TEACHING TRANSPORT PHENOMENA WITH INTERACTIVE COMPUTERS TO THE NINTENDO GENERATION

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This paper is the result of collaborative work between myself (E.E. Wolf) and my son (J.E. Wolf). It is written from my perspective since it relates to my accumulated years of teaching, while my son's contribution relates to computer software development.

In my twenty years of teaching chemical engineering courses, I have always been challenged by how best to involve students in the specific subject being taught. I have devised many strategies to reach as many students as I could, and I am especially fond of teaching via the Socratic method. But the evading and delaying tactics of students who do not get involved in class have often led me to call on a student who will most likely know the answer I am looking for. Unfortunately, this process leads to a dialogue between a select group of students and myself, to the delight of those students who prefer to be left alone. As a result, the effectiveness of the in-class learning process is significantly reduced, and whatever students learn to pass the exam is done primarily outside class (usually from a textbook).

This process of selective teaching occurs especially in large classes where it is obviously impractical to reach everyone. Many students are thus deprived of the benefits of the experiential learning process because they do not participate in the inquiry that the classroom provides. Our teaching methodology needs to be revised in order to improve class participation.

Computers may be the media needed to achieve experiential learning. It has always amazed me how fast young people learn computer games compared to how long it takes me to save Mario™ from all the traps in his unforgiving virtual world. The younger generation (the Nintendees?) that has been exposed to these games from early childhood seems to be able to learn new games even without the aid of a manual. This learning process is mainly experiential through computer interaction with the player. If we could only get students to learn at a fraction of the pace with which they learn these games, we could significantly improve our teaching capacity.

Several learning studies[1] have shown that involving students in the educational process is the key to better learning. I recall results from a study showing that when the sensorial perception of information is only auditory (the average lecture), the retention rate is about twenty percent. In a setting that includes both audio and visual aids, retention increases to forty percent (transparencies always help!). When the process also includes an interactive element, however, wherein students participate (small classes/recitations where students ask questions), retention rises to eighty percent. I still remember some problems discussed long ago when I was a graduate student in our process-design brainstorming sessions. All of us, I believe, experience events that create such an impression in our minds that they remain in our memory for years. Special circumstances cause the brain to activate the processes required for long-term memory. We

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do not yet completely understand this process, so the next best thing is to create classroom experiences that stimulate similar responses.

I have been teaching transport phenomena to chemical engineering juniors for some time. This subject is well suited to intense interactive teaching via question-and-answer sessions because it rests firmly on a few fundamental principles. The conservation laws provide the axioms from which the basic governing equations can be derived for most engineering problems. In the past, after explaining the basic principles, I developed in-class examples of their applications by asking the students questions about the model that describes the problems, about the assumptions and boundary conditions involved, and finally, about the method for solving the problem. After receiving the answers from some selected student, I would reveal my own answers on a transparency. Initially, I would develop the equations using shell balances and, later, by using the simplified vector forms of the general conservation equations. To avoid selecting the same students every time, I would use randomly picked numbers to select a student from the class list. This step-by-step process was slow, but it generally received good reviews from the students. I felt, however, that many students had not really participated and I felt that I needed a more effective teaching method.

Several learning studies have shown that involving students in the educational process is the key to better learning. . . . Special circumstances cause the brain to activate the processes required for long-term memory. We do not yet completely understand this process, so the next best thing is to create classroom experiences that stimulate similar responses. . . . Clearly, computers can get people involved . . .

Clearly, computers can get people involved in a particular task. The main use of classroom computers involves homework assignments, problem solving, and improved visual presentations via special animated simulations. Computer networks also provide an opportunity to reach students outside the classroom with assignments and notes.

Notre Dame recently inaugurated a special teaching facility (DeBartolo Hall) in which each classroom is equipped with state-of-the-art communications facilities. In particular, there are two classrooms where there is a computer available for every student. These computers are connected to a local area network (LAN) that communicates with a server and with a podium that is also equipped with a computer. This setting presented the opportunity I was looking for—the ability to simultaneously reach and involve every student. A room in which every student has a computer at his command means that each student could be asked to answer the same question and could provide his or her own individual answer. The challenge was to create an interactive teaching method to work with these facilities.

Translating this idea into reality required software. I thought that such software would be available in the marketplace, but alas, I found no program that seemed suitable, and the project was put on hold for a year. Fortunately, my son was available for the summer, and with the help of a grant from Notre Dame's Office of University Computing, I asked him to translate my concept into workable software. He is a chemical engineering and an art major, he had taken my transport phenomena course, and he happens to be well versed in computers. So, a rare father-son academic partnership emerged.

THE PROGRAM

Things developed quickly, although it took more than the summer to complete the working version (an extra month was required). In the previous semester, with the help of our secretarial staff, I had transferred my teaching notes to a computer disk, which helped expedite the development of the interactive software. After learning six different computer languages, I have become a devoted Macintosh user, so Hypercard was chosen to be the development environment.

Table 1 (next page) shows the course outline. I first go over the principles (denoted as LECTURES on the outline) and then present the application of the principle as a problem (shown as Lessons). The outline is a hybrid of the texts of Bird, Stewart, and Lightfoot (BSL)[2] and Welty, Wicks, and Wilson (WWW).[3] The reference column in the outline refers to either a specific example from WWW or to notes adapted from BSL (especially when dealing with macroscopic balances). The course has three credit hours and it is the second semester of a year-long course. It covers fundamental heat and mass transport; fluid mechanics is covered in the first semester.

The software was designed as a sequence of "cards" (small windows of text and graphic information) that ask generic questions applicable to most lessons. For cases in which this format does not match (*e.g.,* turbulent flow considerations) a regular lecture format is used. The first card displayed is the problem statement; it is displayed in the lower half of a

TABLE 1
Course Outline: Transport Phenomena II (Heat and Mass Transport)

Session	Topic	Ref
LECTURE 1	TRANSPORT TUTOR, CONSERVATION'S LAWS	NOTES
LECTURE 1	CONTINUITY, MOMENTUM BALANCE	NOTES
LECTURE 1	CONSERVATION OF ENERGY, HEAT CONDUCTION IN SOLIDS	NOTES
Lesson 1	Heat conduction, plane wall	17.1
Lesson 2	Heat conduction, composite walls	17.1
Lesson 3	Heat conduction, cylinder	17.1
LECTURE 2	HEAT CONDUCTION IN SOLIDS, VECTOR APPROACH	NOTES
Lesson 4	Heat conduction with constant source	17.2
Lesson 5	Heat conduction with variable source	17.2
Lesson 6	Heat transfer from extended surfaces	17.3
Lesson 7	Two-dimension heat conduction	17.4
Lesson 8	Unsteady heat conduction, semi-infinite wall	18.1
Lesson 9	Unsteady heat conduction, lumped systems	18.1
LECTURE 3	DIFFERENTIAL ENERGY BALANCE IN FLOW SYSTEMS	NOTES
Lesson 10	Boundary layer analysis-laminar flow	19.4
LECTURE 4	TURBULENT FLOW CONSIDERATIONS	19.7
LECTURE 5	NATURAL CONVECTION	20
LECTURE 5	CONVECTIVE HEAT TRANSFER CORRELATIONS	20
LECTURE 6	MACROSCOPIC ENERGY BALANCE	NOTES
Lesson 11	Heat transfer equipment design	22
FIRST MIDTERM EXAM		
LECTURE 7	MASS TRANSFER MECHANISMS	24
LECTURE 8	POINT DIFFERENTIAL MASS BALANCE	25
Lesson 12	Diffusion in gases: stagnant gas film	26.1
Lesson 13	Diffusion is gases: equimolar counter-diffusion	26.1
Lesson 14	Diffusion in gases: surface reaction	26.2
Lesson 15	Diffusion in liquids: gas absorption without reaction	26.1
Lesson 16	Diffusion in liquids: gas absorption with reaction	26.2
Lesson 17	Unsteady diffusion in liquids	27
Lesson 18	Diffusion in solids, porous catalyst pellet	Notes
Lesson 19	Diffusion and convection	26.4
Lesson 20	Boundary layer analysis, laminar flow	28.4
LECTURE 9	TURBULENT FLOW CONSIDERATIONS	28.6
LECTURE 10	INTERPHASE MASS TRANSPORT	29
SECOND MIDTERM EXAM		
LECTURE 11	CONVECTIVE MASS TRANSPORT CORRELATIONS	30
LECTURE 12	MACROSCOPIC MASS BALANCES	NOTES
LECTURE 13	MASS TRANSFER EQUIPMENT DESIGN	31
Lesson 20	Design of a batch tank	31.2
Lesson 21	Design of a continuous contact tower	31.3
LECTURE 14	REVIEW	NOTES
FINAL EXAM		

page-length screen during the entire time that the student works on the problem. An example is shown in the bottom half of Figure 1 corresponding to Lesson Three on heat conduction in a cylinder. The problem statement card comes equipped with a help button that, when clicked, opens a window that provides hints to the students should they need them.

With the appearance of the Problem Statement card at the bottom of the screen, a First Questions card appears at the top of the screen. It contains a series of multiple-choice questions that students answer by clicking on a box next to the answer they have selected. The box is then highlighted. The questions asked are the ones all transport students should ask themselves each time they attempt to solve a problem; the answers are the simplifying assumptions that apply to the problem. Once the student has answered these questions, he or she can move on to the next card by clicking on the arrow at the bottom of the page.

So far, the software appears rather one-sided; in fact, the program was designed so that students could review their classroom work outside class in one of the computer clusters around campus. But the software really becomes interactive when it is used in conjunction with another piece of commercially available software (Screen Link or Timbuktu) that allows the professor to view a student's screen on the podium computer. And the interaction does not stop there since the professor's screen can be projected on a large projection screen in front of the entire class. After first checking with the student to avoid embarrassing him or her, the student's work can then be seen by the entire class. This allows the professor to go over various points in the problem and to clarify possible mistakes, particularly regarding assumptions, etc., as they occur in a student's thinking process. It also creates an opportunity for the class to ask questions or for clarification on a particular issue.

The professor's version of the program contains a class list from which a student is randomly selected each time (see Figure 2). This undoubtedly creates an incentive to become involved during class. In every session I emphasize that mistakes can be corrected at this stage before they become misconceptions that cost the student dearly in their exams.

After completing the First Questions card, the students move to the Problem Set-Up card. At the top of this card (see Figure 3, next page) is a simplified form of a conservation law: the time rate of change term [Acc] equals the rate of change due to transfer through open surfaces by convection [ΔFc] plus the rate of change due to transfer through closed surfaces by diffusion (of heat or mass) [ΔFd] and the rate of generation of the quantity being conserved [Rg]. This form of the equation, although not strictly rigorous, represents the majority of situations encountered in transport problems. In the special case of momentum, gravitational forces are considered as a generation term.

The rest of the card consists of a scratch board that is initially blank. In this space the student is expected to apply the conservation equation at the top of the page to the problem at hand, keeping in mind the assumptions made on the previous card. (The students can always check by clicking on the back arrow that takes them back to the previous card.) The student should develop a solvable differential equation. Using a standard keyboard, typing mathematical notation is often difficult, if not illegible, so this software has a special menu for the most commonly used symbols. A symbol menu appears by clicking the button at the bottom of the card, and clicking on any of the individual menu characters inserts that character at the last place the student typed. Figure 4 (next page) shows an example of what a student could type in this space using the shell balance approach for the example problem. Again, to move ahead, the student clicks on the arrow at the bottom of the card.

The next card (see Figure 4), the Boundary Conditions card, asks questions about the type of equation that the student has developed and the corresponding boundary conditions that are appropriate to solve the equation. Students must know the answers to these questions in order to choose the correct

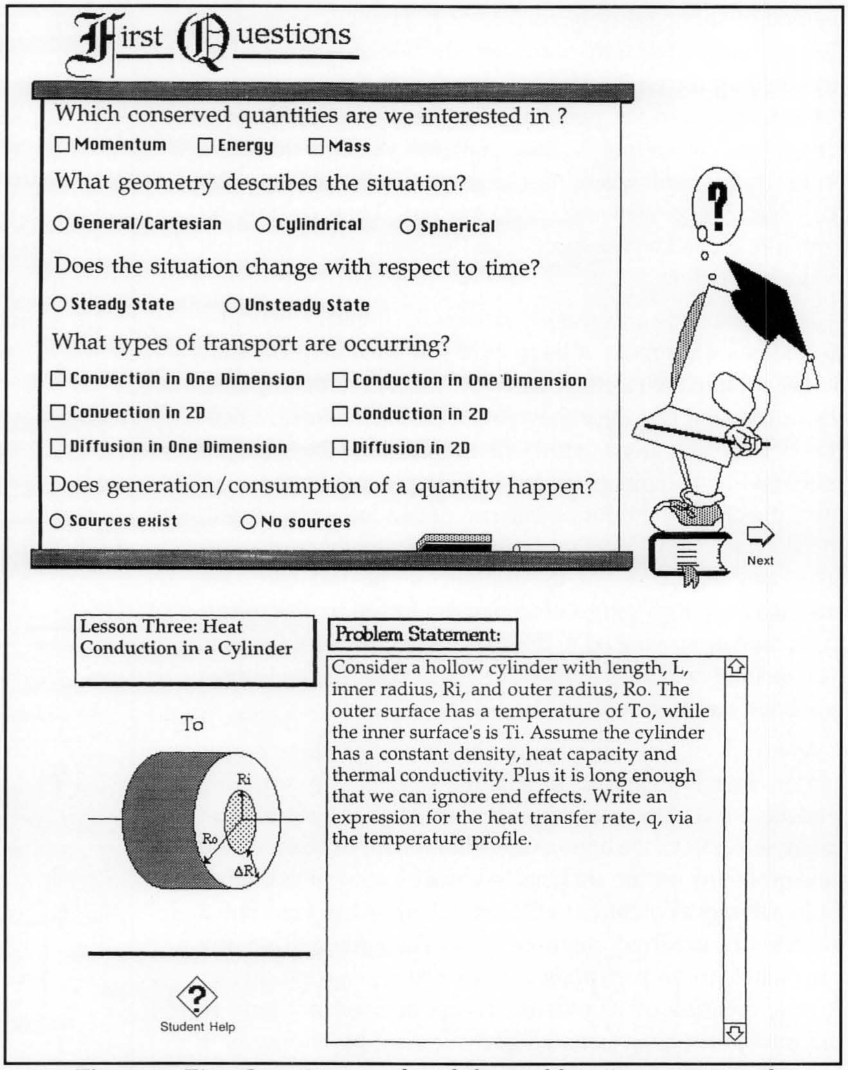

Figure 1. *First Questions card and the Problem Statement card (which remains open in the lower half of the screen along with all other cards).*

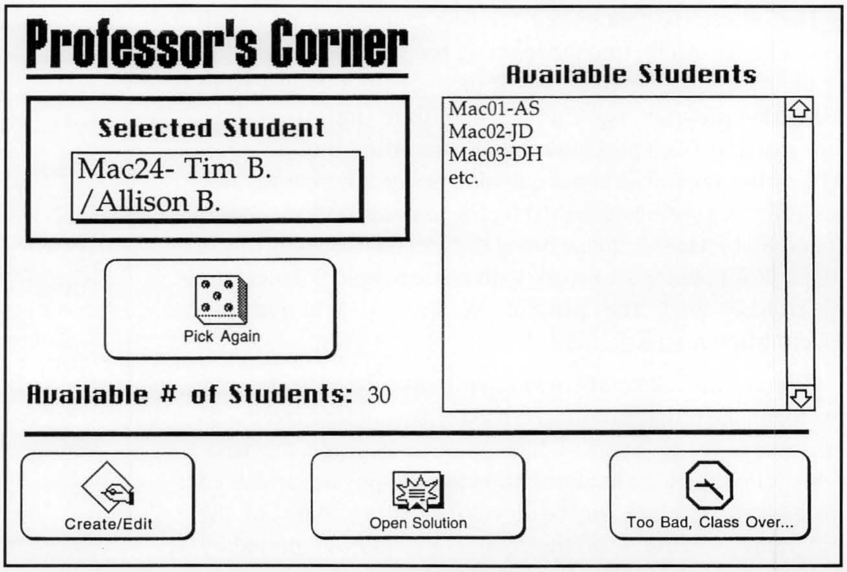

Figure 2. *The screen in the professor's computer podium.*

method of solving the equation (which they will attempt on the next card). Questions about the equation are answered by highlighting the circle next to each correct characteristic of the equation, and the boundary conditions are typed in on fence signs. When this card is completed, students can move on to the last card, where they attempt to solve the equation they have developed and characterized. They do this by typing in a chalkboard space with the same menu available to them as before.

These last two cards usually present the greatest difficulty to students since most of them have forgotten their calculus at this point in their college career. (Students somehow have the impression that once they pass a calculus course, calculus is over and done with!) In the case of the example problem, the technique needed is a simple integration. Figure 5 illustrates the solution in terms of two integrations with the corresponding integration constants, temperature profiles, and heat flux. At the bottom of the last card, the students have the options of saving the lesson to disk, printing it, and/or moving on to the next lesson. Most of the time the students save the lesson—thus, in a sense, the traditional notebook has been replaced by a disk.

As professor, several more options are available to me, as can be seen in Figure 2. In addition to randomly selecting students for review of their work as mentioned before, I can easily select from the options at the bottom of my card to add new problems for the students to work on as well as choose from a library of pictures to illustrate them. Also, I can pull a particularly involved solution up on the screen from my own stack to help explain it. Since the program allows for the creation of new cards, it can be used not only in the transport phenomena course but also, by adding new lessons, in similar courses.

SUMMARY OF A TWO-YEAR EXPERIENCE

The interactive features of the program permitted me to gain a better insight into the learning process than I could get in the traditional lecture. One of the benefits I gained from using this program was learning how little students assimilate material from previous courses into their present ones. My earlier comment about calculus is not a humorous one but reflects a well-established feeling among students. I also found that after solving so many differential balances it was difficult for students to work with macroscopic balances, in particular with the plug flow model, when using macrodifferential balances.

Clearly, there are many ways to improve the software. For example, the program could be used with standardized mathematical software such as Mathematica to graph the solutions. Obviously, animations showing the physics involved in a given problem can be developed using many of the programs available from the computer centers supported by federal programs. As software such as described here be-

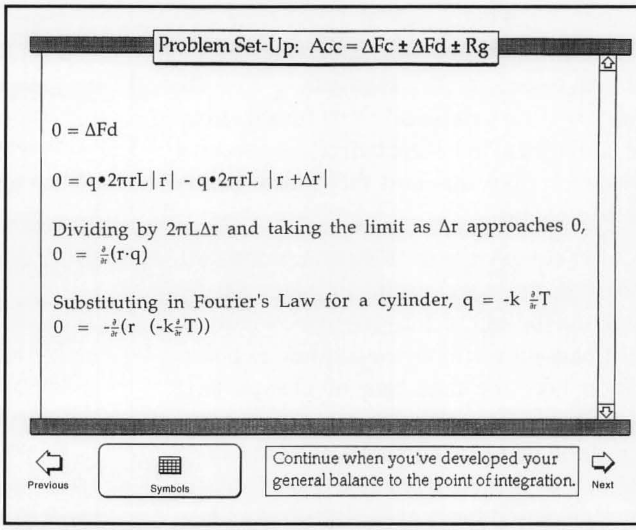

__Figure 3.__ Problem Set Up card, initially empty, showing how to set up the problem using shell balances.

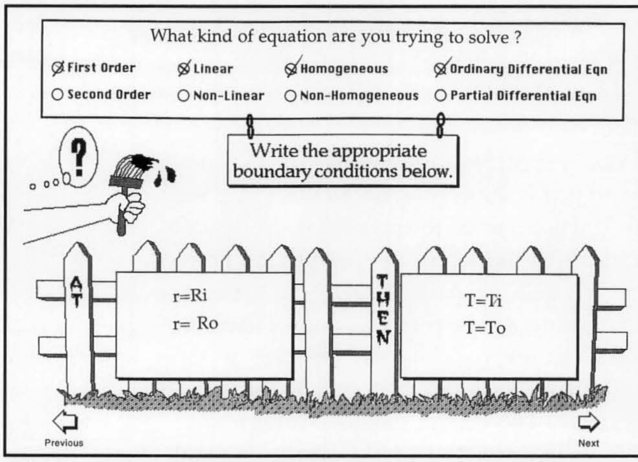

__Figure 4.__ Boundary Conditions card and classification of the type of equation to be solved.

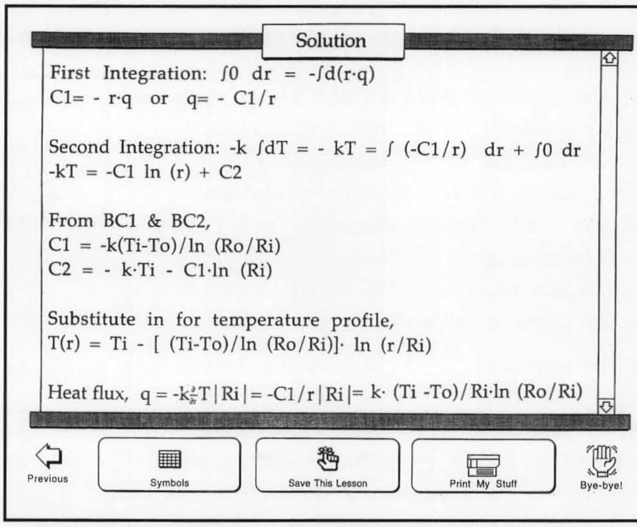

__Figure 5.__ Solution card, initially blank, showing the completed solution for the selected problem.

comes commercially available, more interactive features can be added (for example, a method for self-grading). Another alternative to the interactive mode is to include a short test as part of the software, with some sort of point system to evaluate the answers. This, however, would eliminate the direct interaction and make the presence of the professor less relevant. I still believe that direct interaction is the best experiential learning.

The first time I tried the program the class had fifty-five students, and every class was conducted in the computer lab. I was not able to cover all the material listed in Table 1 (in particular, the applications of macroscopic balances). Some of these examples are revisited in our Design I course, so I covered only the fundamentals. The second time around, the new class of seventy-two students could not be accommodated in a single session in the computer lab, so I divided the class into two sections. Each section attended the computer lab once a week for 75 minutes in addition to a 75-minute lecture for the entire class in a classroom where there was a podium computer to display my lectures. The interaction here was the traditional question-and-answer format. Several of the lessons which had been worked out previously during the tutorial were assigned as homework problems. This required that I volunteer 75 minutes of my time to teach the course.

Even though it takes more time to cover the material when using interactive software, it was an interesting experience. The interactive features motivated the class and provided an incentive for the students to get involved. Above all, it made teaching fun for me, and the majority of the class enjoyed it as well. In the computer lab I found I had to alert the students to the fact that class was over, instead of listening to the impatient rattle I would usually hear as the period drew to a close.

The first time the course was presented, most teaching evaluations were very positive, but there was a small group (about 4%) that did not like the software and strongly voiced their preference for the regular lecture. I suspect that for those unfamiliar with computers, the new format presented an extra burden of gaining computer literacy and this produced the negative reaction. The second time around when I combined the tutorial with the regular lectures in a 50-50 mix, there were no negative responses as to the use of computers in the classroom. This time I also posted the lectures ahead of time so the students would have copies available during class. I am still struggling with the question of whether or not to give students access to the solutions or let the class work them out. While computers can be wonderful tools when used conscientiously, they can also be expeditious copying machines, which defeats the purpose of experiential learning.

The method is not limited to chemical engineering but can also be applied to many different disciplines. During a week-end when the parents visited the university, I hosted an open house for them where I set up a riddle for them to solve. Everybody seems to have enjoyed the experience—even those who did not get the right answer. I also used videos to illustrate physical phenomena, such as boundary layer flow. This gave the students a visual experience that equations do not impart.

The method is still limited to situations where there are classrooms with networked computers. Undoubtedly, there will be more of these in the future, and software such as described in this paper will become commonplace. I envision a future when computers will be an active part of our teaching technology. We should continue to introduce the latest multimedia technology into the classroom to improve what I believe are less-than-effective teaching methods.

REFERENCES

1. Wankat, P.C., and F.S. Oreovicz, *Teaching Engineering,* McGraw-Hill, New York, NY, (1993)
2. Bird, R.B., W. E. Stewart, and E.N. Lightfoot, *Transport Phenomena,* John Wiley & Sons, New York, NY (1960)
3. Welty, J.R., C.E. Wicks, and R.E. Wilson, *Fundamentals of Momentum, Heat, and Mass Transfer,* 3rd ed., John Wiley & Sons, New York, NY (1984) ❐

ChE new books

The Physiology and Biochemistry of Prokaryotes, by White; Oxford University Press, 200 Madison Avenue, New York, NY 10016; 378 pages, $45 (1995)

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Introduction to Chemistry, 7th ed., by Dickson; Wiley, 605 Third Avenue, New York, NY 10158; $20.95 paper (1995)

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Laser Techniques in Chemistry, by Myers and Rizzo; Wiley, 605 Third Avenue, New York, NY 10158; 429 pages, $125 (1995)

Encyclopedia of Chemical Technology: Lasers to Mass Spectrometry, 4th ed., Kirk-Othmer; Wiley, 605 Third Avenue, New York, NY 10158; 1094 pages, $295 (1995)

Advances in Photochemistry, Vol. 20, by Neckers, Volman, and Bunau; Wiley, 605 Third Avenue, New York, NY 10158; 301 pages, $95 (1995)

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Ketenes, by Tidwell; Wiley, 605 Third Avenue, New York, NY 10158; 665 pages, $69.95 (1995)

Conformational Theory of Large Molecules: The Rotational Isomeric State Model in Macromolecular Systems, by Mattice and Suter; Wiley, 605 Third Avenue, New York, NY 10158; 448 pages, $54.95 (1994)

Interfacial Transport Processes and Rheology, by Edwards, Brenner and Wasan; Butterworth's, (1991)