely helpful. Figure 1 shows an actual Web page of our class that contains lecture material prepared using text with audio, hyperlinks, and additional explanations.

"Interactive/interaction" refers to learning by doing something. For engineering classes, using interactive programs to show various kinds of results is becoming more frequent. Examples could include the behavior of a chemical plant (students define the characteristics of the plant and observe its performance), fabrication of a micro-electro-mechanical system (students design/define sequential processes and understand the characteristics and performance of the system that is created), etc. When such an interactive tool is available on the Web, it can easily be linked to the class notes for the students' benefit.

Two effective examples in this course were the simulation tools ThermoEMP and TSUPREM-4.[15,16] ThermoEMP (*e.g.,* http://www.uic.edu/classes/che/che494/) is a computer program that calculates the chemical equilibrium compositions of microelectronic materials processing and the thermodynamic and transport properties of the equilibrium mixture (formed after reaction); results are generated through a methodology that minimizes the Gibbs free energy of the system via a rigorous thermodynamic analysis.[17] The minimum temperature above which oxide-free silicon growth (a very important requirement in the microelectronics industry) can take place, oxide-free silicon carbide growth in a variety of reaction environments, or the effects of dichlorosilane flow rate and temperature on the selective epitaxial growth of silicon can, therefore, be effectively studied with ThermoEMP. A remarkable aspect of these case studies is that students experience key issues in real-life problems and have the opportunity to see that solutions can be obtained, in some cases at least, within a very short period of time without doing any experiments (*e.g.,* from fundamental knowledge-driven simulation tools).[15] TSUPREM-4 (licensed from Technology Modeling Associates (TMA), Inc.; http://www.uic.edu/classes/che/che494/) is a computer program for simulating the processing steps involved in the manufacture of silicon integrated circuits, discrete devices, and MEMS;[18] in fact, a wide range of processing steps can be modeled by this program. Several examples demonstrating the effectiveness of TSUPREM-4 have been presented and discussed in Ref. 15.

SOME ADVANTAGES

Web-based learning was beneficial for those students who could not attend classrooms because of personal or professional commitments, limited financial resources, or physical limitations. On a whole, all participants in the class, including the professor/teaching assistant, had something to learn. The instructors and students received immediate feedback. The student responses on the "instructor and course evaluation" at the end of semester also indicated that Web-based learning was useful for those students who perhaps were shy and reluctant to ask questions in public. Another advantage was accessibility. Instructional material was available twenty-four hours a day, eliminating conflicts with one's schedule. Because the instructional material was always available, learning was self-paced.

From the intructor's point of view, preparation, editing, and publishing all the material on the Web for the first time was a huge undertaking that was made possible with the help of an Internet-expert teaching assistant (Sanjit S. Dang), an expert multimedia professional (Raymond A. Matthes), and financial resources from the University of Illinois at Chicago. Our expectation is that once the class material is in electronic format, it will probably be easier to modify and keep up-to-date.

ASSESSMENT OF STUDENTS' PROGRESS

Assessing the progress of students in the Web-based course was similar to the conventional classroom. Each lecture had a quiz, which was graded electronically by the instructor/teaching assistant. Although some of the Web management tools allow one to create simple multiple-choice quizzes that are automatically graded by the system when the student submits the quiz, we decided against using multiple-choice quizzes in our course. While this resulted in substantially greater effort in preparation and grading, this system of testing was found to be much more effective and challenging to the students. However, more sophisticated kinds of assessments could be prepared using, for example, Mallard, a web-based interactive quizzing tool (http://www.ews.uiuc.edu/Mallard/Overview).

Homework was posted on the Web and had to be returned electronically to the instructor/teaching assistant. (Homework was also accepted in paper format during the Spring of 2000 since the course was on the Web for the first time then.) Exam assessment might be done electronically, but with the present technology it was deemed safer to do it the old-fashioned way—in a classroom. Before each exam, there was one help session offered in both formats: in the classroom (extensive version) and on the Web (abbreviated version). Overall, in the learning expectations and in the grading of problems and tests, there was some differentiation between advanced undergraduates and graduate students taking this class. All students had to do the same amount of core work, but undergraduates were not required to do extra work and case studies.

A direct comparison of the averages on the mid-semester and final exams in the Web (Spring 2000) and traditional formats (Spring 1997, 1998, and 1999) of the course showed that students taking the course in the Web format scored about 15% higher than those in the traditional one. In such comparisons, however, two apparent assumptions have to be considered: (i) the exams had comparable difficulties, and (ii) the average caliber and background of the students who took the course during the last four spring semesters were the same. While we believe that the former assumption is a good one, the latter assumption is very difficult to check.

STUDENTS' FEEDBACK AND EVALUATIONS

The feedback and written evaluations of the students on the scope and instruction effectiveness of the two Web-based semiconductor simulation tools, ThermoEMP and TSUPREM-4, were overwhelmingly positive: (i) students strongly agreed that it was easy to figure out how to use the simulation tools; (ii) they strongly agreed that the overall class experience was enhanced by the use of the software; (iii) they strongly agreed that it was convenient to have universal access to programs via the Web; and (iv) they would like/have liked to use the simulation tools in other classes too.

The feedback and written evaluations of the students on the scope and instruction effectiveness of their first ever Web-based course included several useful points. The students were strongly positive about

- *The convenience of taking a lecture at any time, any place, and at any pace they wished*
- *The effectiveness of learning through the use of several multi-media approaches*
- *The use of one quiz for each lecture*
- *The availability of hyperlinks to several Web sites of interest and reference*
- *The help session(s) before each exam*

and, perhaps, above all

- *The half-hour weekly meetings held in the classroom throughout the semester. (These meetings turned out to be very important in the trouble-shooting of many aspects of the implementation of this Web course.)*

The help session(s) before each exam in the classroom format were offered as extra help during this first year of the implementation of the course. We anticipate that beginning next year, the help sessions, if any, will be totally on the Web. The live-help sessions in the classroom before each exam, as well as the weekly classroom meetings, were praised as 'extremely helpful.'

The students had a variety of comments for other aspects of the Web-based course experience:

- *It was difficult to 'stay on task,' that is, quite a few students indicated they would most likely go through the lectures, quizzes and homeworks of this course as late as possible, since they did not have to go to the classroom at certain times, on specific days.*
- *There were a few difficulties early on, during the implementation of the course; they were related with the timing and 'error-free' posting of the course material as well as the fact that this was the first Web-based course for everyone involved, students and instructors alike.*
- *More ways of student-student and student-instructor interactions (like increased participation in live chat rooms among students, live video-conferencing, etc.) could have been used.*

Possible suggestions/solutions to the issues mentioned above could include enforced deadlines for quizzes, increased use of chat rooms (in particular, video-conferencing), and continuous improvements of and additions to the posted material on the Web. We anticipate implementing such solutions by the time the course is offered in the spring of 2001.

A direct comparison between the scores on the instructor and course evaluations at the end of each of the last four spring semesters, 1997-1999, with the traditional format of the course, and the scores for the 2000 Web presentation, revealed that the "instructor's overall effectiveness" (one of the two required items in all evaluations at UIC) was the same each year, while the "overall quality of the course" (the other required item in the evaluations) had a slightly higher score for the Web format. These results should be viewed, however, in the context that all course evaluation scores were already close to the highest possible number. Also, the course had a comparable number of students each time.

Further insight that was gained from our experience on the shortcomings and how to improve attempts at true 'distance' education included: (i) the unavailability of effective means for proctoring tests and exams outside the classroom, (ii) the substantial benefit from video-conferencing, (iii) a need for more thinking about minimizing students' tardiness with the class material (typically up to the time a test or homework problem set is due), and (iv) a partial lack of ideas on how to handle students who may be willing to finish the course material (and everything else) at a fast pace, say, in 8 weeks instead of 16 weeks.

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BOOK REVIEW: *Engineering Flow and Heat Exchange*

Continued from page 343.

low pressure, "molecular" flows. Here the concept of "molecular slip" is introduced.

Chapter 5 contains, as mentioned above, concepts and problems of non-Newtonian flow explained in a direct and simple-to-understand fashion. The student is reminded that, in general, this complex fluid can be treated as Newtonian with an additional term and all that is required is to find the correction due to the non-Newtonian behavior. Since most fluids in industrial practice are non-Newtonian, the introduction of this material is, I think, crucial. Furthermore, rheometry to measure non-Newtonian behavior is also presented in detail.

The first part of the book, also contains chapters on flow in porous media and in fluidized beds. They are also well written, with many examples and actual industrial applications both solved and presented as homework problems.

The second part of the book, on heat transfer and heat exchanger design, is also enlightening, crisp, and well constructed. Chapters 9, 10, 12, and 13 contain the usual material on different forms of heat transfer, combined heat transfer, and two-fluid heat exchanger design. Here again, it is assumed that the student has taken a previous introductory course in heat transfer since familiarity with, for example, the Nuselt number is required. The material in Chapters 11, 14, and 15 contains unsteady heating and cooling and design of direct-contact exchangers and regenerators—material usually not covered in standard texts. The second part ends (Chapter 16) with a set of recommended problems involving material contained in the book, keeping in mind practical, industrially relevant applications.

There is an extended Appendix with very useful information such as transformation of units, some material properties, dimensionless groups, and values of more important parameters such as heat transfer coefficients in different geometries. The text also comes (available to the instructor) with a set of solutions to the problems in each chapter , with every second problem being solved. The problems in the last chapter (16) all have solutions. The illustrations in the book are inspired and clear, while the nomograms, mostly for heat transfer calculations, are up-to-date and easy to use.

Over all, this is an excellent book, written with the heart. The reader can visibly appreciate this. It should be a permanent fixture on the bookshelf of any engineer who studied or uses fluid flow and heat transfer in his work. ❐