CHEMICAL ENGINEERING EDUCATION AND THE THREE C's: COMPUTING, COMMUNICATION, AND COLLABORATION

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ABSTRACT

As we enter the 21st century, it is clear that chemical engineering education will be profoundly influenced by the Information Age. The three R's that were the basis for education in the beginning of the 20th century will be replaced by the three C's arising out of information technology: computing, communication, and collaboration. Within chemical engineering education computing is well-established in every course in the curriculum but there is considerable potential for growth and enhancement. The present trends toward greater user interaction and visualization will continue, and tools like simulation will grow in importance, lessening the typical user's need to know about the underlying numerics. The use of digital communication will automate laboratory experiences and make them more productive. Communication tools such as digital libraries and Internet 2 will also greatly enhance the student and faculty experiences. Collaboration will become more palpable in changing current modes of instruction and research. The use of multimedia will transform both classrooms and content presentation and can enhance the learning experience of all students.

Introduction

The transformation from the Industrial Age to the Information Age is having a profound impact on both industry and academia. Universities have moved to networked environments that permit faculty, staff, and students to have access to the World Wide Web anytime and anywhere. Many faculty are beginning to use information technology (IT) to enhance the collaborative component of education, with an increased focus on the learning process. They will share courses over the Internet, access digital libraries, write electronic books, and perhaps even form a virtual chemical engineering department using digital shared content from multiple departments. We have already seen the formation of networks of faculty, who share research ideas and data over the Internet on a daily or hourly basis (a virtual collaboratory).

The expectations and needs of incoming students for digital facilities and curricula are being shaped by a world of pervasive microprocessors and telecommunications in their lives. They are equally comfortable talking on a cell phone or using asynchronous communication by chat or e-mail. Their entertainment is found on the world-wide web, e.g., music is provided by sharing of computer files (cf. Napster). The new digital generation is not intimidated by computers, demands interaction, views learning as a plug and play experience, won't read a manual but learns through experimentation, expects well-designed user interfaces, and may not learn best through the linear seriatim process. Given the current students in universities and the expanding capabilities of informative technology, the role of the computer in engineering is expanding from simply computing to include communication and collaboration (the three C's).

2.0 Computing in Chemical Engineering Education

The capacity of computing hardware has improved by orders or magnitude over the past forty years evolving from mainframes to today's multifunctional personal computer/workstation. These striking developments have occurred while cycle costs have been greatly reduced, and the computer has become a ubiquitous tool for increased productivity in engineering practice. Prior to the mid-1980s, the lack of professional software and inexpensive computing equipment limited computing experiences for undergraduate engineers, but no such constraints exist today. Historically the use of computing in the curriculum has focused mainly on a single course: numerical analysis. Starting in the 1990s, commercial simulators such as ASPEN, PRO-II, CHEMCAD, and HYSIM were widely adopted in universities via educational discounts, aided by user-friendly interfaces (front-ends) and PC-based software packages. The use of computer-aided simulation in the capstone senior design course can certainly be characterized as a major success story in the education of chemical engineers. However, the ubiquitous nature of PCs on university campuses has not yet caused a quantum change in the way computing is taught or applied in the typical chemical engineering department, nor is the use of computing pervasive throughout the curriculum in a typical department.

In courses such as thermodynamics, transport phenomena, unit operations, separations, and reactor design, there is still only a modest level of computation at many universities. Certainly in the thermodynamics and separations area, there is a lot to be gained by introducing simulation packages and molecular modeling subroutines. Sandler's latest edition on thermodynamics has a set of computer disks including equations of state and connections to TK Solver. Reactor design is a particularly interesting case, in that powerful numerical solution methods for reactor design, ordinary and partial differential equations, and parameter estimation for these systems have not been utilized in most textbook presentations. However, the most recent edition of the leading textbook in reactor design by Scott Fogler has introduced interactive computer exercises for demonstration of important concepts, and utilizes Polymath for reactor simulation. Another reactor textbook forthcoming by John Ekerdt and Jim Rawlings makes extensive use of numerical analysis via Octave. Both Polymath (www.cache.org) and Octave (www.che.wisc.edu/octave) were developed by chemical engineering educators but have applicability outside of this field.

Some courses in chemical engineering, such as process control and optimization, are computer-intensive by their very nature, and there are quite a few professional PC-based software packages that are available for student use, sometimes via the world wide web. Today packages such as GAMS offer easy-to-use interfaces to combine algebraic modeling procedures with optimization to solve almost any linear or nonlinear programming problem (including integer variables) of reasonable size. Many of the major libraries of mathematical software include individual callable routines for most variations of numerical analysis and optimization. The NAG Fortran Library (available as a toolbox of MATLAB) contains routines which perform such tasks as equation solving, unconstrained optimization, and various linear algebra operations.

In the 1980's a major move away from FORTRAN and C optimization began as optimizers, first LP solvers and then NLP solvers were interfaced to spreadsheet systems for desktop computers. The spreadsheet has become a popular user interface for entering and manipulating numeric data. Spreadsheet vendors are increasingly incorporating analytic tools accessible from the spreadsheet interface that permit access to external databases. Examples include statistical packages, optimizers, and equation solvers.

Microsoft Excel incorporates the routine, SOLVER, which operates on the values and formulas of a spreadsheet model. Current versions (4.0 and later) include an LP solver and mixed integer programming (MIP) capability for both linear and nonlinear problems. The user specifies a set of cell addresses to be independently adjusted (the decision variables), a set of formula cells whose values are to be constrained (the constraints), and a formula cell designated as the optimization objective. The solver uses the spreadsheet interpreter to evaluate the constraint and objective functions, and differences those computations to generate derivatives. The NLP solution engine for the Excel solver is GRG2.

Process control courses have adopted a defacto standard of MATLAB for dynamic simulation and controller design (www.mathworks.com). MATLAB is augmented with a large number of specialized toolboxes, many of which originated from academic software developed by faculty and graduate students (e.g., model predictive control toolbox). Graphical presentation of results makes these packages useful for iterative design and analysis, and graphical user interfaces such as SIMULINK make solving closed-loop analysis problems much easier than using either transfer function or state space equation formats. So far the only textbook with extensive use of MATLAB-based homework problems is by Tom Marlin, although it is planned for the next edition of Seborg, Edgar, and Mellichamp.

What about the needed computing skills in the undergraduate curriculum in the future? The focus should be on what kinds of experiences and computer-enhanced problem-solving abilities chemical engineers must have when they graduate. B.S. Ch.E graduates should:

1. Know how to use a modern technical library to search for information located in electronic databases, and how to access electronic information services through the World Wide Web.

2. Understand the implementation of elementary algorithms for the numerical solution of engineering problems. These algorithms should include algebraic and differential equation solving, linear algebra, and optimization.

3. Be able to solve more sophisticated engineering problems using appropriate applications software. The types of problems include material and energy balances, optimization problems with constraints, and statistical data analysis.

4. Be familiar with software for computer-aided process design and analysis.

5. Have experience with computer-based instrumentation, process control, data collection, and analysis.

How should this material be taught? Courses should teach how to implement elementary algorithms for problem-solving. The most useful tools are numerically oriented and allow students to explore the use of different algorithms, problem formulation, and means to visualize the results. Note that programming language expertise is not included in the above list. There are several excellent higher-level language alternatives for numerical analysis as a required course, including MATLAB, Mathematica, and Maple. These tools allow one to script solution algorithms very efficiently, and include excellent visualization and problem-solving toolboxes. Using such metacomputing tools allows omitting FORTRAN as a required course from the undergraduate curriculum in favor of these alternatives.

Ideally, students would enhance their computer-based problem-solving skills continually as they pass through the standard curriculum. Thermodynamics, fluid mechanics, and heat and mass transfer allow many opportunities for students to solve problems involving algebraic equations, integration, data regression, and challenges in visualizing solutions. Reaction engineering process design and process control and design courses offer opportunities for dynamic simulation of realistic models.

3.0 Communications

The digital science and information revolution is rapidly transforming the ways faculty and students collaborate, solve problems, and disseminate knowledge. The integration of computers, telecommunications, audio, video, multimedia, and other digital technologies creates a worldwide information environment that can be accessed easily from the laboratory, office, field, and home. While it is difficult to perform experimental research at a distance, sharing of expensive specialized equipment through virtual connections will become more common in the future. Faculty in the future will rely more heavily on computational and visualization tools, with relatively less investment in equipment and laboratory facilities. Experimentation is relatively more expensive to perform with today's stringent safety requirements. Most faculty will need to stay up to date in some aspects of IT in order to carry out cutting-edge research, which may impact the types of faculty hired by chemical engineering departments.

Most U.S. universities are now members of Internet 2, which provides high bandwidth capabilities (over 100 times as fast as today's commodity Internet) for faculty communication and distance education. This includes, for example, digital libraries with audio and video content, collaboration and immersion environments, remote monitoring of experiments, and data-intensive applications (see www.internet2.edu).

4.0 Collaboration

Collaborative tools now allow researchers throughout the world to share results regularly, on a daily or even hourly basis via informal collaboratories. This of course can be expanded to educational materials, where faculty can share software and educational content over the world wide web, thus mitigating the "not invented here" mentality that is common in most universities. One attempt to foster such cooperation in chemical engineering education is the new web site www. cache.org, sponsored by the CACHE Corporation.

Electronic publishing and the gradual replacement of paper-based modes for carrying out the business of higher education will certainly impact chemical engineering education in the future. We have seen the first wave of construction of digital libraries; both the American Chemical Society and Elsevier are being fairly aggressive in moving toward complete digitization of scientific and engineering journals, while AIChE has proceeded more cautiously. Clearly both faculty and students find having access to the text of journal articles and other digital content on one's desktop to be a tremendous productivity tool.

Electronic books may eventually replace part of the traditional book publishing market. The high cost of textbooks and the collective weight of five books in a backpack are certainly incentives for students to use electronic media in the future. Computer companies are developing devices that feel like a book but permit downloading of material from the web.

Significant progress in changing the paradigm of textbook publishing may occur over the next five to ten years, where the contents of a book would be entirely on-line. This would be advantageous for incorporating interactive exercises based on simulation in an integrated way, converting the traditional textbook into courseware that is much more comprehensive than the hard copy versions used today. This would allow faculty to selectively incorporate parts of books into their courses. Perhaps the best example of an electronic book combined with a distance education course in chemical engineering has been developed by Scott Fogler (see http://www.umich.edu/~cre/ .   Another electronic textbook under development that bears watching is on molecular modeling (see http://flory.utk.edu).

Collaborative Approaches to Teaching and Learning

Collaborative learning environments can be active agents that interact with students, expand the information horizons of students, and enable effective interactions across both time and distance. Use of such systems in teaching and learning is growing rapidly. In such environments a computer presents and combines text, graphics, audio and video (multimedia), with links and tools that let the user navigate, interact, create and communicate. This technology can interact with students in new ways, e.g., to give students experiences through simulations of logical and physical systems.

Excellent teachers use varying lecture styles that actively engage students in the learning process. Information technology also allows a pure lecturing format to be supplemented or in some cases replaced by an integrated lecture/laboratory situation. In this mode the instructional material is presented on the computer with the conceptual elements explained and supplemented by the instructor's lecture. At the end of the presentation, a laboratory exercise is executed on the computer under the supervision of the instructor to give experience in application of the concepts or processes (see www.center.rpi.edu/PewGrant.html for examples). The interactive mode of intermingled lecture and laboratory has a very high reinforcement value. The computer system is used to mediate the rate at which information is presented to each individual student.

In the so-called "studio" approach, the lecturer can move among the students, looking over their shoulders and serving as an advisor and facilitator. Teaching and learning becomes more a one-on-one or small group exercise and less a remote lecture exercise. The instructor thus is transformed from being a "sage on a stage" to a "guide on the side". This integrated lecture/laboratory mode of instruction is now being used in industrial training, particularly in the software industry. Learning and cognitive studies have shown definitively that personalized learning via immediate feedback has a significant impact on retention.

An extension to the use of technology in the discussion is distance education, which is the combination of technology-based education with technology-based delivery of a complete course. Distance education has been defined as any formal approach to learning in which a majority of the instruction occurs while educator and learner are at a distance from one another. Anyone who has listened to a Pavarotti CD but never heard the great tenor in person has certainly received a certain level of enjoyment (and perhaps inspiration) from this great singer, even though the interaction is not face-to-face.

Distance education appears to be a good fit for continuing education, where highly motivated, mature students make sure they learn what is needed. Having such classes offered at a convenient time and place (asynchronous mode) is critical for professionals with full-time jobs, who need to update their skills and knowledge base in response to changes in the economy. The availability of streaming media technology (audio and video) over the Internet eventually will make delivery of courses to personal desktop computers an economic reality. The faculty member's office then becomes the studio, which will make educational delivery at lower cost than with the interactive television mode currently employed at many universities. This may suggest the merging of this approach with the traditional classroom, leading to hybrid lecture/distance education courses.