COMPUTING SKILLS IN THE CHEMICAL ENGINEERING CURRICULUM

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Abstract

The practice of chemical engineering has become strongly dependent on computing, but with the exception of courses in design and control, the chemical engineering curriculum generally does not utilize computer-based methods in order to enhance students' problem-solving skills. One reason is that popular textbooks tend not to be computer-oriented. Previous efforts by CACHE in 1985 to influence accreditation guidelines for computing skills in chemical engineering have been valuable, as have various projects aimed at making computer tools available throughout the curriculum. It is time to re-evaluate the list of preferred computer skills for chemical engineers, and to integrate computer-enhanced problem-solving skills throughout the curriculum. We propose de-emphasizing computer programming language skills (such as FORTRAN) in favor of using professional software packages based on higher level languages such as Matlab.

Introduction

There is no doubt that the revolution in computing and information technology during the past 40 years has changed the industrial world. In contrast, the typical engineering educator, rather than being on the cutting edge of those developments, has been slow to incorporate new computer-based ideas in curriculum, teaching methodologies, and educational materials. With a few notable exceptions, mainly in the area of process systems engineering, computing and information technologies have not had a major impact on the chemical engineering canon. Word processors and spreadsheets are used to prepare lab reports, but there has not been a substantial shift in the core curriculum. At most institutions, thermodynamics is not taught any differently than it was 30 years ago. If computers are so important, why is Bird, Stewart and Lightfoot, now in its fourth decade, still the model for teaching transport phenomena? It is apparent that in the eyes of a large number of faculty the investment made by students in learning computer languages and programming does not yield any discernible advantage in the training of chemical engineers. The questions of how extensively computers should be used and which computing skills should be taught in the undergraduate chemical engineering curriculum are difficult to answer for several reasons:

- There is no generally agreed upon ‘core’ set of computing skills necessary for being a productive engineer, either in academia or in industry.
- The availability of professional software now makes many engineering tasks, including computer programming, simple to carry out.
- Providing and maintaining a state-of-the-art facility for engineering computation is expensive, in terms of both capital and human resources.
- Development of high quality computer-based lessons is quite costly in terms of faculty and staff time.

This chapter discusses these points in the context of the historical evolution of computer usage in chemical engineering. Key influences include chemical engineering textbooks, computing aids disseminated by the CACHE Corporation, industrial practices, several prior reports produced by the CACHE Corporation, and the ABET-AIChE accreditation criteria. Unfortunately, the current ABET-AIChE criteria provide only general guidance, and there is a significant mismatch between the traditional academic view of computing and the needs articulated by practicing engineers.

After analyzing the state of affairs in computer-based education, we suggest some strategies for outfitting graduating engineers with practical, computer-enhanced problem-solving skills. These strategies de-emphasize the mechanics of computer use and the traditional reliance on scientific programming languages such as FORTRAN in favor of integrating higher-level, mathematically-oriented software systems into the curriculum.

Evolution of Computing Skills Since 1960

The capability of computing hardware has improved by orders of magnitude over the past forty years (Seader, 1989), evolving from mainframes to today’s multifunctional personal computer/workstation. These striking developments have occurred while cycle costs were actually reduced, and the computer has become an omnipresent 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. However, the ubiquitous nature of PCs on university campuses has not caused a quantum change in the way computing is taught or applied in the typical chemical engineering department. In fact, instead of computing practices influencing the way textbooks are written, the opposite effect seems to have occurred, namely popular textbooks have dictated the computing activities (or the lack thereof) in a given course.

The solution of chemical engineering problems in the 1950s and 1960s was limited to graphical techniques or manual manipulation of a few algebraic equations, often solved by trial and error. Very little matrix analysis was employed, except perhaps the crude solution of linear equations by determinants. Ordinary differential equations (almost always initial value problems) were solved by analytical or graphical integration. The textbook by Hougen, Watson, and Ragatz (1943) was exemplary of this approach. It is important to realize that the inertia brought on by the use of popular textbooks over as long as twenty years without revision has the tendency to stultify teaching practices and limit innovations in areas such as computing. For example, the books by Hougen et al. (1943); Bird, Stewart and Lightfoot (1960); McCabe, Smith and Harriott (1993); Levenspiel (1962); and Coughanowr and Koppel (1965) are texts that dominated various core courses in sophomore through senior years for long periods of time. The publication of a new undergraduate textbook in chemical engineering during the 1990s has become a relatively rare occasion, and factors that could encourage more textbook writing, such as direct encouragement from university administration or less emphasis on research, are unlikely to change during the rest of this century.

The first chemical engineering textbooks with strong ties to computer applications were the numerical analysis books by Lapidus (1962) and Carnahan et al. (1969). These books served as important bridges between the developments in other engineering disciplines, mathematics, computer science, and chemical engineering. However, they probably were perceived in the 1960s and 1970s as research-oriented texts rather than serving a standard undergraduate course in chemical engineering. Today about half of the U.S. chemical engineering departments teach their own numerical analysis course with specific chemical engineering applications, while the other half utilize a course outside the department. The choice is usually determined by the size of the department, with larger departments customizing their own course.

While a few innovative educators introduced some applications of numerical analysis into core courses, a fragmented state of affairs still existed in the early 1970s. In order to provide some assistance to faculty who wanted to share computer software for specific courses, the CACHE Committee, with financial support by the National Science Foundation, published a seven-volume set of books entitled *Computer Programs for Chemical Engineering Education*. These volumes were distributed to all departments in the U.S. and Canada and covered the curriculum areas of stoichiometry, kinetics, control, transport phenomena, thermodynamics, design, and stagewise computations. Included were 97 debugged and tested FORTRAN programs written by a large group of chemical engineering educators. It is interesting to note that even in the late 1980s, these books were still being distributed, although usually outside the United States.

The next large push in the area of computer applications was in the area of design, led again by the CACHE group. In the early 1970s, process simulation programs for computer-aided design of continuous steady-state vapor-liquid and liquid-liquid processes were beginning to be used at a number of companies. With built-in libraries of subroutines for equipment and thermodynamic property models and techniques for converging iterative computations when nonlinear equations and/or recycle loops were involved, these so-called flowsheeting programs performed material and energy balance calculations and, in some cases, sized and determined the cost of equipment. Before using the program, the user was required to develop a flowsheet and a set of design specifications. In 1974, the FLOWTRAN simulator of Monsanto, consisting of 160 subroutines and 60,000 lines of FORTRAN code and data, was made available through CACHE for educational use by departments of chemical engineering via a national computer network. Subsequently FLOWTRAN modules for different mainframe computers and workstations became available, thus reducing the cost of utilization for most universities. During the past 20 years FLOWTRAN has been employed mainly in senior design courses, with 190 tapes of the code disseminated to departments (141 in the United States). Sales of the FLOWTRAN textbook (Seader, Seider and Pauls, 1974) totaled 15,000 during that same period. In the late

1970s it became generally accepted in academic circles that the senior design experience should be computer-intensive. More recently, commercial simulators such as ASPEN, DESIGN II, PROCESS, CHEMCAD, and HYSIM also became readily available to universities for a modest fee. User-friendly interfaces (front-ends) and PC-based simulators have eliminated many of the barriers to using such 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, integration of computing skills throughout the curriculum (from the sophomore year to the senior capstone design course) was rarely done in 1970s and 1980s. In fact, attempts to introduce a high level of computing in the sophomore material and energy balance course did not receive general acceptance at all. In 1969, the first published textbook to treat stoichiometry using digital computation was authored by Henley and Rosen (1969). Although manual methods were also included, the emphasis was on machine methods. Particular attention was paid to techniques for solving systems of nonlinear equations and converging recycle loops. The book appeared before most educators felt comfortable with numerical methods for digital computers, hence it never received widespread adoption. More recently, a similar fate befell the textbook by Reklaitis (1983). While it is now feasible to introduce some form of flowsheet simulation in this course, apparently very few educators use such software.

Similarly, in courses such as thermodynamics, transport phenomena, unit operations, separations, and reactor design, there is still only a modest level of computation in each of these courses at most universities. Certainly in the thermodynamics and separations area, there is a lot to be gained by introducing simulation packages and VLE subroutines. Sandler's second edition (1989) text on thermodynamics does have 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 textbook presentations. The current leading textbook in reactor design (Fogler, 1986) has introduced interactive computer exercises for demonstration of important concepts, but reactor simulation is not emphasized.

CACHE recognized the need to stimulate more activity outside design and control; in 1990 CACHE published a set of six chemical engineering lessons, which exploited the powerful features of the IBM PC. Written by six well-known educators and their students, these lessons covered the areas of fluid mechanics, thermodynamics, reactor engineering, and separations. The lessons were distributed to 100 departments of chemical engineering with unlimited copying privileges. This effort has been continued up to the present time by NSF grants at the University of Michigan, Purdue University, and the University of Washington, in cooperation with CACHE.

Some courses in chemical engineering, such as process control and optimization, are computer-intensive by their nature, and there are quite a few professional (and semi-professional) software packages that are available for student use. It has only been since the mid-1980s that user-friendly efficient computer codes (often PC-based) have become available for optimization, as reviewed by Edgar and Himmelblau (1988). Today packages such as LINDO, GINO, and GAMS offer easy-to-use interfaces to solve almost any linear or nonlinear programming problem of reasonable size. Similarly in the process control field, packages such as CC, Matrix-X, and Matlab make dynamic open and closed-loop simulation quite easy to perform. Unfortunately, none of the commonly used textbooks (Seborg, Edgar and Mellichamp, 1989; Smith and Corripio, 1985; and Stephanopoulos, 1984) present homework problems using such general purpose software.

Position Papers on Computing Skills

In 1985, the CACHE corporation recognized the tremendous lack of uniformity in computing experiences across the U.S. and authored a position paper specifying a particular set of computing competencies that all chemical engineering graduates should possess. This was the first effort in chemical engineering to influence training of undergraduates *vis-a-vis* computing skills. The main recommendations from the body of the report are as follows:

1. The chemical engineering graduate must be familiar with at least one operating system for personal and mainframe computers. This implies ability to manipulate files, perform text editing, and develop graphic displays.
2. The chemical engineering graduate must be competent in the use of at least one scientific programming language, i.e. have a sufficient understanding of programming logic to test and adapt programs written by others. In addition, he or she should be able to evaluate programs written by others in order to perform software selection.
3. The chemical engineering graduate must have experience in the computer-aided acquisition and processing of information.
4. It is desirable for each student to conduct at least one search using information retrieval from electronic data bases such as Chemical Abstracts Service and Scientific Information Systems.
5. It is desirable for the chemical engineering graduate to have experience in the use of word processors and graphics programs as well as spreadsheets for the generation of reports.
6. Although it is too early to require that all graduates have experience with electronic mail and external data bases, such a requirement should be feasible in the next 2-5 years.
7. It would be desirable for the student to have an appreciation of principles of numerical analysis (including convergence and stability) and non-numeric programming (such as used in artificial intelligence).

The CACHE position paper had a direct impact on accreditation requirements in chemical engineering, as discussed in the next section.

About the time the CACHE position paper was issued, a study on changes in the curriculum of chemical engineering was published by the Septenary Committee at the University of Texas. This committee, composed of industrial leaders from a wide variety of companies which employ chemical engineers, made extensive recommendations on how the teaching of chemical engineering should be changed so that the B.S. chemical engineer is better prepared for the competitive environment in today's (1985) workplace. It is interesting that they reached many of the same conclusions as did CACHE. Additional recommendations beyond those proposed by CACHE included:

8. All courses involving calculations should make extensive use of the computer and the latest software. Application should be frequent as students progress in the curriculum. Clearly, adequate computer hardware and software must be freely available to the student either through superior centralized facilities, individual PC's, or both. Extensive development of professionally written software for chemical engineering should be pursued.
9. A great deal of time can be saved in addressing designed equipment such as reactors, fractionators, and absorbers by emphasizing rigorous computer calculations and the simplest shortcut procedures. Valid shortcut methods require a solid conceptual base that assists in developing an intuitive feel for a problem. However, most intermediate (manual) calculation procedures should be eliminated unless they have real conceptual value. Existing software for algebraic and differential equation solving make simulations and design calculations quite straightforward.
10. Laboratory reports should use word processing when possible, and graphical presentation of data should be emphasized, using computers with modern graphics capabilities.
11. Some hands-on experience using current practices of computer data acquisition and control with industrial-type consoles should also be encouraged.
12. In the design course in engineering, students learn the techniques of complex problem-solving and decision-making within a framework of economic analysis. The very nature of processes requires a systems approach, and the ability to analyze a total system is one of the desirable attributes of chemical engineers. Rigorous economic analysis and predictive efforts should be required in all decision processes, given the availability of modern simulation tools.

Current Accreditation Requirements

Other engineering fields were addressing the need for computer skills in roughly the same time frame as chemical engineering, described in the previous section. The Accreditation Board for Engineering and Technology (ABET) is responsible for the accreditation of engineering programs in the United States and publishes general criteria for accreditation (1993). The current ABET position on computing skills in engineering curricula was proposed in the mid-1980s (new criteria will be in place in the near future):

> "Appropriate computer-based experience must be included in the program of each student. Students must demonstrate knowledge of the application and use of digital computational techniques for specific engineering problems. The program should include, for example, the use of computers for technical calculations, problem solving, data acquisition and processing, process control, computer-assisted design, computer graphics, and other functions and applications appropriate to the engineering discipline. Access to computational facilities must be sufficient to permit students and faculty to integrate computer work

into coursework whenever appropriate throughout the academic program."

A later section of the same document offers additional specific criteria developed by AIChE for chemical engineering programs, which was largely influenced by the 1985 CACHE statement presented earlier. The part discussing computing skills for chemical engineers is as follows:

> "Computer Use. Appropriate use of computers must be integrated throughout the program. Acceptable computer use will include most of the following: (1) programming in a high-level language; (2) use of software packages for analysis and design; (3) use of appropriate utilities such as editors; (4) simulation of engineering problems."

A more recent addition is that students must be exposed to the use of statistics in data analysis and problem solving.

ABET has encouraged a broader view of design to include more open-ended problems throughout the curriculum, rather than concentrating these kinds of problems in the capstone design course only. This view suggests that computer-based interactive problem solving can be employed to explore various options and alternative solutions for a given problem. For example, in the calculation of pressure drop in a pipeline, one can explore the effect of pipe diameter on velocity and pressure drop by use of the computer and also evaluate the operating costs of pumping vs. pipe capital costs. The personal computer or workstation has become an effective device for exposing students to open-ended problems.

Discussion

The general engineering accreditation statement on computing seems reasonable and consistent with what chemical engineers appear to be doing on the job. The criteria focus on what is done with computers rather than on the tools used to accomplish the task. However, because the criteria are so general, they do not offer a lot of guidance other than to give some examples of routine engineering activities.

The second passage relevant to chemical engineering has a somewhat different character. Items 1 and 2 presumably address the use of a language like FORTRAN for routine computation; however, recent CACHE surveys (discussed later in this paper) have shown that FORTRAN programming is not a critical skill for engineering practice. Items 3 and 4 are rather vague, but could be interpreted to include the spreadsheet analysis of process flowsheets, or the use of process flowsheet simulators.

Some of the items discussed in the 1985 CACHE position paper have lost their significance in the face of wide-spread adoption of computing technology on campuses. For example, E-mail has gone from the exotic to mundane in less than ten years. Specifying that students should know how to use word processors and email today is akin to asking students to learn to use the telephone or copy machine. Students accomplish these things on their own for very practical and immediate needs. Learning to use these tools well is another matter, and, to this end, there is no substitute for critical evaluation by faculty. Nevertheless, items 5 and 6 of the 1985 CACHE recommendations are probably no longer necessary.

On many campuses, libraries are providing an increasing number of electronic services for all of their patrons. For example, electronic bibliographic services are now incorporated as part of the electronic card catalog. Similar services are now available through the Internet.

Clearly, engineers must learn how to access information, and that now implies electronic access and database searching. If we insist that students learn how to use the library and reference materials, there may no longer be a need to specify a specific computing competency in electronic data access. Rather, we can assume that student will learns (or figure out) the relevant computing techniques as they learn to use a modern technical library.

Of the seven computing competencies proposed by CACHE, the first three probably take care of themselves in the normal course of a rigorous undergraduate education. While they are important professional engineering skills, there is not immediate need today to list them separately as desired computing competencies.

The remaining items concern more specific skills traditionally associated with scientific computing, and retain much of their significance. However, these items must be interpreted in terms of current computing technology. For example, on most campuses and at an increasing number of companies, the traditional mainframe has given way to a distributed model for computation. For routine work, most users have access to a graphical user interface (GUI) that simplifies routine tasks. Nevertheless, engineering users must have a sound understanding of how to set up and structure their files and directories, and how to access resources distributed over a network.

In a similar vein, there has been much change in what is meant by a scientific programming language. The authors primarily had FORTRAN in mind when item 2 was formulated. A 1993 CACHE survey discussed in the next section has shown that FORTRAN and other comparable general-purpose programming languages such as C and Pascal are not often used by most engineers once they are on the job. While it is still true that FORTRAN and mathematical subroutine libraries are very important for numerically intensive work, the use of FORTRAN for more routine uses has been supplanted by general purpose applications software.

Spreadsheets are now pervasive in engineering use. The newer commercial spreadsheets are easy to use, allow the user to easily document the results, and offer sophisticated equation solving and optimization functions. Spreadsheets should be viewed as a very useful item in the engineer's toolbox.

Current Use of Computers by Practicing Engineers

In 1993, CACHE sponsored a survey on the use of computing by engineers in the process industries (Davis, Blau and Reklaitis, 1993). Engineering management and recent B. S. chemical engineering graduates were surveyed at four major companies. The recent graduates were primarily in technical positions (83%) and in their jobs for less than five years (75%). Their managers typically had over 15 years experience (75%) with job descriptions that included technical management (76%). An additional survey was conducted of instructors at a number of universities. A total of 367 responses were obtained from these three groups. One of the goals of the survey was to compare the perceptions of the three groups regarding computer usage.

Among the results, the surveys of engineering management and recent graduates found that most of the engineers average 20-40% of their time at the computer, and another third spend 40-60% of their time at the computer. Academics significantly underestimated this level of usage, estimating that 70% of practicing engineers would spend 20% or less of their time at the computer. These statistics are a remarkable indication of how the computer has become a central feature of the technical workplace.

What tools do chemical engineers use when working at their computers? The surveys found that large fractions of the recent graduates make frequent use of spreadsheets (74%), presentation graphics (80%), database systems (70%), and electronic communications (89%). Managers and academic instructors heavily underestimated this pattern of computer use among recent graduates.

How do engineers use these tools? The recent graduates said their primary use of spreadsheets was for data analysis (75%), material balances (40%), economic studies (25%), and numerical analysis (24%). Databases were used for access to project information and process data. The use of computers to prepare reports and technical documentation was acknowledged by virtually everyone.

The surveys also revealed some tools that recent graduates do not use. Most (92%) say they never or seldom program in FORTRAN or another computer language. The overwhelming majority (85%) say they never use numerical method libraries such as IMSL or mathematical packages (86%).When asked if their company expected them to be literate in different computer language paradigms, 86% of the recent graduates said no. In fact, many companies explicitly tell their engineers *not* to write software because of the difficulty of maintaining such programs written by individuals.

Some rather obvious conclusions can be drawn from these survey results. Foremost is the simple observation that the set of tools chemical engineers use to do their jobs has changed significantly over last few decades. FORTRAN, compilers, and subroutine libraries have given way to spreadsheets, databases, and professionally prepared applications software. These tools are used to perform traditional engineering tasks, such as flowsheet analysis and data manipulation.

Beyond the traditional engineering tasks of quantitative analysis, computers have become a key tool for report writing, data access, and electronic communications. Because the computer is used for so many functions, many engineers are spending a significant amount of their time working at their machines.

Computer Skills for the Next Decade

When CACHE was formed twenty-five years ago, computers were expensive resources that were accessible on a relatively limited basis. Users had to be efficient, and they only had a limited set of tools to accomplish their tasks. That picture has changed dramatically. Computers are now ubiquitous and cheap, and there is a rich set of tools for doing routine tasks. Since computers are used for so many things, we can assume that students will learn on their own the routine skills of word processing, electronic mail, and file management.

What can we say about the needed computing skills in the undergraduate curriculum, both now and in the next century? We believe the ten-year old statement on computing skills is now off the mark. The focus should now be on what kinds of experiences and computer-enhanced problem-solving abilities chemical engineers must have when they graduate. The list below is not radically different from the previous position papers, and perhaps illustrates that changes in academia come about with great difficulty and on a time scale approaching glacial phenomena. Graduating engineers 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.

The difficulty comes when trying to reduce these general principles to practice. Some of these items can be incorporated into the standard chemical engineering canon. For example, a modern unit operations laboratory would likely have at least several pieces of equipment with computer-based instrumentation, and perhaps a process control experiment. The last item above could be addressed in this framework. Similarly, the items regarding information access and computer-aided design could be integrated as part of traditional process design course, or even introduced into the sophomore level course on material and energy balances.

The items regarding problem-solving are more difficult to integrate into the curriculum without students first having some sort of systematic introduction. Clearly there is mathematical component that requires students to have had an exposure to algebraic and differential equations, calculus, and linear algebra.

The key is for the freshman and sophomore years to integrate rudimentary computer skills into courses such as mathematics and physics. Unfortunately, at many universities science departments lag behind engineering in introducing such technology. If problem-solving skills are to be developed and used in the other courses, a sophomore level course may be the most practical option in which students would learn several of these techniques.

How should this material be taught? One purpose is to teach how to implement elementary algorithms for problem-solving. While practicing engineers might use spreadsheets for this purpose, teaching requires a vehicle well-suited to efficient development of numerical algorithms. A second purpose is to teach students how to formulate and solve larger scale problems that might involve differential equations or constrained optimization. For teaching purposes, 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 we do not include programming language expertise in the above list. FORTRAN coupled with mathematical libraries has been a traditional tool. However, there are several excellent higher-level language alternatives, including Matlab, Mathematica, and Maple. These tools allow one to script solution algorithms very efficiently, and come with excellent visualization and problem-solving toolboxes. Our opinion is that the case for using these tools is now so overwhelming, that it would be legitimate to entirely omit FORTRAN from the undergraduate curriculum in favor of these alternatives.

The resistance to adding another course to the curriculum is well-known. Many departments currently require their students to take a computer programming course, and then follow that with a numerical analysis course, for a total of five to seven semester credit hours. If one de-emphasizes teaching of a traditional programming language in favor of higher level software combined with numerical analysis, it may be possible to recover as much as three credit hours for other needs. Such a combined course is already being taught at a few departments such as at the University of Texas (UT).

Algorithm development and programming structures are both covered in the UT course (four credit hours), and a native programming language contained in the software package Octave (authored by Eaton, 1994) is used to introduce programming structures to the students[1]. Other programming concepts taught include flowcharts, if-then-else structure, the looping (iteration) structure, and comparison operators. It is still necessary to spend about a month teaching students the operating system (Unix workstations are employed) and covering utilities such as file and directory manipulation, text editing, and job control. Given the choice between writing FORTRAN programs and using Octave to solve an ODE, the students invariably select the latter approach. The second half of the course surveys numerical analysis topics (with applications), which include finite difference methods, matrix algebra, and linear and nonlinear equation solving.

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 and process control courses offer opportunities for dynamic simulation.

Conclusions

In order to develop the new paradigm of problem-solving skills, it will be necessary to develop more computer-based lessons in subjects such as transport, thermodynamics and separations. Improvements in standard textbooks to include a stronger computer orientation will also be valuable. However, strong leadership in many departments is needed to increase communication among faculty who teach core courses and encourage more integration of computer skills. One or two champions for computing in a department can facilitate the necessary chang-

1. Available via anonymous ftp from ftp.che.utexas.edu in the directory /pub/octacve

es. Multimedia computing may offer new ways to enhance the traditional lecture format. For example, the concept of a "studio" style of teaching using computers in order to cluster students into small groups has been implemented in large classes such as freshman physics at some universities. Such teaching techniques can make new computer-based problem-solving tools a major focus in each course and offer an enhanced learning experience for engineering students.

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HISTORY OF CACHE AND ITS EVOLUTION

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Abstract

A definitive archival account of the 25-year history of CACHE from 1969-1994 is given, including the events leading up to the formation of the CACHE Committee in 1969, followed by incorporation in 1975. The history is presented mainly in terms of the chronological development of the many CACHE products that have been distributed to educators and the parallel incorporation of "computing" into chemical engineering curricula. Emphasis is placed on the synergistic effects of many educators and representatives from industry working together to advance the use of computers in chemical engineering education.

Two significant events occurred in the mid-1950s that were to drastically alter the education of a chemical engineers. The first was the introduction of the IBM 704 digital computer with its built-in floating-point arithmetic. The second was the development of the easy-to-use, high-level, procedure-based programming language of J. W. Backus and others of IBM, called FORTRAN. The IBM 704 came with a FORTRAN language compiler and subroutines written in that language were automatically handled. Almost overnight, chemical engineers in universities sought ways to learn FORTRAN and write computer programs to solve difficult or tedious problems.

Quickly, it became apparent that educators needed assistance in making the transition from precomputer techniques to computer-aided methods, which often involved numerical rather than analytical means to obtain a solution. Starting in 1958, the year after the introduction of FORTRAN, the University of Michigan initiated a project under the direction of the late Professor Donald L. Katz, with support from the Ford Foundation, to study the use of computers in engineering education. This project was extended to engineering design, with funding from the National Science Foundation (NSF) to: (1) train engineering design teachers in computer-aided design, (2) study the role of the computer in design, and (3) generate representative computer-oriented design problems.

The final report of the Michigan project, which was published in 1966 under the title *Computers in Engineering Design Education*, made the following recommendations to engineering schools:

1. Give introductory courses on computer programming and digital computation.
2. Teach model building, numerical methods, and optimization.
3. Integrate computer work into engineering science and design courses.
4. Stress open-ended problems.
5. Provide time-shared interactive computing to all students.
6. Train engineering teachers to use computers.

These recommendations still hold true today. Chemical engineering education is indebted to Donald L. Katz for his vision and his success in acquiring sufficient funding and recruiting qualified faculty to conduct such an important project.

Soon after the completion of the Michigan project, three textbooks were published that provided the three teaching tools needed for Recommendation (2): the first on model building entitled *Process Analysis and Simulation*, by Professors David M. Himmelblau and Kenneth B. Bischoff, the second entitled *Applied Numerical Methods*, by Professors Brice Carnahan, H. A. Luther, and James O. Wilkes, and the third entitled, *Optimization: Theory and Practice*, by Professors Gordon S. G. Beveridge and Robert S. Schechter. The numerical methods book, which was dedicated to Donald Katz, covered both theory and applications for interpolation, differentiation, integration, use of polynomials, linear algebraic equations, nonlinear algebraic equations, ordinary differential equations, partial differential equations, and statistics. The book was complete with comprehensive explanations and solutions, including listings of standalone FORTRAN programs for 40 example problems. A book entitled *A FORTRAN IV Primer*, by Professor Elliott I. Organick, provided a complete discussion on programming in FORTRAN.

Two other important events took place in the late 1960s. First, a widely publicized computer-aided chemical process design program called PACER (Process Assembly Case Evaluator Routine), was developed by Professor Paul T. Shannon at Purdue University, and reported in 1963. It was made available to chemical engineering departments at universities, following an instructional PACER workshop at Dartmouth College, April 23-28, 1967 that was attended by 20 chemical engineering professors from the United States and Canada. PACER was mainly a modular executive program for directing steady-state material and energy balance calculations for flowsheets that could include recycle streams. PACER had a limited library of unit-operation models and lacked a physical property estimation package. However, it was open-ended so that users could add operation and property models.

On November 22-23, 1968, Professors Rodolphe L. Motard and Ernest J. Henley, at a workshop at the University of Houston that was attended by 42 professors, introduced a more advanced simulation program called CHESS (CHemical Engineering Simulation System). It was apparent at this workshop that exciting computer-aided tools suitable for use in teaching chemical engineers could be developed and would be welcomed by educators. However, there was also concern that programs developed independently by educators might not be well documented and debugged. Also, most chemical engineering departments were neither equipped for nor disposed toward maintaining program libraries and providing consultation services. What was needed were standards and inter-university cooperation, which could be achieved by the formation of a committee.

Also in 1968, Lewis G. Mayfield, of the National Academy of Engineering (NAE), visited the University of Pennsylvania and suggested to Professor Warren D. Seider (who had a joint appointment there in chemical engineering and electrical engineering) the formation of a national committee of chemical engineering educators to be patterned after a similar committee for computer science in electrical engineering, called COSINE, which was sponsored by the NAE. As a result of this suggestion, Warren Seider, together with Professor Brice Carnahan of the University of Michigan and Professor Rodolphe (Rudy) L. Motard of the University of Houston organized a meeting, held on April 11, 1969 at the University of Michigan. This meeting was attended also by Professor William Surber of Princeton University and a member of the COSINE Committee, and the following 11 chemical engineering educators who were selected because they were engaged in the preparation of computer programs at their respective colleges and universities:

James Christiansen, University of Oklahoma

Eugene Elzy, Oregon State University

Lawrence B. Evans, Massachusetts Institute of Technology

Edward A. Grens, University of California at Berkeley

A. I. Johnson, McMaster University

Ernest J. Henley, University of Houston

Richard R. Hughes, University of Wisconsin at Madison

Matthew J. Reilly, Carnegie-Mellon University

Paul T. Shannon, Dartmouth College

Samuel L. Sullivan (for Robert E. C. Weaver), Tulane University

Arthur W. Westerberg, University of Florida

Brice Carnahan acted as chairman for the meeting and Warren Seider was acting secretary. The attendees agreed that there were numerous incentives for inter-university cooperation and that a committee should be formed, with the goal "to accelerate the integration of digital computation into the chemical engineering curriculum by sustained inter-university cooperation in the preparation of recommendations for curriculum and course outlines and new computing systems." Following a review of computing activities being conducted by each attendee, working sub-groups were formed in the areas of curriculum, standards, physical properties, new projects, and proposals. The group agreed to meet again in the Fall of that year. Immediately following the meeting, Rudy Motard suggested the acronym SEED for the name of the committee. However, SEED was already copyrighted and so a second choice, CACHE (Computer Aids for Chemical Engineering Education), was selected.

The committee needed a central base for its operations and a source of funds to support meetings, workshops, and the preparation and distribution of reports. With the encouragement of Dr. Newman A. Hall, Executive Director of the Commission on Education (COE) of the NAE, the proposal sub-group, consisting of Warren Seider, Brice Carnahan, and Richard R. Hughes, prepared a 53-page proposal, which, after minor changes by the NAE, was submitted on July 14, 1969 to the NSF as a proposal from the COE of the NAE, under the signatures of Gordon S. Brown, Chairman of the COE, Newman A. Hall, B. L. Kropp, Deputy Business Manager of NAE, and James H. Mulligan, Jr., Executive Secretary of NAE. A total of $120,812 was requested to start on January 1970 for a two-year period.

The first official meeting of the CACHE Committee was held on Tuesday, November 18, 1969 in Washington, D.C., during the week of the AIChE Annual Meeting, from 10:00 AM to 12:15 PM in the Columbian Room of the Mayflower Hotel. The founding members, all of whom were appointed by COE of the NAE for the interim until the conclusion of the initial forthcoming (hopefully) NSF funding period, consisted of the above attendees at the April 11, 1969 meeting, plus:

Robert V. Jelinek, Syracuse University

J. D. Seader, University of Utah

Imre Zwiebel, Worcester Polytechnic Institute

Professors Cameron M. Crowe of McMaster University, C. Judson King of the University of California at Berkeley, and Dale F. Rudd of the University of Wisconsin at Madison had been invited to join the committee, but declined because the committee included other faculty from their universities. Pending NSF funding, Newman Hall offered the services of Mrs. Jean P. Moore, Administrative Assistant of the COE/NAE, for distribution of mailings and support of subcommittee activities. Much of the meeting was spent in discussing efforts of members of the committee in areas of steady-state and dynamic simulation. An additional sub-committee was formed for the latter area. In addition, an ad-hoc subcommittee was established to draft governing rules and by-laws.

At the first official meeting, the CACHE Committee voted in favor of maintaining Brice Carnahan as Acting Chairman and Warren Seider as Acting Secretary until funds had been received from the NSF. During the 25-year period from 1969-1994, CACHE has been fortunate to have had outstanding and dedicated leadership and membership. Complete lists of CACHE officers and members are given in Appendices I, II, and III of this history.

The inevitable delays in obtaining federal funding occurred. Although meetings of subcommittees were held in the interim period, the next full meeting of the CACHE Committee was not held until April 2-3, 1971 in Ann Arbor, Michigan, following notice on February 18, 1971 that the NSF had finally approved the proposal, but had reduced the budget to $80,060 for the two-year period of January 1, 1971-December 31, 1972. This funding allowed $29,650 per year for all CACHE Committee activities, exclusive of overhead charges. The Ann Arbor meeting was attended by 16 of the 17 founding members of the CACHE Committee plus four observers, Dr. Newman Hall, and Jean Moore. Warren Seider was elected Chairman, with Lawrence Evans as Vice-Chairman, and Arthur Westerberg as Secretary.

Of an approved two-year budget of $63,650, $28,450 was allocated to the five subcommittees (Curriculum, Standards, Physical Properties, Dynamic Systems, and New Projects), each of which presented a report on their progress since the Washington, D.C. meeting held 17 months earlier. The most impressive report came from Professor Ernest Henley, Chairman of the Curriculum Committee, who reported on plans for the collection, review, and publication of small stand-alone FORTRAN computer programs in seven curriculum areas: stoichiometry, kinetics, control, transport, thermodynamics, stagewise computations, and design. The programs would be solicited from faculty by a letter dated April 10, 1971. The success of this project may be judged by the fact that proposals for almost 500 FORTRAN programs were submitted to CACHE from all over the world in 1971. Of these, 97, representing the efforts of almost 100 faculty members, were selected for publication. Each selected program had to be thoroughly documented and tested by the curriculum area coordinator.

By March 1973, using camera-ready copy supplied by program authors, the first two volumes (Stoichiometry with 13 programs and Kinetics with 21 programs) of a seven-volume set of programs had been distributed to all departments of chemical engineering in the United States and Canada, as well as interested departments in foreign countries. In conjunction with the assembly of the seven volumes of computer programs, the Standards Subcommittee of CACHE, chaired by Prof. Paul Shannon, issued in May, 1972 an important CACHE publication entitled *Standards for CACHE FORTRAN Computer Programs,* which included a detailed and widely referred to example of recommended programming style and documentation, prepared by Prof. Brice Carnahan for a program called GOLDEN, which performs a single-variable optimization by Golden-Section search.

Two other decisions were made at the Ann Arbor meeting. The first was to periodically publish and distribute a newsletter to all interested departments of chemical engineering. The first newsletter, edited by Prof. Lawrence Evans, was distributed to approximately 2000 faculty members in June, 1971, shortly after the Ann Arbor meeting. The cover page of the newsletter displayed, for the first time, the CACHE logo, which was provided by Jean Moore and has been used ever since. Until 1981, the newsletter was published approximately once each year. However, starting with the March 1981 issue (No. 12), it has been a biannual publication. Larry Evans (1971-73 and 1977-80), Cecil Smith (1975-77), J. D. Seader (1981-84), and David Himmelblau (1984-date) have served as Editor of the *CACHE News*. For some unknown reason, issue No. 10 was never published. A special 25th Anniversary Issue for Fall 1994 (No. 39), with a silver-colored cover was published in November 1994.

The second decision made in Ann Arbor was to designate a local CACHE representative in each of the departments in the United States and Canada. Each representative was to serve as a focal point for communication between CACHE and the institution of the representative. By March 1973, 123 local CACHE representatives from as many universities had been designated, with their names and schools listed in *CACHE News* No. 3. Starting with the 1977 AIChE Annual meeting, held in New York City, CACHE began holding an annual reception for CACHE representatives and interested faculty. At these receptions, CACHE members, task force members, or invited speakers discuss and demonstrate new products and receive feedback from faculty. At the November 1978 and 1979 AIChE meetings in Miami Beach and San Francisco, there were luncheon meetings of the CACHE representatives, with 70 and 66 in attendance, respectively. Another luncheon for 44 representatives was held at the New York City

AIChE meeting in November 1987. Today, almost every chemical engineering department in the United States and Canada, as well as many foreign countries, has a CACHE representative. On November 16, 1994 at the AIChE Annual Meeting in San Francisco, the CACHE 25th Anniversary Reception was held for representatives, associates, and former CACHE trustees. Approximately 400 attended this very successful reception.

Although voting membership in the CACHE Committee was limited from the beginning, the committee made every attempt to involve as many faculty members as possible in the work of the CACHE subcommittees. For example, in mid-1971 the Physical Properties Subcommittee, chaired by Prof. Rudy Motard, had 11 members, 9 of whom were not members of the CACHE Committee. The Dynamic Simulation Subcommittee, chaired by A. I. Johnson, had 8 members, 6 of whom were not members of CACHE and 3 of whom were graduate students.

One of the main reasons for forming the CACHE Committee was the possibility of coordinating efforts to introduce computer-aided process simulation into the chemical engineering curriculum. Indeed, almost every one of the 17 founding members of CACHE had been involved in the development of this new and exciting area of computer-aided design and analysis. Paul Shannon had developed the PACER program. Rudy Motard had developed the CHESS program, which included a physical property program called TAP by Ernest Henley. Motard had developed the MAD version of PACER and was preparing a dynamic simulation program called PRODYC. A. I. Johnson had developed a modified PACER-like program called MACSIM, and an interactive, time-sharing version called GEMECS, and was preparing DYNSYS, a dynamic simulation program, LINSYS, a material balancing system for linear equations, and GEMOPT for optimization. Warren Seider had developed a physical properties system for simulators, an automatic translator for converting FORTRAN programs into PACER routines, and a dynamic simulator called REMUS. Eugene Elzy had written the DISCOSSA simulator, which was tailored to each run by a compiling and linking step. Richard Hughes, while at Shell Development, had helped develop CHEOPS, a large simulation and optimization program. J. D. Seader, while at Chevron Research in 1959, had initiated and supervised the development of the Chevron system for generalized heat and material balancing, which used an equation-solving approach. Art Westerberg assisted Prof. Roger Sargent at Imperial College in the development of SPEEDUP, an equation-based, steady-state and dynamic simulator. Jim Christensen had developed programs in SNOBOL for recycle analysis and design variable selection. Imre Zwiebel used the PACER executive routine together with his own FORTRAN subroutines for a pyrolysis reactor, distillation columns, and a partial condenser and quench system to complete the detailed design and analysis of an ethylene manufacturing plant. Brice Carnahan was completing the development of an interactive dynamic simulation program called DYSCO. Larry Evans had just completed, with partial support from the NSF, an extensive survey on the current status of and future prospects for computer-aided chemical process design, which was published in the April 1968 issue of *Chemical Engineering Process.*

The first efforts by CACHE in the simulation area were taken by the Dynamic Simulation Subcommittee, which had been formed at the first meeting of CACHE. In December, 1971 that subcommittee, chaired by A. I. Johnson, recommended the use of the DYFLO dynamic simulation computer program of Roger G. E. Franks, a Senior Consultant for Engineering Computation and Analysis at E. I. du Pont de Nemours & Co., Inc. in Wilmington, Delaware. The FORTRAN code for DYFLO was published by Franks in a 1972 textbook entitled *Modeling* *and Simulation in Chemical Engineering* by Wiley-Interscience. To provide instruction on the use of DYFLO, CACHE held a three-day workshop at Purdue University on October 26-28, 1972 for 25 faculty members. Roger Franks was the principal lecturer, with assistance from Purdue Prof. John Woods. Dynamic simulation represented the first major encounter, for many chemical engineers, with the problems of solving "stiff" systems of ordinary differential equations. During the 20-year period from 1972 to 1992, DYFLO was used by many universities, but is now being displaced by more comprehensive programs developed by Aspen Technology, Hyprotech, and Simulation Sciences. In 1985 and 1989, CACHE attempted to obtain use by universities of Shell's DYMODS and Imperial College's SPEEDUP dynamic simulators, respectively, but without success. However, the latter is now available to universities through Aspen Technology.

At the Buck Hill, Pennsylvania meeting of CACHE on September 2-3, 1971, the Large-Scale Systems Task Force was formed, with J. D. Seader as Chairman. With the dynamic simulation program of Roger Franks soon to be available, this new task force was given the charge of investigating the possibility of acquiring the use of an industrial steady-state process simulation computer program for educational use at universities. The academic programs, PACER and CHESS, were already being used at a number of universities, but the 1968 survey by Larry Evans showed that much more useful simulation programs, with large data banks for pure chemicals and large libraries of models for processing equipment and mixture physical properties had been and were being developed by industry. Hopefully, one or more of these simulators might be made available to chemical engineering students.

By the following CACHE meeting, held at the Sonoma Mission Inn on December 3-4, 1971, following the annual AIChE meeting in San Francisco, the Large-Scale Systems Task Force had sent questionnaires to 15 potential suppliers of these industrial steady-state process simulators and had formulated a sample problem that would test their ease of use, robustness, and efficiency. By the next CACHE meeting, held at the Lake of the Ozarks, Missouri on May 24-26, 1972, the task force had received four favorable responses and four industrial simulation systems had been tested: GEPDS of General Electric, FLOWTRAN of Monsanto Company, PACER-245 (a commercial version of PACER) of Digital Systems Corp., and PDA of McDonnell-Douglas Automation, Inc. Of these four, the task force determined that FLOWTRAN was the most desirable and the task force was instructed to seek an agreement with Monsanto for the use of FLOWTRAN by universities over a national computer network. Furthermore, this system met the guidelines listed in the CACHE publication, *CACHE Guidelines for Large-Scale Computer Programs*, which was issued by the task force in February, 1973.

By December 1, 1972 at the CACHE Committee meeting at Grossinger's following the New York AIChE annual meeting, the Large Scale Systems Task Force reported that a preliminary oral agreement had been reached between CACHE and Monsanto on the use of FLOWTRAN, but details still needed to be worked out before a final approval could be obtained. The original request was for the use of FLOWTRAN through the service bureau of Monsanto Enviro-Chem Systems, Inc., established for outside commercial users of FLOWTRAN. However, in March 1973 Monsanto terminated the service bureau, thus eliminating that means of accessing FLOWTRAN. University of Texas' Professor John J. McKetta of the CACHE Advisory Committee called Mr. F. E. Reese, Vice President and General Manager of Monsanto, to discuss other means of acquiring FLOWTRAN. Mr. Reese's response was encouraging. Therefore, on June 13, 1973, in a formal letter to Mr. John W. Hanley, President of Monsanto Company, CACHE requested that Monsanto consider other means for allowing chemical engineering faculty and students to use FLOWTRAN for both course work and research. With the additional support and assistance of M. C. Throdahl, J. R. Fair, and S. I. Proctor of Monsanto, approval for the use of FLOWTRAN via a national computer network, was granted by Monsanto Company in a letter from Jim Fair dated November 9, 1973. This approval included assistance in implementing the system by providing a grant and loaning specialists from the Monsanto Corporate Engineering Department.

Starting on May 10, 1974, Dr. Allen C. Pauls of Monsanto directed a three-day training course on FLOWTRAN, which was attended by Richard R. Hughes, H. Peter Hutchison, J. D. Seader, Warren D. Seider, and Arthur W. Westerberg. On June 5, 1974, at a meeting of the CACHE Committee in Seven Springs, Pennsylvania, Dr. Proctor of Monsanto formally presented CACHE with a Monsanto grant, in the amount of $7,000 in cash and $21,000 in services, and conditions for making FLOWTRAN available to universities. For a department to use FLOWTRAN, a three-party agreement, drawn up by Monsanto, had to be signed by the department, CACHE, and Monsanto, so as to make sure that the program would only be used for educational purposes.

The FLOWTRAN project marked the first attempt by CACHE to distribute computing services via a computer network. In connection with this effort, the Program Distribution Task Force, chaired by Warren Seider, completed the document *CACHE Guidelines for Computer Networks* in June 1974. As a result of that effort, CACHE began a cooperative venture with EDUCOM (The Inter-university Communications Council) to help develop an educational computer network. In 1976, an article by the Program Distribution Task Force entitled, "Aspects of Software Dissemination in Chemical Engineering," was published in the proceedings of the EDUCOM Fall Conference. On September 28-29, 1978 at Washington, D.C., CACHE, under the direction of Seider, Westerberg, and EDUCOM representatives, sponsored an NSF-funded networking conference entitled "How Can the Chemical Engineering Discipline Best Utilize Networks for the Sharing of Computer-Based Resources in Research and Teaching"; it was attended by 25 educators.

By the end of 1977, CACHE had: (1) held five 4-day FLOWTRAN workshops, under the administration of the Continuing Education Department of the AIChE, in Evanston, Houston, Boston, Madison, and Philadelphia to instruct a total of 90 faculty in the use of the program; (2) written and distributed three books, *FLOWTRAN Simulation - An Introduction*, *CACHE Use of FLOWTRAN on UCS* (a national network), and *Exercises in Process Simulation Using FLOWTRAN;* (3) formed a FLOWTRAN User's Group; and (4) began to issue a FLOWTRAN Newsletter edited by Professors J. Peter Clark and Jude T. Sommerfeld.

Until 1982, FLOWTRAN could only be accessed from the UCS network. After that, Monsanto released the source code to CACHE and approved the preparation of load modules for 14 different computer/operating system combinations so that universities could run FLOWTRAN on their own computers. The conversion of the FLOWTRAN source code to load modules for various systems was greatly facilitated by a very careful conversion carried out by the University of Michigan under the direction of Brice Carnahan, which was the subject of two detailed reports that were distributed to other converters. The cost to license the load module was $175 to universities supporting CACHE and $250 to others. In May 1987 Professor Lorenz T. Biegler of Carnegie-Mellon University, and a member of CACHE, completed the preparation of an SQP optimization routine as an add-in to FLOWTRAN.

On April 4, 1994, after almost 20 years of providing the use of FLOWTRAN to universities and when a number of more advanced commercial simulators had entered the market and were being licensed to universities at low cost, Monsanto announced that they would discontinue licensing FLOWTRAN to universities. During the 20-year period of the CACHE FLOWTRAN project, 59 universities used the program on the UCS network, 190 FLOWTRAN load modules were distributed to universities (141 in the United States, 11 in Canada, and 38 in 21 other foreign countries), and 15,000 copies of three editions of *FLOWTRAN Simulation - An Introduction*, which had been printed in Ann Arbor, Michigan under the direction of Brice Carnahan, were sold. Today, almost all departments of chemical engineering teach their undergraduates the use of computer-aided, steady-state chemical process simulation.

Although the biannual *CACHE News* and the annual receptions for CACHE representatives have been and continue to be the main means of communicating CACHE activities and products to faculty, CACHE officers, trustees, and committee members have, from time to time, published general and specific articles about CACHE in magazines, journals, and special reports. The first such article appeared as a CACHE report on January 1, 1972, and was entitled *Origins and Organization of the CACHE Committee*, by Seider, Evans, and Westerberg. Other articles have followed, including:

"Computers in Education: How Chemical Engineers Organized the CACHE Committee," by Seider, Evans, and Westerberg, in *EDUCOM Bulletin*, Vol. 8, No. 2, pp 10-17, Summer 1973.

"Use of FLOWTRAN Simulation in Education," by J. Peter Clark and Jude T. Sommerfeld," in *Chemical Engineering Education*, p 90, Spring 1976.

"What is CACHE?," by Himmelblau and Hughes, in *Chemical Engineering Education*, pp 84-87, Spring 1980.

"Computer Graphics in Chemical Engineering Education," by Edgar, in *Chemical Engineering Progress*, pp 55-59, March 1981.

"Computer Graphics in ChE Education," by Reklaitis, Mah, and Edgar, in *Engineering Education*, pp 147-151, December 1983.

"The Impact of Computers on Undergraduate Education," by Finlayson, in *Chemical Engineering Progress*, pp 70-74, February 1984.

"Computer Aids in Chemical Education," by Edgar, Mah, Reklaitis, and Himmelblau, in *ChemTech*, pp 277-283, 1988.

"Education and Training in Chemical Engineering Related to the Use of Computers," by Seader, in *Computers and Chemical Engineering*, Vol. 13, pp 377-384, 1989.

"Computer Aids for Chemical Engineering Education: An Assessment of CACHE — 1971-1992," by Seider, in *Computer Applications in Engineering Education*, Vol.1, No. 1, pp 3-10, 1992.

Since its inception, CACHE has sought ways to cooperate with the ASEE in providing summer education in computing for chemical engineering faculty. In August 1972, Warren Seider made a presentation on the mission and activities of CACHE to an audience of nearly 100 educators, on a rainy afternoon, at the ASEE Summer School for Chemical Engineering Faculty in Boulder, Colorado. A similar presentation was made by Paul Shannon on June 27, 1973 to another 40-50 educators. In August 1977, at the ASEE Summer School for Chemical Engineering at Snowmass, Colorado, CACHE held demonstrations and workshops on interactive computing. At subsequent ASEE summer schools in 1982 at the University of California at Santa Barbara, in 1987 at Southeastern Massachusetts University, and in 1992 at Montana State University, CACHE typically organized and assumed responsibility for seven or eight computing sessions. These summer sessions have provided an exceptional opportunity for CACHE to inform chemical engineering educators of new educational computing tools.

During its first quarter century, CACHE also maintained close ties with the AIChE. One trustee (Hughes) served as Vice-President and then President of AIChE from 1981-1982, eight trustees (Hughes, Himmelblau, Evans, Seader, Seider, Seinfeld, Edgar, Finlayson and Fogler) served 3-year terms as Director, and another (Edgar) was elected Vice President of the Institute in 1995 and assumed the Presidency in 1996. Many CACHE trustees have held offices in the CAST Division, where they have been responsible for computing sessions at AIChE meetings. A number of trustees have received Institute awards: (1) Seinfeld, Edgar, Stephanopoulos, Morari, and Kim for the Allan P. Colburn award; (2) Sandler and Denn for the Professional Progress award; (3) Finlayson, Denn, Seinfeld, and Westerberg for the William H. Walker award; and (4) Douglas and Fogler for the Warren K. Lewis award. The Founders award was given to Himmelblau in 1992. Since its inception in 1979, the Computing in Chemical Engineering Award of the CAST Division has been given to a CACHE trustee (Hughes, Carnahan, Mah, Evans, Westerberg, Reklaitis, Himmelblau, Douglas, Seader, Motard, Seider, Stephanopoulos, and Grossmann) every year but three. The CAST Computing Practice Award was given to a CACHE industrial trustee, Siirola, in 1991. Seinfeld, Smith, Morari, and Arkun have received the Donald P. Eckman Award and Edgar has received the AACC Education Award. The annual Institute Lecture has been given by Seinfeld (1980), Seader (1983), Westerberg (1989), and Douglas (1993).

At the February 20-23, 1972 AIChE Annual Meeting in Dallas, the CACHE Committee sponsored its first symposium, which consisted of two sessions on Computer-Aided Process Synthesis. Over 100 persons attended the sessions, which were chaired by Seader and Elzy. A review article on that topic, co-authored by Seader, appeared in the January 1973 issue of the *AIChE Journal*. Since then, CACHE has sponsored symposia at AIChE meetings in St. Louis in May 1972, in Washington, D.C. in November 1983, and in Anaheim in May 1984. On November 5, 1989, Biegler presented an AIChE seminar on optimization at the San Francisco meeting. On November 11, 1990, Cutlip presented a seminar on the use of POLYMATH for numerical calculations at the AIChE Annual meeting. A special symposium entitled, “Computers in Chemical Engineering Education - 25 Years of CACHE,” was held on November 16, 1994 at the AIChE Annual meeting in San Francisco, chaired by Cutlip and Himmelblau. Four papers were presented: (1) Edgar, “Process Control Education: Present, Past, Future,” (2) Fogler, “Ghosts of Interactive Computing: Past, Present, Future,” (3) Stephanopoulos, “Knowledge, Computers, and Process Engineering: A Critical Synthesis,” and (4) Carnahan, “2001 -

A Computing Odyssey."

At the Buck Hill meeting on September 2-3, 1971, operating policies were established for the CACHE Committee. Some of the important policies were: (1) a maximum of 18 members, (2) a task force structure in which the chairman must be a CACHE member, but other members of the task force could be non-members, including participants from industry and government, as well as faculty, (3) election of new members each year by the present members, (4) a three-year term of membership, but with provision for re-election, and (5) election of a new vice-chairman and secretary each year, with the current vice-chairman automatically becoming the next chairman. These operating policies remained in effect, with only minor changes, until March 25, 1974, when CACHE was incorporated as a non-profit corporation in the state of Michigan, with Brice Carnahan as the Registered Agent, but with a business address in Cambridge, Massachusetts. The Articles of Incorporation were prepared by Betty Ann Weaver, Attorney at Law in Glen Arbor, Michigan and sister of Bob Weaver, newly elected CACHE secretary.

At that time, CACHE had a part-time secretary, Cindy Driear, a lawyer, William Thedinga of the firm of Bingham, Dana & Gould, and an accountant, Joseph Cullinan, all residing in the Boston area. CACHE had also established checking and savings accounts with the Cambridge Trust Company and Cambridge Savings Bank, respectively. The first balance statement showed assets of $5,519 and liabilities of $2,994. On June 6, 1974, at Seven Springs Inn in Champion, Pennsylvania, the first meeting of the trustees (made up from current CACHE Committee officers and members) of the newly formed CACHE Corporation was held. New Bylaws were presented by Bob Weaver and ratified after a few minor revisions. These Bylaws added an Executive Officer, who would also act as Treasurer, and an Executive Committee. Meetings of the trustees would be held twice each year; new officers would be elected each year, except that the Vice-President would automatically succeed to the presidency; and the number of trustees would be limited to 21 chemical engineering educators, who would serve for three-year terms, but with the possibility of re-election.

On October 2, 1974 Solomon Watson of the law firm of Bingham, Dana & Gould in Boston suggested that CACHE could enhance its attempt to gain tax-exempt status with the IRS if CACHE would form a Massachusetts not-for-profit corporation of the same name, into which the recently formed CACHE Corporation of Michigan would merge. On December 6, 1974 at a trustee's meeting at Boar's Head Inn in Charlottesville, Virginia, the CACHE membership voted to accept the merger plan. On February 26, 1975 the CACHE Committee became The CACHE Corporation in The Commonwealth of Massachusetts. Early in 1975, the IRS approved an exemption from Federal income tax and on March 15, 1976 the corporation in Michigan was dissolved.

When the CACHE Corporation Bylaws were approved on June 6, 1974, Ernie Henley questioned the restriction of membership to those in academia. At the December 2-4, 1976 meeting at The Abbey, Lake Geneva, Wisconsin, the trustees approved a motion by Duncan Mellichamp and David Himmelblau that CACHE elect industrial affiliates as non-voting members to serve for one year. At the August 5-7, 1977 meeting at Snowmass Village, Colorado, the trustees approved a motion to extend the term for industrial members to three years. The first three industrial members elected were Theodore Leininger of DuPont, Edward Rosen of

Monsanto, and Louis Tichacek of Shell Oil. At the May 17-19, 1979 meeting in St. Louis, the term of office for President, Vice-President, and Secretary was increased to two years. At the November 12-13, 1981 meeting at Cancun, Mexico, an extensive revision of the Bylaws was approved. The number of (voting) trustees was increased to 28, but the number of academic trustees was limited to 21 and the number of industrial (including government employees and consultants) was limited to 7. The Executive Officer-Treasurer would be appointed by the President for an unspecified number of years. To date, the Executive Officers of CACHE have been Larry Evans (1974-1980), J. D. Seader (1980-1984), and David Himmelblau (1984-date). At the November 5-7, 1992 meeting in Coral Gables following the AIChE meeting in Miami Beach, CACHE approved an extensive revision of the Bylaws prepared by Jeffrey Siirola, an industrial trustee. The revision was made to clarify certain statements, add consistency, improve organization, and delete obsolete or irrelevant material.

By 1974, the impact of CACHE on the use of computers in chemical engineering education began to be recognized by industry and, as mentioned above, CACHE began to recognize the importance of working closely with industry. Starting in 1974 with the Monsanto grant to CACHE for the FLOWTRAN project, CACHE began to receive some industrial grants annually. The following companies have contributed financial support to CACHE during the 20-year period from 1974 to 1995: Chevron Research Corporation, Chiyoda Chemical Engineering and Construction Company, Digital Equipment Company, Dow Elanco, DuPont Committee on Educational Aid, EXXON Educational Foundation, The Halcon SD Group, Monsanto Chemical Company, Olin Chemicals Corporation, Pfizer Foundation, Process Simulation International, Rust International Corporation, Simulation Sciences Incorporated, Shell Companies Foundation, Tektronix, Tennessee Eastman Company, Weyerhaeuser Company, and the Xerox Foundation.

The first of the three most memorable CACHE meetings was the one held on December 3-4, 1971 at the Sonoma Mission Inn, following the annual AIChE meeting in San Francisco. No one present has forgotten it. The Inn is located in the heart of the wine country north of San Francisco. California is noted for the many beautiful Catholic Missions located along most of the length of the state. But the Sonoma Mission Inn turned out to be a retirement home that also served as an overflow motel for the region. The rooms were spacious, but old and poorly furnished with door locks that used latch keys, many of which didn’t work. Meals were served mostly family style on paper table cloths. Except for the retired people living there, we were the only guests. To make matters worse, it rained both days we were there. Following this meeting, at the suggestion of Ernest Henley, the Ed Grens Memorial Prize was established for acknowledging never-to-be forgotten meeting arrangements. To date that cherished prize has gone to: (1) Edward Grens for the 1971 Sonoma meeting, (2) Warren Seider for the 1978 Spring Lake meeting, and (3) Thomas Edgar for the 1986 Biloxi meeting. On the positive side at the Sonoma Meeting, Larry Evans presented the outline of a proposal to the NSF for continued support of CACHE for the three-year period of 1973-75 to: (1) develop and evaluate new computer-based courses and curricula, (2) create special computer aids for education, and (3) determine effective mechanisms for distributing computing materials. Without additional funding from NSF, the future operation of CACHE would have been in peril because no other sources of funding had been forthcoming.

Like the first proposal to the NSF for support of CACHE, the second proposal would be sponsored and submitted by the COE of the NAE. It was determined that the best chance for funding the proposal was with the Division of Undergraduate Education in Science, where Dr. Gregg Edwards was the Assistant Program Director for the Science Course Improvement Program. In January 1972, the CACHE officers discussed plans for the proposal with Dr. Edwards, who gave little encouragement. However, on a return visit by the CACHE Executive Committee in May 1972, in which some proposal changes were discussed, Dr. Edwards expressed some optimism. The 54-page formal proposal, written largely by Larry Evans, CACHE Vice-Chairman, was sent on September 27, 1972 with a request for $94,014 for the 3-year period. The proposal emphasized the exploitation of new computing technology to carry out projects that would lead to self-sufficiency for CACHE. Accordingly, the proposal called for the establishment of three new task forces: (1) the Modularized Instruction Task Force to coordinate the development of 100 teaching modules, (2) the Real-Time Laboratory Task Force to coordinate the preparation of instructional material for undergraduate laboratories, and (3) the Program Distribution Task Force to identify workable mechanisms, including computer networks, to distribute small and large-scale computer programs and modules. Prior to the meeting of June 6-8, 1973 at Ann Arbor, Michigan, the NSF funded the three-year proposal for a total of $93,884. CACHE now had until the end of 1975 to find new ways to support its activities.

At the November 30 - December 2, 1972 meeting at Grossingers in New York, David M. Himmelblau was elected to membership in CACHE. He quickly developed a concern for the future financial survival of CACHE and determined that a reliable and steady source of income was essential. Because it was becoming apparent that CACHE could provide continuing and worthwhile educational computing services to departments of chemical engineering in universities, he suggested at the December 5-7, 1974 meeting at Charlottesville, Virginia that CACHE should consider a periodic solicitation of all departments in the United States and Canada. In return, the departments would receive discounts on CACHE products. At the following meeting, held on April 2, 1975 in Houston, his idea was put into effect. At the August 21-23, 1975 meeting in Andover, Massachusetts, Himmelblau was appointed Chair of a Standing Committee for Development. At the November 20-22, 1975 meeting at San Diego, Himmelblau announced that approximately 65 schools had pledged or contributed $200. A second solicitation was initiated in the Spring of 1978 which resulted in 64 contributions from schools in the United States and Canada. Since then, schools have been solicitated for two-years of support every other year and more recently on a yearly basis. Starting with the September 1982 issue (No. 15) of *CACHE News*, departments supporting CACHE have been listed. That list has continually grown and has expanded to include departments outside of the United States and Canada. In the Spring 1994 issue (No. 38) of *CACHE News*, the list included 110 departments in the United States, 16 departments in Canada, and 22 in other countries. During the past 3 years, the solicitation of departments has brought an average annual income to CACHE of $15,500.

The first CACHE proposal to a Federal agency for a specific project came from the Modularized Instruction Task Force, chaired by Ernest Henley, who became the President of CACHE in 1975. Funded by the NSF as Grant No. HES75-03911 on July 1, 1975 through the office of Dr. Gregg Edwards for a total of $145,790, the CHEMI (Chemical Engineering Modular Instruction) Project, had as its goal the development and distribution of from 50 to 80 self-study, single concept, text modules covering the entire chemical engineering undergraduate curriculum, including the seven areas covered in the earlier CACHE computer program volumes, which had been developed under the leadership of Ernest Henley. Each module was to be from 7 to 15 pages in length, containing theory and examples suitable for a one-hour lecture and with homework exercises. The modules would be solicitated from the worldwide chemical engineering community. William Heenan of the University of Puerto Rico agreed to be the Executive Director for the project, which was announced in the December 8, 1975 issue of *Chemical and Engineering News.*

This project was a model of organization. By June 1976, the preparation of about 70% of the modules had been commissioned. By June 1977, 67 modules had been completed. Although the 3-year project was moving along quite well, it became apparent early in 1978 that it could not be completed by mid-1978. Accordingly, CACHE requested and was granted, on June 2, 1978, a no-cost contract extension until May 31, 1979. At the May 17-19, 1979 meeting of CACHE in St. Louis, Ernest Henley reported that 111 modules had been completed in six areas, the Design area having been delayed. He also reported that an agreement had been reached with Hal Abramson of the AIChE to publish the modules, which ultimately numbered 230.

CACHE donated its copyrights to all the modules developed under the CHEMI Project and provide $16,000 toward printing the volumes. The AIChE set aside $100,000 towards the printing and distribution of all six volumes. Later, The AIChE made the decision to cluster the modules into groups of 3-11 and publish them in six series of 3-7 volumes each under the title *AIChEMI Modular Instruction*. In the October 1980 issue of *Chemical Engineering Progress*, the AIChE announced the publication of the first six volumes of the AIChEMI Modular Instruction Series available for $15 each. In January 1981, all chemical engineering departments in the United States and Canada received a copy of the 93-page Vol. 1: “Analysis of Dynamic Systems” of Series A: *Process Control*, edited by Thomas F. Edgar, who had been elected a CACHE Trustee at the December 2-4 meeting at Lake Geneva, Wisconsin. By 1987, the Design series had been added and the AIChE had published a total of 36 volumes. Solutions to the homework exercises were available under separate cover.

At the May 17-19, 1979 meeting of CACHE in St. Louis, Missouri, David M. Himmelblau, who became President of CACHE on June 7, 1978 at the meeting at Spring Lake, New Jersey, announced that he had submitted to the NSF a follow-up proposal to the CHEMI Project entitled, “Assessment of Alternative Distribution Systems for Modular Instructional Materials.” The purposes of this project were to complete additional undergraduate-level teaching modules, create 80 graduate-level modules, prepare 500 abstracts of topics not covered in the modules, test the modules that had been and were being produced, and experiment with ways to disseminate and encourage use of the materials through an on-line system on a computer network. On September 12, 1979 CACHE received notice from the NSF for funding of the proposal under Grant No. SED-79-13021 for a total of $298,500 for the 4-year period from September 12, 1979 to September 30, 1983. An additional $36,384 under Grant No. SED-81-16698 was added on August 19, 1981 and the expiration date was extended to September 30, 1984 on March 9, 1983. Funding actually ran out in March 1984 and the final report to the NSF was sent on March 30, 1984. This project was one of the first to demonstrate that a large educational data base could be computerized. During the period of the CHEMI Project, a Conference on Software Portability was held at the University of Texas at Austin on November 23, 1981.

At the September 2-3, 1971 meeting at Buck Hill Falls, Pennsylvania, Lawrence Evans reported that, based on a survey of 153 universities, interest in real-time computing was growing rapidly. By 1972, it was estimated that approximately 50 departments would have equipment for such computing. Accordingly, a task force was formed, chaired by Eugene Elzy, to assess the role of real-time computing in the chemical engineering curriculum. In October 1973, the task force published an interim report which listed: (1) specifications for real-time digital computing systems, (2) experiments utilizing real-time digital computers, and (3) sample outlines for courses in real-time computing. A second survey, completed in January 1974, indicated continued growing interest. Therefore, a CACHE Workshop, arranged by Cecil Smith (who had become a Trustee in 1972) as part of the AIChE Continuing Education program, was held on December 1-2, 1974 in Washington, DC. The 13 paid attendees received instruction on establishing and operating real-time computing systems. At the following CACHE Trustee's meeting held on December 5-7, 1974, Duncan Mellichamp, who had become a Trustee just a year before, became the new Chairman of the Real-Time Task Force and announced that plans were well underway for 12 members of the task force to prepare the *CACHE Monograph Series in Real-Time Computing*. The first of eight monographs, which eventually totaled more than 700 pages, was published by CACHE in the summer of 1977. Through generous grants from EXXON and Shell, CACHE distributed a full set of monographs to each CACHE-supporting department. The project was completed in 1978 and the monographs were available for purchase until 1985. Approximately 500 sets of the monographs were sold by CACHE at prices ranging from $15 to $28.

Another task force formed early in the history of CACHE was the Physical Properties Task Force, chaired by Rudy Motard, whose CHESS program included TAP, the first widely available computer program, developed by Henley, for estimating the properties of gas and liquid mixtures. In August, 1972 the task force published a very useful 35-page *CACHE Physical Properties Data Book* by Michael R. Samuels, which included extensive listings of sources of physical property data, including 19 handbooks, 69 general data tabulations, and 24 reference sources, indexed by property type. This book was distributed to all chemical engineering departments in the United States and Canada.

At the AIChE National Meeting at St. Louis in 1972, Ronald L. Klaus and Rudy Motard presented a paper entitled, "Design of a Physical Property Information System for Undergraduate Education." A detailed report on a proposed project for developing such a system was presented by the task force in an October 1974 final report. The system would be modular so that a university could assemble its own system structure. The project was abandoned when it was learned that many such systems were being developed by industry. One such system, developed jointly by the Institution of Chemical Engineers and the Engineering Sciences Data Unit in England, is PPDS (Physical Property Data Service). In 1981, Rudy Motard obtained grants from DuPont and Simulation Sciences, Inc. to enable the installation of an academic version of PPDS on the TELENET communication network at Carnegie Mellon University. His booklet, *Introduction to CACHE Version of Physical Property Data Service*, described the use of the system on the network. The CACHE version of PPDS contained data records of 18 constants for 50 common chemicals, and methods for calculating 15 different vapor and liquid mixture properties. Unfortunately, the service was little used because the biggest need for properties was in simulation, and programs like FLOWTRAN that had built-in physical property estimation systems. Nevertheless, the project demonstrated the use of a computer network to share a proprietary program and stimulated interest in large physical property data systems.

In the early 1970s, little interest was shown by academia in the United States in teaching plant safety to undergraduate students in chemical engineering. The 1968 second edition of *Plant Design and Economics for Chemical Engineers* by Peters and Timmerhaus devoted only one page to the subject. The 1980 edition increased this to about three pages. Finally in the 1990 edition, following the tragic December 1984 Bhopal, India accident in a pesticides plant that released a lethal cloud of methyl isocyanate, killing more than 6,000 people, injuring 200,000 or more, and leaving tens of thousands permanently impaired, almost 30 pages were devoted to health and safety in chemical plants. This early neglect had not been the case in England, where a guide entitled, *Flowsheeting for Safety* was published by the Institution of Chemical Engineers in 1976 and widely used thereafter. At the November 30 - December 2, 1972 meeting at Grossinger's in New York, Gary J. Powers was elected a Trustee. Powers, with Dale F. Rudd and Jeffrey J. Siirola, had developed in the early 1970s the first process synthesis computer program, AIDES, and the first textbook on process synthesis. Powers was now turning his attention to the related topics of reliability and safety. At the December, 1974 meeting at Charlottesville, a Safety and Reliability Task Force was organized, with Powers as Chair, to assemble material on safety and reliability technology for the chemical engineering curriculum. On April 17, 1975 Powers and Henley submitted a CACHE proposal to the Sloane Foundation for funding a safety and reliability project. However, because CACHE did not have a tax-exempt status at that time, the Sloane Foundation would not entertain the proposal. Subsequently, a revised proposal for about $100,000 was submitted to the Exxon Foundation to install safety and reliability programs on a network for use by faculty and students. That proposal also failed to be funded and activity by CACHE in this area was suspended until 1982 when Himmelblau obtained a process troubleshooting computer program developed by Professor Ian D. Doig of Australia. That program, which simulates malfunctions in two different plants and was described in *CACHE News* No. 17 (September 1983), was distributed by CACHE in the Spring of 1983. Today, material for teaching safety to chemical engineers is widely available through the Center for Chemical Process Safety of the AIChE and in recent textbooks such as *Chemical Process Safety* by D. A. Crowl and J. F. Louvar (1990).

Also at the December 1974 meeting at Charlottesville, Weaver proposed a new CACHE effort for assembling teaching materials in resource management, with particular attention to the data bases. The Resource Management Task Force was organized with Weaver as Chair. By the August 1975 meeting in Andover, Massachusetts, the task force had submitted a CACHE proposal to NSF for funds to produce educational materials for undergraduate courses. At the suggestion of the NSF, the proposal was expanded to include macroeconomics, allocation studies, and the creation of data bases. A third revision was submitted in 1976 for about $200,000. At the November 16-18, 1978 meeting at Nassau, following the annual AIChE meeting in Miami, several unsuccessful attempts at funding with the NSF, the Dreyfus Foundation, and the Ford Foundation were reported. The primary difficulty had been in trying to define the problem from a chemical engineering viewpoint. Although a number of trustees felt that there was a need for instruction in resource management, the task force was dissolved at the May 17-19, 1979 meeting in St. Louis. A textbook for chemical engineers on the subject of resource management, entitled *The Structure of the Chemical Processing Industries*, was published in 1978 by Professors Wei, Russell, and Swartzlander of the University of Delaware.

At the December 5-7, 1974 meeting in Charlottesville, Virginia, the Computer Graphics Ad-Hoc Task Force was formed with Richard S. H. Mah as Chairman. Dick Mah had been elected a Trustee the previous year and, along with Brice Carnahan and H. Scott Fogler, who had been a elected Trustee in November 1975, believed that computer graphics could have a tremendous impact on education. However, at that time extraordinary resources were required to store graphical images and standards were lacking. On August 3-4, 1977, the task force held an "Interactive Computing Workshop" in conjunction with the ASEE Summer School for Chemical Engineering Educators at Snowmass Village, Colorado. At that time, they also conducted a survey on graphics usage in education. In 1978, the task force published a 66-page CACHE report entitled *Computer Graphics in Chemical Engineering Education*, in which software and hardware were discussed, along with potential applications in chemical engineering. Included were the results of the survey, which showed that although 90% of the 31 respondents had graphics terminals, only 15% were using computer graphics in coursework. At the November 17-19, 1977 meeting in Buck Hill Falls, Pennsylvania, the ad-hoc task force was made a full task force, with Thomas Edgar as Chairman. By August 1, 1979, as reported in an article entitled *Computer Graphics in Chemical Engineering Education* by Edgar in the March 1981 issue of *Chemical Engineering Progress*, a new survey showed that 67 of 87 reporting departments now had graphics devices. Thirty-five percent of the respondents were using graphics to help in the teaching of such topics as dynamics and control, design, kinetics, heat transfer, thermodynamics, distillation, and stoichiometry. Many were using graphics for simple plotting.

In the Spring of 1983, a third CACHE report, entitled *Computer Graphics in the ChE Curriculum, ASEE/NSF Position Paper*, by G. (Rex) V. Reklaitis, Mah, and Edgar was published. Rex Reklaitis had been elected a Trustee on November 30, 1980 at the meeting in Hershey, Pennsylvania and had become the Chairman of the Computer Graphics Task Force at the Fontana, Wisconsin meeting, November 20-22, 1980. The position paper presented a five-year plan for the revitalization of undergraduate education by the focused introduction of interactive computer graphics technology and courseware. The plan called for an equipment grant program, a computer-aided instruction courseware development program, a software clearinghouse, and a faculty training program. CACHE would be successful later in obtaining grants for courseware development. Edgar and Reklaitis of the Computer Graphics Task Force were guest editors for a special CACHE-sponsored 1981 issue (No. 4) of *Computers and Chemical Engineering*, which included 11 refereed articles on the application of computer graphics in chemical engineering.

At the August 21-23, 1975 meeting held at Andover, Maine, a standing Committee for Publications was organized, with Brice Carnahan as Chairman. In 1974, Carnahan had brought to the attention of CACHE that books could be printed from camera-ready copy and bound with a long-lasting soft-cover binding at a low cost by several printers in Ann Arbor, Michigan. Furthermore, Ulrich's Bookstore in Ann Arbor could be used as the distributor. Carnahan became the CACHE publisher. The products were either sold from Ulrich's Book Store or distributed from the Carnahan warehouse (his garage). CACHE publications were advertised in the *CACHE News*. By 1989, so many publications were available that the first *CACHE Catalog of*

Products was published after preparation by Michael F. Doherty (who had been elected a Trustee at the November 6-8, 1986 meeting in Key West, Florida). The 1994 issue of the catalog, edited by Margaret Beam of the CACHE office, lists 75 different CACHE products.

On August 12, 1981, IBM announced its personal computer (PC), based on the Intel 8088 microprocessor. This unit had 10 times the internal memory of the first microcomputers, and could process 16 bits at a time internally; an Intel 8087 coprocessor chip could be added to greatly speed-up floating-point scientific and business calculations. By the end of 1983, IBM had shipped an estimated 500,000 machines and a wide variety of software had become available, including word processing, spreadsheets, database management, communications, data processing, and graphics. Computing was ready to migrate from the Computer Center to the desktop. CACHE had already been made aware of the impending development of microcomputers at the April 14-16, 1976 meeting at the Lake of the Ozarks in Missouri because of information provided by Joseph D. Wright (industrial trustee from XEROX), who had became a Trustee in November 1975 and Chairman of the Real-Time Task Force at the Ozarks meeting.

At that same meeting, H. Scott Fogler, who had a great interest in the improvement of teaching methods, became a Trustee. At the June 7-9, 1978 meeting at Spring Lake, New Jersey, Fogler was appointed Chair of the Personal Computers Task Force. At the Nov. 29-30, 1979 meeting at Carmel, California, following the AIChE Annual meeting in San Francisco. Fogler announced that he and Carnahan had submitted a CACHE proposal to NSF on Personal Computing. Although the initial version of the proposal considered the preparation of programs for hand-held calculators with magnetic strips, that task was deleted and the proposal was focused on desk-top microcomputers of the PET and Apple type. However, in 1982 the task force did publish *Hand-Held Programmable Calculators: A Review of Available Programs for Chemical Engineering Education*, edited by Professor F. William Kroesser; this volume was followed by a more extensive listing of published calculator programs in the March 7, 1983 issue of *Chemical Engineering* by another source.

On June 23, 1980, NSF awarded a two-year grant of $128,000 to CACHE, to fund the proposal by Carnahan and Fogler. This project, which would become known as the MicroCACHE project, involved: (1) the development, by Carnahan, of a microcomputer-based delivery or authoring system for educational materials and programs and (2) the production of a small number of educational modules to test the system and demonstrate its effectiveness. The project was completed in April 1983. The final authoring system included a graphics package, a database management package, a numerical analysis package written in FORTRAN, and 13 prototype educational modules to test and demonstrate the system. In addition, two stand-alone modules, written under Fogler's direction, involved the simulation of a packed-bed reactor and the design of a multicomponent distillation column. Although the Apple II Plus microcomputer was selected as the hardware vehicle, an IBM PC version of MicroCACHE, prepared with other sources of funding was the initial system distributed by CACHE, starting late in 1984. Early in 1986, a second IBM PC version of the MicroCACHE software was announced. By April 1987, 30 copies of the software had been purchased from CACHE by departments. The most recent version of MicroCACHE is called MicroMENTOR, which consists of system management software for distribution of departmental computing resources to networked personal computers, lesson authoring software, and 11 instructional modules prepared with the authoring system for PCs running under DOS or OS/2.

Another venture by CACHE into the use of microcomputers began in 1981 with the election of Peter R. Rony as a Trustee. At that time many chemical engineering faculty recognized that computer interfacing in the laboratory was about to shift from relatively expensive minicomputers to much less expensive microcomputers, as predicted by Wright. Starting in 1974, Rony had written and edited monthly columns on computers and, more particularly, on microcomputer interfacing, in *American Laboratory and Computer Design*. He had authored nine popular books (called the “Bug” books) on integrated circuits, programming, and interfacing of microprocessors, and had conducted several short courses on those topics. At the April 8-9, 1981 meeting in Houston, CACHE approved a five-day course on microcomputer interfacing/programming to be given by Rony for 20 interested faculty, at the lowest possible cost, at Purdue University on February 11-15, 1982. The great success of the course led to an additional five-day course on October 21-25, 1982 at the University of Pennsylvania. One participating faculty member commented that this course was the most important thing that CACHE had done to date.

On February 12, 1984, Rony and Wright published the results of a survey entitled, “Microcomputers and Personal Computers in American and Canadian Departments of Chemical Engineering.” They received 46 responses and concluded that interest in the use of microcomputers was growing rapidly and that the introduction of the IBM PC with a 16-bit Intel chip promised a very bright future for the personal computer. In November 1984, Wright arranged for appearance of the survey results in the April 1980 issue (No. 14) of *CACHE News,* and signaled the importance of faculty members having their own personal computers. In 1982, he began compiling lists of programs for microcomputers and arranged a visit by the CACHE Trustees to the Xerox Palo Alto Research Center (PARC) where much of the early research that culminated in the graphical interface of the Apple Macintosh computer was carried out.

At the November 20-22, 1980 meeting at Fontana, Wisconsin, Bruce A. Finlayson was elected a Trustee. Finlayson had authored two important books in numerical mathematics for chemical engineers and was one of the first faculty to have his own personal computer and to recognize its advantages over mainframe computers, particularly in the graphics area. Beginning with the April 1984 issue (No. 18) of *CACHE News*, he wrote a series of articles entitled “Programs for PCs,” which described in detail available software of interest to chemical engineers. By the Spring 1993 issue, Finlayson had described 24 programs.

Starting in the 1970s, and especially in 1976 with funding by the NSF and the DOE for the LINPACK project of the Applied Mathematics Division of Argonne National Laboratory, high-quality public-domain software for numerical methods began to become available. At the November 12-13, 1981 meeting in Cancun, William E. Schiesser, an important contributor to the development of software for the numerical solution of ordinary and partial differential equations, became a Trustee of CACHE. Beginning in 1975, he had served as Chairman for the biannual AICA/IMACS International Symposia on Computer Methods for Partial Differential Equations. Starting in the September 1982 issue (No. 15) of *CACHE News*, he wrote a series of articles on available high-quality software for the solution of systems of linear, nonlinear, ordinary differential, partial differential, and differential-algebraic equations. Most importantly, he became a distributor for several of the more widely used packages, so that copies could be obtained by faculty from him. By the Spring 1989 issue of *CACHE News*, Schiesser had written seven articles on these programs. Much of this type of software is now readily available over the Internet by accessing netlib@ornl.gov, from which an index of all available programs can be obtained by E-mail request. While this software was almost exclusively used on mainframes, minicomputers, and workstations when the software first became available, much of the software runs at an adequate speed on today's PCs.

Another early thrust by CACHE in computer-based instruction using desktop computers was made by Stanley I. Sandler and Michael B. Cutlip, who were also elected Trustees at the November 1981 meeting. At that time, the Control Data Corporation had developed a worldwide educational computer system called PLATO, which used special touch-screen terminals connected to a dedicated mainframe computer. Sandler and Cutlip were among the chemical engineers who were leaders in developing PLATO software. At the July 30 - August 1, 1982 meeting at Ojai, California, they were appointed Co-Chairs of a new Computer-based Instruction Task Force. The PLATO system had already been evaluated by Cameron M. Crowe, based on his experiences with second-year chemical engineering students in a material balance, energy balance, and thermodynamics class. The PLATO lessons had been prepared by Sandler, Charles A. Eckert, N. A. Ashby, and S. C. Miller. Crowe's evaluation, which appeared in the April 1982 issue (No. 14) of *CACHE News*, stressed the importance of PLATO in practicing problem solving and reviewing concepts. Unfortunately, the cost of using the PLATO system was too high for it to receive widespread use at universities. However, the potential use of a desktop computer with a graphical user interface to assist computer-based instruction was well established by the task force.

On July 6-11, 1980 at New England College, Henniker, New Hampshire, Professors Richard S. H. Mah, who had been elected Trustee in 1973, and Warren D. Seider conducted the first International Conference on the Foundations of Computer-Aided Chemical Process Design (FOCAPD), which was organized by the CAST Division of the AIChE, supported by the NSF, and sponsored by the Engineering Foundation and the AIChE, with the proceedings being published by the AIChE. The conference brought together 146 participants from industrial and governmental laboratories and universities of 16 countries to listen to, discuss, and critique 30 papers. Because design methods and tools were being improved at a rapid rate due to the ready availability of computers of increasing capability, the success of the Henniker conference suggested that such a conference should be held every three or four years. Just prior to the conference, Mah wondered why CACHE couldn't provide the management and arrangements for such a conference. Of course, that would include setting the fee for the conference, providing the advertising, assuming the financial risk in the event that the conference did not at least break even, and publishing the proceedings. At the June 12-14, 1980 meeting at Hershey, Pennsylvania, Mah presented a proposal for CACHE to provide management and arrangements for specialized research conferences and an Ad Hoc Committee on Conferences was formed with Mah as the Chair. At the November 20-22, 1980 meeting at Fontana, Wisconsin, Mah's proposal was approved and in 1982, the CACHE Conferences Task Force was formed with Mah as the Chair. Prior to the formation of this task force, CACHE had only engaged in projects involving teaching. Now CACHE would also involve itself in sponsoring conferences related to research. Periodic conferences managed by CACHE could provide a much-needed steady source of additional revenue through conference fees and sales of proceedings. CACHE could provide financial assistance to young faculty to attend such conferences. The main goal of the conferences would be to provide a mechanism for engineers from industry, government, and academia to share their viewpoints and directions.

The first CACHE-arranged research conference, called FOCAPD-83, was the Second International Conference on Foundations on Computer-Aided Process Design held at Snowmass Village, Colorado on June 19-24, 1983. Art Westerberg and Dr. Henry H. Chien of Monsanto Company served as conference chair and co-chair, respectively. The conference, whose management by CACHE was approved by the CAST Division of AIChE, was sponsored by the NSF, nine companies, and CACHE, and had 162 attendees from 12 countries divided almost equally between industry and academia. The conference proceedings, which included 22 papers, were edited, printed from camera-ready copy, and distributed by CACHE, under the direction of Carnahan. Registration and conference arrangements were handled by Seader and Vickie S. Jones. Total income to CACHE for the conference was $104,000, with $21,500 coming from the NSF, $11,000 from industrial sponsors, and $71,500 from registration fees at an average of $440 each. The NSF funds were the result of a proposal of May 1, 1982 to the NSF by Westerberg. All of the NSF and industrial-support funds were used to partially defray conference fees and travel expenses for invited speakers and session chairs. In addition, CACHE provided a total of $2,600 for the partial support of young faculty who were invited to attend the conference. Total expenses for the conference were $83,400. By May 30, 1984, following sales of the proceedings to libraries and individuals not attending the conference, the net income to CACHE for the conference was about $25,000. Of this, $15,000 was set aside to back-up future conferences. The first CACHE conference was considered a huge success both technically and financially. However, with respect to the latter, it was recognized that the profit-attendance curve is very steep. Had the attendance been only 100, CACHE would have lost money.

At the November 18-20, 1982 meeting at Newport Beach, California, Thomas F. Edgar, who had become President of CACHE at the April 8-9 meeting in Houston, suggested that CACHE should offer to manage the Third International Conference on Chemical Process Control. These so-called CPC conferences were initiated in 1976, with the second conference in 1981. The offer was accepted, and CPC III, chaired by Manfred Morari and Thomas J. McAvoy, was held from January 12-17, 1986 at Asilomar Conference Grounds, California, with 145 participants from 16 different countries. The ability of CACHE to manage research conferences was now firmly established and had become an important source of income for the organization. Since the FOCAPD-83 and CPC III conferences, the following additional CACHE conferences have been held:

July 5-10, 1987 – "Foundations of Computer-Aided Process Operations (FOCAPO I) – Chaired by G. V. Reklaitis and H. Dennis Spriggs – Park City, Utah – 135 participants.

July 10-14, 1989 – FOCAPD-89 – Chaired by J. J. Siirola, I. E. Grossmann, and G. Stephanopoulos - Snowmass Village, Colorado – 170 participants.

February 17-22, 1991 – CPC IV– Chaired by Y. Arkun and Harmon Ray – Padre Island, Texas – 158 participants.

July 18-23, 1993 – FOCAPO II – Chaired by David W. T. Rippin, J. C. Hale, and J. F. Davis – Mount Crested Butte, Colorado – more than 100 participants.

July 10-15, 1994 – FOCAPD-94 – Chaired by M. F. Doherty and L. T. Biegler – Snowmass Village, Colorado – 143 participants.

July 9-14, 1995 – ISPE-95 – "Intelligent Systems in Process Engineering" – Chaired by G. Stephanopoulos, J.F. Davis, and V. Venkatasubramanian – Snowmass Village, Colorado – Snowmass Village, Colorado – Snowmass Village, Colorado – 145 participants.

January 7-12, 1996 – CPC-V – Chaired by Jeffrey Kantor and Carlos Garcia– Snowmass Village, Colorado – Tahoe City, California – 143 participants.

To facilitate the management of conferences, especially with regard to the sharing of duties between CACHE management and conference chairs, Mah, with assistance from the task force, prepared the *CACHE Conference Chairman's Manual* that was issued on March 15, 1982. At the November 11-13, 1993 meeting in St. Louis, Siirola became the new chair of the Standing Committee on Conferences and, with Mah, prepared a major revision of the conference chairman's manual. Plans are underway for future conferences to be held in 1997, 1998, and 2000.

Starting in August of 1966 and finishing in 1977, Professor Buford D. Smith of Washington University, with partial funding from the Exxon Education Foundation, supervised the development of a series of 22 design case studies prepared by chemical engineers at Monsanto, Amoco, DuPont, Phillips Petroleum, Foster Wheeler, Washington University, Newark College of Engineering, Notre Dame University, University of Delaware, University of Toledo, Purdue University, and University of Arkansas. During the 1970s, these design case studies, together with AIChE Student Contest Problems, had been become the major sources of design problems for senior design courses in chemical engineering.

At the November 20-21, 1980 meeting at Fontana, Wisconsin, George Stephanopoulos, who had been elected Trustee in 1977, was appointed Chair of the newly organized Process Design Case Studies Task Force whose assignment was to determine whether a new set of design case studies that made more use of computer-aided design tools should be prepared. At the November 12-13, 1981 meeting, Manfred Morari, who had been elected Trustee at the Fontana meeting and who became the new Chair of the Process Design Case Studies Task Force at that meeting, presented the following findings of the task force concerning the available design case studies: (1) they did not exercise an integrated approach, (2) they usually did not stress the synthesis of alternatives, and (3) they did not take advantage of computer-aided design tools. Therefore, Morari proposed that the task force supervise the development and publication of a new series of process design case studies based on current computer-aided design philosophy.

The first CACHE process design case study, completed in September 1983 and entitled *Separation System for Recovery of Ethylene and Light Products from a Naphtha-Pyrolysis Gas Stream*, was based on a problem statement posed by EXXON and developed into a case study by A. Michael Lincoff of Carnegie Mellon University under the supervision of Ignacio E. Grossmann, who was elected a Trustee at the November 4-5, 1983 meeting in Williamsburg, Virginia, and Gary E. Blau who was later elected as an industrial trustee (Dow Chemical Co. and later Dow-Elanco) on December 1-3, 1988 at the Leesberg, Virginia meeting. The design study involved the synthesis of a separation sequence, optimization of column pressures, and synthesis of a heat-exchanger network. The design calculations were made with an interactive process simulation program called DESPAC.

Since the first CACHE Process Design Case Study, six additional case studies have been edited by Morari and Grossmann and published by CACHE for use by universities; the most popular is Vol. 6, with more than 90 copies sold as of early 1995:

Vol. 2 - *Design of an Ammonia Synthesis Plant* - Problem posed by Phillip A. Ruziska of Exxon Chemicals - Solution by Stacy G. Bike under the supervision of Grossmann - May 1985.

Vol. 3 - *Preliminary Design of an Ethanol Dehydrogenation Plant* - Problem posed by Union Carbide - Solution under the supervision of Biegler and Hughes - May 1985.

Vol. 4 - *Alternative Fermentation Processes for Ethanol Production* - Solution by Samer F. Naser under the supervision of Steven E. LeBlanc and Ronald L. Fournier of the University of Toledo - April 1988.

Vol. 5 - *Retrofit of a Heat Exchanger Network and Design of a Multiproduct Batch Plant* - Solutions by Richard D. Koehler and Brenda A. Raich under the supervision of Grossmann - May 1990.

Vol. 6 - *Chemical Engineering Optimization Models with GAMS* - Problems prepared by faculty and students at Carnegie Mellon, Northwestern, and Princeton with coordination by Grossmann - October 1991.

Vol. 7 - *Process Integration of an Ethylene Plant* - Problem posed by EXXON and solution prepared by Gert-Jan A. F. Fien and Y. A. Liu of Virginia Tech - 1994.

In the Spring 1989 (No. 28) issue of *CACHE News*, Jeffrey C. Kantor, who became a CACHE Trustee in November 1992, published an article entitled, “Matrix Oriented Computation Using Matlab (Matrix Laboratory),” which had been developed in FORTRAN by Cleve Moler in 1981 and included most of the numerical algorithms from LINPACK and EISPACK, of which Moler also was a co-author. Initially, Matlab was a public-domain program, but with the advent of PCs in the early 1980s, Moler and others formed The MathWorks, Inc. to market PC-Matlab, written in C for portability and efficiency. By 1991, Matlab had grown considerably in popularity. Toolboxes had been added, including the Control System Toolbox, and the program was being used by students at more than 80 universities worldwide. In his article, Kantor showed how Matlab could be used to increase the productivity of a course in process control. At the April 6-7, 1991 meeting in Woodlands, Texas, The Process Design Case Studies Task Force announced that Manfred Morari and N. Lawrence Ricker, with Douglas B. Raven and a number of other contributors, were developing a CACHE Model Predictive Control Toolbox (CACHE-Tools) based on the use of Matlab functions for the analysis and design of model predictive control (MPC) systems. MPC had been conceived by industry in the 1970s and had steadily gained in popularity until by the 1990s it had become the most widely used multivariable control algorithm in the chemical process industries. The first version of CACHE-Tools was distributed on October 30, 1991. A presentation and demonstration of CACHE-Tools was made at the November 20, 1991 CACHE Open House at the Los Angeles AIChE meeting by Yaman Arkun, who had been elected a Trustee in November 1986. An article on CACHE-Tools by Morari and Ricker appeared in the Spring 1992 issue (No. 34) of *CACHE News*. By early 1995, more than 40 copies of CACHE-Tools had been sold to departments.

At the November 4-5, 1983 meeting in Williamsburg, Virginia, a suggestion was made for CACHE to focus more on the ChE curriculum and its needs and less on computer technology. Accordingly, an Ad Hoc Committee on Curriculum was formed with Morton M. Denn, who had been elected a Trustee in November 1981, as Chair, with the goal of assisting chemical engineering departments to effectively integrate computing and computer technology into undergraduate education. One of the factors considered by the committee was the expectations of industry for chemical engineers entering the work force. At the November 29-December 1, 1984 meeting at Carmel, California, the Curriculum Task Force was formed with Denn and Seider as Co-Chairs. At the following meeting on March 28-29, 1985 at Woodlands, Texas, the task force presented a position paper entitled, “Expectations of the Competence of Chemical Engineering Graduates in the Use of Computing Technology.” This paper, which was published in the Winter 1986 issue of *Chemical Engineering Education* with an introduction by Denn, was approved by CACHE for distribution to the AIChE Education and Accreditation Committee. The paper listed the following expectations:

1. The graduate must be familiar with at least one computer operating system.
2. The graduate must be competent in at least one scientific programming language.
3. The graduate must be experienced in computer-aided acquisition and processing of information.
4. The graduate should have conducted at least one information retrieval search from an electronic data base.
5. The graduate should have experience in the use of a word processor and a graphics program for the generation of reports.
6. In the near future, the graduate should have experience with electronic mail and external data bases.
7. The graduate should have an appreciation of the concepts of numerical analysis, including convergence and stability.
8. The graduate should be familiar with the use of spreadsheets.
9. Most importantly, computing should be integrated throughout the curriculum and more use should be made of open-ended problems.

The March 28, 1985 position paper was transmitted by letter of May 6, 1985 from Mah, then President of CACHE, to Professor Bryce Andersen, then Chairman of the AIChE Education and Accreditation Committee. Also, all chairs of chemical engineering departments in the United States were sent a copy of the position paper and informed of the letter to Andersen by another letter from Mah of May 16, 1985. Concurrent with the development of the CACHE position paper, the Chemical Engineering Department of the University of Texas at Austin commissioned a group of industrial leaders to recommend changes in chemical engineering education. Their report, which was sent to all chemical engineering departments in the United States and is summarized in the October, 1985 issue of *Chemical Engineering Progress*, included the following corroborative statement about computing:

> "Educators must fully recognize the major position that the computer and professionally written software play in the modern practice of the profession. The computer should become the dominant calculational tool early in the curriculum."

The impact of CACHE and the University of Texas on computing in the undergraduate chemical engineering curriculum may be judged by the following quote, which did not appear in the early 1980s but does now appear, in the 1994-95 "Criteria for Accrediting Programs in Engineering in the United States" of ABET in cooperation with the E & A (Education and Accreditation) Committee of AIChE:

> "IV.C.3.g. Appropriate computer-based experience must be included in the program of each student. Students must demonstrate knowledge of the application and use of digital computation techniques for specific engineering problems. The program should include, for example, the use of computers for technical calculations, problem solving, data acquisition and processing, process control, computer-assisted design, computer graphics, and other functions and applications appropriate to the engineering discipline. Access to computational facilities must be sufficient to permit students and faculty to integrate computer work into course work whenever appropriate throughout the academic program."

The recommendations of CACHE for computing skills were amended at the December 1-3 meeting in Leesberg, Virginia and transmitted in a letter of December 20, 1988 from Seider to John W. Prados of ABET. These recommendations now are included as an appendix to the ABET accreditation materials distributed by the E & A Committee of AIChE to chemical engineering program evaluators for accreditation.

To assist professors in making use of computing technology in under-graduate courses other than design and control, the Curriculum Task Force, at the Woodlands, Texas meeting in 1985, proposed that CACHE publish a series of open-ended problems with an emphasis on problem formulation and the seeking of a solution, rather than the development of a computer program. In the Fall of 1987, CACHE published and distributed *CACHE IBM PC Lessons for Chemical Engineering Courses Other than Design and Control*, with the following six lessons in color graphics format prepared largely by students under the direction of the listed professors:

1. "Slurry Flow in Channels" - Denn
2. "Supercritical Fluid Extraction" - Seider
3. "Gas Absorption with Chemical Reaction" - Seinfeld
4. "Design of Flash Vessels and Distillation Towers" - Finlayson
5. "Heterogeneous Reaction Kinetics" - Fogler
6. "CSTR Dynamics and Stability" - David T. Allen

At the November 14-16, 1985 meeting in St. Charles, Illinois, George Stephanopoulos, who was re-elected as Trustee in December 1984 after his return from Greece, informed the trustees that considerable progress had been made recently in artificial intelligence (AI) and that important contributions could now be made in process engineering by knowledge-based (or expert) systems. He proposed that CACHE introduce knowledge-based, computer-aided tools into the mainstream of chemical engineering education. Accordingly, an Ad Hoc Committee on Expert Systems was formed with Stephanopoulos as Chair. At the November 6-8, 1986 meeting in Key West, the committee became the Expert Systems Task Force, with work under way to publish case studies and monographs. Three volumes of case studies, written by Venkat Venkatasubramanian who was elected Trustee on November 7, 1992, edited by Stephanopoulos, and entitled *Knowledge-Based Systems in Process Engineering*, were published and distributed in the Fall of 1988. The volumes, which presented the following four subjects, provided an excellent introduction to the subject of expert systems for chemical engineers:

1. *A General Introduction to Knowledge-Based Systems*.
2. *CATDEX: An Expert System for Diagnosing a Fluidized Catalytic Cracking Unit*.
3. *PASS: An Expert System for Pump Selection*.
4. *CAPS: An Expert System for Plastics Selection*.

The next step taken by the Expert Systems Task Force was to prepare an in-depth series of monographs covering all aspects of artificial intelligence as they might apply to chemical engineering. James F. Davis, who had been elected Trustee on November 14, 1987, became a co-editor of the volumes with Stephanopoulos. The first three volumes of the series, entitled *Artificial Intelligence in Process Systems Engineering*, with the following titles, were published and distributed in the Fall of 1990, followed by a fourth volume in the Spring of 1994:

1. *Knowledge-Based Systems in Process Engineering: An Overview* by Stephanopoulos.
2. *Rule-Based Systems in Chemical Engineering* by Davis and Murthy S. Gandikota.
3. *Knowledge Representation* by Lyle H. Ungar and Venkat Venkatasubramanian.
4. *An Introduction to Object-Oriented Programming in Process Engineering* by Ronald G. Forsythe, Jr., Suzanne E. Prickett, and Michael L. Mavrovouniotis.

In addition, Stephanopoulos and Mavrovouniotis were guest editors for a special September/October 1988 issue of *Computers and Chemical Engineering*, which featured 15 refereed articles on research and development in artificial intelligence in chemical engineering and was distributed with CACHE funds to all chemical engineering departments in the United States and Canada.

At the July 23-24, 1993 meeting at Mt. Crested Butte, Colorado, the Expert Systems Task Force reported that the case studies and monographs were attracting interest in AI, and process systems engineers were now beginning to come to a good appreciation of what AI could and could not do. AI techniques, such as knowledge-based systems, heuristic search, neural networks, and object-oriented programming were being successfully integrated with applied mathematics and operations research for process engineering applications. They proposed that CACHE manage an international conference on intelligent systems in process engineering to be held in 1995. The conference was approved by the CACHE Conferences Task Force.

Although E-mail is widely used and taken for granted today by chemical engineers, this was not the case in 1983 when CACHE organized the Ad Hoc Committee on Communications (E-mail) at the Williamsburg, Virginia meeting with Rony as Chair. Although E-mail, together with TELNET to log on to a remote computer and FTP to transfer files between a local and a remote computer, had been available at universities via the ARPANET national network, conceived in 1968 and in service by 1971, these services had been used mainly by computer scientists and other engineering professionals with government contracts. In *CACHE News* No. 19 of September 1984, Rony announced that in a one-year experiment, the committee would: (1) gather information on existing networks, (2) coordinate an E-mail experiment with a small group of interested chemical engineers, (3) determine potential chemical engineering applications, and (4) determine whether a ChE E-mail service should be established.

At the March 28-29, 1985 meeting at The Woodlands, Texas, the ad hoc committee became the Electronic Mail Task Force. In the April 1986 issue of *CACHE News* (No. 22), Rony announced, in a two-part article, some of the results of the CACHE national electronic mail experiment. Despite much publicity, interest in E-mail among chemical engineers remained low at that time. Although CACHE authorized 150 mailboxes on the COMPMAIL+ service, only 10-15 accounts were used actively. However, the use of E-mail to transfer files at a relatively low cost was amply demonstrated by Rony, Editor of *CAST Communications*, who transmitted by COMPMAIL+ the articles for the April 1985 issue to Associate Editor Wright, who supervised the final layout of the issue for printing. Some article files were also sent by COMPMAIL+ to Himmelblau for *CACHE News*.

By 1987, a number of wide-area networks had been established, including ARPANET, CSNET, BITNET, USENET, and NSFNET. In particular, BITNET (Because It's Time), which had been established as a financially self-supporting network with no central administration or paid staff by CUNY in 1981 to link university computers for inter-university communications and with only 65 hosts, had, by 1985, reached 1,000 host computers. Besides E-mail, BITNET offered other services including a bulletin board and file transfer. In the April 1986 issue of *CACHE News* (No. 22), Rony recommended that chemical engineers use BITNET for E-mail. In the Fall 1989 issue of *CACHE News* (No. 29), the Netlib system for distributing public domain mathematical software via electronic mail was announced. The index can be obtained by sending the message Send Index to netlibl@epm.ornl.gov. In that same issue and the following one, Rony presented an extensive user's guide to electronic mail, including the Internet, which had now become the major gateway for connecting networks. By January of 1994, 2,217,000 host computers were on the Internet. Today, almost all chemical engineers in academia, industry, and government have E-mail addresses.

Thanks to the Internet, E-mail addresses are relatively simple, being of the general form: username@machine.dept.inst.domain. For example, seader@uuserv.cc.utah.edu. A large list of E-mail addresses for chemical engineers is maintained on a gateway machine at the University of Texas at Austin by Rony, James B. Rawlings, and John W. Eaton. The list can be obtained by sending the message Send Index to chelib@che.utexas.edu.

At the November 14-16, 1985 meeting in St. Charles, Illinois, an Ad Hoc Committee on Simulated Laboratory Experiments was organized with Reklaitis as Chair. He told CACHE of plans by Robert Squires and himself to pursue funding from industry and the NSF through CACHE to prepare a series of simulated process engineering laboratory/pilot plant experiments with an industrial process orientation for use by students at universities to fill an important gap in their education. The approach would be for the student to solve a process engineering problem as if he/she were in industry. The student would: (1) view a video tape of an actual industrial process showing the equipment and the control panel, along with a discussion of operating conditions and safety features, (2) be given a description of a process engineering problem for a section of the process that requires a solution, (3) carry out some experimental work to obtain necessary data, (4) carry out simulations with the data to solve the problem using both steady-state and dynamic models, and (5) prepare a report with recommendations. A problem involving a new resid hydrotreater of Amoco was already formulated.

At the December 1-3, 1988 meeting at Leesberg, Virginia, the ad hoc committee was replaced by the Simulated Laboratory Modules Task Force and Reklaitis reported that NSF had agreed to fund the development of five simulated laboratory modules over three years for $270,000, with additional industrial support for the formulation of the problems from Amoco (hydro-desulfurization), Dow Chemical (latex emulsion polymerization), Mobil (catalytic reforming), Air Products (process heat transfer), and Tennessee-Eastman (methyl acetate from coal). On August 10, 1989 a workshop for interested faculty was held at Purdue University on use of the Amoco problem. By 1990, the Amoco, Dow, and Mobil modules were in beta-test, and a workshop for 23 faculty on the use of the modules was held at Purdue University on July 27-29, 1990. An article on the Amoco module appeared in the Spring 1991 issue of *Chemical Engineering Education*. A third workshop for representatives from 34 departments was held on July 26-28, 1991 at Purdue. By the Spring of 1993, the Amoco, Dow, Mobil, and Tennessee-Eastman modules were ready for distribution by CACHE. All five modules are discussed by Squires, P. K. Andersen, Reklaitis, S. Jayakumar, and D. S. Carmichael in an article entitled, “Multimedia-Based Educational Applications of Computer Simulations of Chemical Engineering Processes,” which appeared in *Computer Applications in Engineering Education*, Vol. 1, No. 1, pages 25-32, 1992.

At the St. Charles, Illinois meeting of November 1985, an Ad Hoc Committee on Laboratory Applications of Microcomputers was formed with Mellichamp as Chair. With the approval of the Trustees, Mellichamp reported that he and Ali Cinar would prepare a survey of the use of computers in undergraduate laboratory experiments. That survey, which resulted in 116 replies to a questionnaire from departments in 10 countries, was published by CACHE in September 1986. From that survey, Cinar and Mellichamp selected 21 experiments and included them in the CACHE publication, *On-Line Computer Applications in the Undergraduate Chemical Engineering Laboratory: A CACHE Anthology*, which was published in June 1988. Construction and instrumentation details are given for each experiment. The authors show how a PC can be used to take the data, and analyze and display the results.

By the mid-1980s, the use of steady-state process simulation was well established in undergraduate education. However, a growing number of chemical engineers were becoming involved in batch processing. GPSS (General Purpose Simulation System) had been created by IBM in 1959 to solve such discrete-event simulation problems, by allowing the user to use time as the basic variable, with varying parameters and process layouts. To assist chemical engineering educators in introducing students to discrete-event simulation, CACHE, in 1988, published a book, written by Daniel J. Schultheisz and Jude T. Sommerfeld, entitled, *Exercises in Chemical Engineering using GPSS,* which included the educational version of the GPSS/PC program and 18 solved problems, covering a wide range of complexity from the unloading of oil tankers to the batchwise manufacture of PVC.

Since 1975, CACHE has had a New Projects and Long-Range Planning Committee, which from time-to-time has been requested by the CACHE Executive Committee to make recommendations. The first major report was issued by the committee, with Seider as Chair, in May 1984. Some major recommendations included the following: (1) consider projects other than computer-related educational aids, (2) keep abreast with the latest changes in computing and systems technology, (3) carefully consider new projects, (4) consider new means of financing activities and projects, and (5) find ways to help young faculty. At the March 5-6, 1988 meeting at New Orleans, Siirola became the first industrial trustee elected to Vice-President, and assumed the task of long-range planning. At the next meeting, in Leesberg, Virginia, he led a soul-searching discussion, during which the following questions were raised: (1) Why don't more faculty use CACHE products? (2) What new products are needed? and (3) How do we achieve better feedback from our customers? At the July 1989 meeting at Snowmass, Siirola arranged for the first of two Future Planning Exercises, the first of which was led by David Stump of Eastman Kodak, to consider the topics of suppliers, inputs, processes, outputs, and customers. At the March 17-19, 1990 meeting at Orlando, Siirola became President of CACHE and reported the results of the Future Planning Exercises, which were slightly modified and issued in final form at the following meeting in Chicago. The accepted mission and vision statements were:

> "The mission of CACHE is to provide leadership and resource materials for advancing the use of computer-based methods and technology in chemical engineering education and practice."
>
> "The goal of CACHE is to be the recognized facilitator in the identification, creation, distribution, understanding, and use of timely computer-based products and services which have a substantial impact on undergraduate, graduate, and postgraduate chemical engineering education."

The key results of the exercises were the following goals:

1. Identify our customers and understand their needs.
2. Gain customer acceptance.
3. Identify existing or facilitate the development of superior products.
4. Facilitate the distribution and understanding of our products and services.
5. Recognize our limits and resources.
6. Operate CACHE in a fiscally sound manner.

In 1974, Fogler published the text-book, *The Elements of Chemical Kinetics and Reactor Calculations,* which included information on and stressed the importance of programmed learning. In his subsequent 1986 book, *Elements of Chemical Reaction Engineering*, he further elucidated that approach and illustrated it throughout the book. This led to an interest in how to develop innovation in problem solving, with the concern that if we are to be economically competitive, our engineers must be able to generate new ideas, processes, and products. In 1988, with the help of six undergraduate engineering students, he assembled a booklet entitled, *A Focus on Developing Innovative Engineers*, which formed the basis of an NSF proposal. The booklet included an approach to teaching innovation and the application of the approach to a large number of industrial problems.

At the December 1988 meeting at Leesberg, Virginia, CACHE organized the Innovative Engineering Task Force chaired by Fogler, who announced that his University of Michigan proposal to NSF, entitled *A Focus on Developing Innovative Engineers*, had been funded for two years at $250,000, with a subcontract to CACHE of $26,000. With Susan M. Montgomery as Project Manager, the project was extended to 1993, by which time (August), four sets of interactive computer modules for PCs running MS-DOS were completed for distribution by CACHE. These four sets, containing a total of 24 modules, were developed to enhance the teaching of material and energy balances (5 modules), fluid mechanics and transport phenomena (5 modules), separations (5 modules), and chemical reaction kinetics (9 modules). Some of the modules include new technologies, while all utilize graphical animations and entertaining motivators, whose design was facilitated by use of the QUEST authoring system. The modules are discussed by Fogler, Montgomery, and Robert P. Zipp in the article, “Interactive Computer Modules for Undergraduate Chemical Engineering Instruction,” which appeared in *Computer Applications in Engineering Education,* Vol. 1, No. 1, pages 11-24, 1992.

At the November 9-11, 1989 meeting at St. Helena, California, Finlayson announced that he had received an NSF grant through the University of Washington with support for CACHE assistance in a project for the development, testing, and evaluation of computer programs for reactor design using state-of-the-art numerical methods on UNIX workstations running X-Window. By 1994, the project was completed. Known as the Chemical Reactor Design Toolbox, the program simulates batch reactors, CSTRs, plug-flow reactors, plug-flow reactors with axial dispersion, and 2-D reactors with axial dispersion, including multiple reactions and heterogeneous reactions, with and without heat transfer and pressure drop.

Also at the St. Helena meeting, the Trustees were informed that Tektronix was marketing a new computational chemistry system, advertised in the May 1, 1989 issue of C&EN under the trade name CACHE. Concern was expressed about the use of the CACHE name and it was decided to have a lawyer investigate what protection CACHE might have and whether the name could be trademarked. At the November 1990 meeting in Chicago, Himmelblau reported that Tektronix had agreed to pay CACHE $10,000 plus $1,000/year for three years as a settlement. CACHE did attempt to register the CACHE trademark, but the application was rejected because of previous related applications by other companies and the potential cost of litigation.

By the November 12-14, 1987 meeting at Southampton, Bermuda, the Large-Scale Systems Task Force, which had been chaired by Jeffrey J. Siirola since November 1984 (Siirola had become an industrial Trustee at the Snowmass meeting in June 1983) announced that it was actively seeking software products in addition to FLOWTRAN. More and more, as PCs and workstations were becoming more pervasive and capable, programs were migrating from main frames to the smaller computers. Accordingly, at that meeting the name of the task force was changed to the Process Engineering Task Force. H. Dennis Spriggs, who had been elected industrial Trustee at the Snowmass meeting while with Union Carbide, was then with Linnhoff-March Process Integration Consultants, who had developed software for heat-exchanger network synthesis. Spriggs informed the task force that one of their products, TARGET II, could be made available to educators. This software was designed to determine the minimum utilities and pinch temperatures for an exchanger network and produce *composite* and *grand composite* plots with a graphical display. Following a favorable evaluation by the task force, Seader prepared a user's guide and distribution of TARGET II began in 1987.

The TARGET II program did not actually synthesize a heat-exchanger network, but only performed the targeting. At the Snowmass meeting in July, 1989, Edward M. Rosen, who had been elected an industrial Trustee at the Snowmass meeting in August, 1977, and was appointed Chair of the Process Engineering Task Force at the Leesberg, Virginia meeting in December, 1988, announced that CACHE had received a favorable evaluation for an educational program, called THEN (Teaching Heat Exchanger Networks), written by S. Pethe, R. Singh, S. Bhargava, R. Dhoopar, and F. Carl Knopf. This program locates pinch temperatures and then allows a student to use heuristics to develop a network using graphics. The program permits stream splitting and identifies heat exchanger loops, as described in an article by Pethe, Singh, and Knopf in Vol. 13, No. 7 of *Computers and Chemical Engineering*, pages 859-860. Distribution of THEN began in 1989.

The next software package that was offered to CACHE and received a favorable evaluation by the Process Engineering Task Force was PIP (Process Invention Procedure), an interactive PC code, written under the supervision of James M. Douglas, for the synthesis of petrochemical gas-liquid processes. Douglas had been elected Trustee at the 1988 Bermuda meeting and in 1988 published an innovative textbook for a senior design course entitled *Conceptual Design of Chemical Processes*. PIP became a CACHE product in the Fall of 1989. At the November 14, 1990 CACHE Open House during the Chicago AIChE meeting, Douglas gave a detailed description of PIP and its use in design. Ever since CACHE was first organized, there was considerable interest in obtaining and distributing *process synthesis* software. With TARGET II, THEN, and PIP, CACHE now had three such products.

At the July 1989 meeting in Snowmass, Michael B. Cutlip, who was elected a Trustee in November 1981, and Mordechai Shacham offered the POLYMATH software package to CACHE for distribution. This was a commercial program that had been developed with a the financial support of and marketed earlier by Control Data Corp. and had been in use at the University of Connecticut since 1983. The package included programs for curve fitting, solving nonlinear systems of equations, solving initial value problems in ordinary differential equations, linear and multiple regression, and manipulation of matrices. By the November 9-11, 1989 meeting at St. Helena, California, Rosen and Seader of the Process Engineering Task Force had evaluated the POLYMATH program and, after some minor revisions, had found it to be a very easy-to-use and useful program that should appeal greatly to undergraduate students. Fogler, who was then President of CACHE had also tested the package and, in a written "President's Perspective" of September 20, 1989 indicated that POLYMATH could be one of a growing number of very user-friendly software packages that were beginning to cause a paradigm shift in teaching toward more complex and open-ended problem assignments. Because of the growing number of undergraduate students who own their own PCs, Rosen developed a novel method of distribution for POLYMATH that was discussed at the November 15-17, 1990 meeting at Chicago. A chemical engineering department would license POLYMATH for $125 the first year and $75 per year thereafter. For that fee, the package could be copied for use during the year by any student or faculty member in the department. Thus, for the first time, a CACHE product would be put into the hands of a student at no cost to the student. Distribution of POLYMATH began in 1990, following a presentation on the package by Cutlip on November 11, 1990 at the AIChE meeting in Chicago and an article by Cutlip and Shacham that appeared in the Fall 1990 issue (No. 31) of *CACHE News*. During the first year of availability, POLYMATH was licensed by 75 departments. Version 3.0 of POLYMATH was described in the Fall 1994 issue of *CACHE News*. Version 4.0 was released in the Summer of 1996.

At the November 15-17, 1990 meeting at Chicago, Ross Taylor and Harry Kooijman offered CHEMSEP, a suite of PC programs for performing rigorous multicomponent multistage separation process calculations, for license to universities by CACHE. In 1977, Fredenslund, Gmehling, and Rasmussen had published a Newton-type code, coupled to the UNIFAC method for determining activity coefficients, for solving such problems. By the end of the 1980s, that type of method had been incorporated into most steady-state simulation programs. However, it was believed that an easy-to-use stand-alone PC-program with a built-in property data bank for about 200 components and a wide variety of thermodynamic property models would appeal to instructors and students for use in a separations course, especially if the program could produce tables and McCabe-Thiele and triangular plots of results. As discussed in an article by Kooijman and Taylor in *CACHE News* No. 35 (Fall 1992), the CHEMSEP project was initiated in February 1988 at the University of Technology in Delft, where the first version of the program was used successfully with undergraduate and graduate students. In 1991, an extended version 2.0 was completed. That version was evaluated by Rosen and Seader and approved for license by CACHE at the March 28-29, 1992 meeting in New Orleans. Following a detailed presentation on CHEMSEP by Taylor at the CACHE Open House on November 4, 1992 at the AIChE meeting in Miami, distribution of the program began. By November 1994, the program had been licensed by 40 departments. Version 3.0, which will include a rate-based model, is scheduled for distribution in the near future.

At the November 21-23, 1991 meeting at Indian Wells, California, Rosen announced that he had been approached by Douglas J. Cooper, who with his students had developed an interactive PC program called PICLES (Process Identification and Control Laboratory Experiment Simulator) that provided a student with "real-world" experience in the study of dynamics and control. The program uses colorful graphics and allows the student to follow the action as decisions are made, and includes models for tanks in series, a heat exchanger, and a distillation column, with controller algorithms ranging from P-only to PID. Following an evaluation by the Process Engineering Task Force and some program revisions, PICLES Version 3.1 was accepted as a CACHE product for license to universities in the Fall of 1993. Cooper presented a detailed description of the software at the CACHE Open House on November 10, 1993 at the St. Louis AIChE meeting. As with POLYMATH, with a department license, the software can be copied for use by students and faculty on their own computers. PICLES was described in issues

37 and 38 of *CACHE News*. By the end of 1994, the program had been licensed by 25 departments. Version 4.0 is described in the Fall 1994 issue of *CACHE News*.

The CD-ROM (Compact-Disk Read-Only Memory) appeared on the market about eight years ago. Although a bright future was predicted, particularly for the coupling of the CD-ROM with graphics, sound, and animation to achieve the multimedia PC (MPC), the promise was more than the reality, mainly because of a lack of standards. That changed late in 1991, when the Microsoft-endorsed MPC standard, ISO (International Standards Organization) 9660, for storing data was adopted. By March 1992, two MPCs and three multimedia upgrade kits were on the market, but none of them rated an Editors' Choice by PC Magazine. By mid-1992, seven companies were offering MPCs and seven different multimedia upgrade kits were available. However, at $800 to $1,900, the price of the kits was high. Finally, by the end of 1994, CD-ROMs and multimedia were here, with more than 5,000 CD-ROM titles, MPCs from almost every PC vendor, and upgrade kits priced at less than $400. Today, anyone purchasing a PC must give serious consideration to making it an MPC.

At the March 28-29, 1992 meeting at New Orleans, Cutlip became President of CACHE and announced that CACHE would celebrate its 25th anniversary in 1994. He also made a compelling case for the use of CD-ROMs for the distribution of CACHE products and documentation. On August 13, 1992 at the ASEE Summer School for Chemical Engineering Faculty at Montana State University, Rony was appointed Chair of an Ad Hoc CD-ROM Task Force with the objective of creating a demonstration CD-ROM disk. Rony's university, Virginia Tech., established a multimedia lab on September 18, 1992 and by 1993 was distributing software to students on CD-ROMs. Rony published two articles on CD-ROM technology in the Fall 1993 and Spring 1994 issues of *CACHE News*. In the latter article, he called for contributions to a 25th Anniversary CACHE CD-ROM. More than 1000 copies of that CD-ROM were distributed to chemical engineering students, faculty, and practitioners at the November 13-18, 1994 meeting of the AIChE in San Francisco. The CD-ROM contains 42 Mb of MacIntosh files and 636 Mb of Windows/DOS files, including Adobe Acrobat Reader for Windows, described in the Spring 1994 issue of *CACHE News*, and several CACHE software products. The 3M Company produced the copies and donated most of the blank disks. Yet another CD-ROM was prepared by Peter Rony during 1995; more than 1000 copies of this new CD-ROM were distributed to students and faculty in the Spring of l996.

On November 18, CACHE held a 25th Anniversary Dinner at the Silverado resort in Napa, California for former and current Trustees and their spouses. For that event, Seider prepared a CACHE Time-Line that listed all of the significant events that had occurred during the first 25-years of the history of CACHE and displayed most of the CACHE products together with photographs that had been taken at some of the CACHE meetings. The dinner was attended by 15 former CACHE Trustees. The first 25 years of CACHE were over. Much had been accomplished by untold hours of donated time by CACHE Trustees and a large number of interested faculty members. To begin CACHE's second quarter century, the Trustees thought it appropriate to elect, as President, Warren D. Seider, who helped organize CACHE in 1969.

Appendix I — CACHE Officers

Chair:

Brice Carnahan	1969-1971
Warren D. Seider	1971-1973
Lawrence B. Evans	1973-1974
Brice Carnahan	1974-1975
Ernest J. Henley	1975-1976

President:

Robert E. C. Weaver	1976-1977
Duncan A. Mellichamp	1977-1978
David M. Himmelblau	1978-1980
Richard R. Hughes	1980-1981
Thomas F. Edgar	1981-1984
Richard S. H. Mah	1984-1986
Gintaris V. Reklaitis	1986-1988
H. Scott Fogler	1988-1990
Jeffrey J. Siirola	1990-1992
Michael B.Cutlip	1992-1994
Warren D. Seider	1994-1996
Lorenz T. Biegler	1996-

Vice Chair:

Lawrence B. Evans	1971-1973
Brice Carnahan	1973-1974
Ernest J. Henley	1974-1975
Robert E. C. Weaver	1975-1976

Vice President:

Duncan A. Mellichamp	1976-1977
David M. Himmelblau	1977-1978
Richard R. Hughes	1978-1980
Thomas F. Edgar	1980-1981
David M. Himmelblau	1981-1982
Richard S. H. Mah	1982-1984
Gintaris V. Reklaitis	1984-1986
H. Scott Fogler	1986-1988
Jeffrey J. Siirola	1988-1990
Michael B. Cutlip	1990-1992
Ignacio E. Grossmann	1992-1994
Lorenz T. Biegler	1994-1996
James F. Davis	1996-

Secretary:

Warren D. Seider	1969-1971
Arthur W. Westerberg	1971-1973
J. D. Seader	1973-1974
Robert E. C. Weaver	1974-1975
Duncan A. Mellichamp	1975-1976
Rodolphe L. Motard	1976-1978
Richard S. H. Mah	1978-1980
H. Scott Fogler	1980-1982
Gintaris V. Reklaitis	1982-1984
Edward M. Rosen	1984-1986
John C. Hale	1986-1988
Michael B. Cutlip	1988-1990
Lorenz T. Biegler	1990-1992
Yaman Arkun	1992-1994
James. F. Davis	1994-1996
Andrew N. Hrymak	1996-

Executive Officer:

Lawrence B. Evans	1974-1980
J. D. Seader	1980-1984
David M. Himmelblau	1984-

Appendix II — Former CACHE Trustees

Name of Former Trustee	Affiliation at Time of Service	Dates of Service
James H. Christensen	University of Oklahoma	1969-1973
Eugene Elzy	Oregon State University	1969-1973
Edward A. Grens	University of California, Berkeley	1969-1973
Robert V. Jelinek	Syracuse University	1969-1973
A. I. Johnson	University of Western Ontario	1969-1973
Matthew J. Reilly	Carnegie-Mellon University	1969-1973
Imre Zwiebel	Worcester Polytechnic Institute	1969-1973
Robert E. C. Weaver	Tulane University	1969-1979
Arthur W. Westerburg	University of Florida	1969-1981
Lawrence B. Evans	Massachusetts Institute of Technology	1969-1984
Rodolphe L. Motard	Washington University	1969-1984
Ernest J. Henley	University of Houston	1969-1985
Richard R. Hughes	University of Wisconsin	1969-1986
Paul T. Shannon	Dartmouth College	1973-1974
Gary J. Powers	Massachusetts Institute of Technology	1973-1977
Cecil L. Smith	Louisiana State University	1973-1979
D. Grant Fisher	University of Alberta	1975-1977
Ronald L. Klaus	University of Pennsylvania	1975-1978
W. Fred Ramirez	University of Colorado	1975-1979
Duncan A. Mellichamp	University of California, Santa Barbara	1975-1987
Lewis J. Tichacek	Shell	1977-1985
Theodore L. Leininger	DuPont	1977-1980
James White	University of Arizona	1978-1980
Bruce A. Finlayson	University of Washington	1981-1992
John C. Hale	E. I. DuPont de Nemours	1981-1995
William E. Schiesser	Lehigh University	1982-1984
Irven H. Rinard	Halcon	1982-1985
Morton M. Denn	University of California, Berkeley	1982-1986
Stanley I. Sandler	University of Delaware	1982-1987
John H. Seinfeld	California Institute of Technology	1983-1991
H. Dennis Spriggs	Union Carbide	1984-1990
John J. Haydel	Shell	1986-1991
Norman E. Rawson	IBM	1986-1994
Yaman Arkun	Georgia Institute of Technology	1987-1995
James M. Douglas	University of Massachusetts	1988-1990
Gary E. Blau	Dow Elanco	1991-1995
Carlos E. Garcia	Shell	1993-1995

Appendix III — CACHE Trustees as of June 1996

Name of Present Trustee	Affiliation	Date Service Began
Brice Carnahan	University of Michigan	1969
J. D. Seader	University of Utah	1969
Warren D. Seider	University of Pennsylvania	1969
David M. Himmelblau	University of Texas	1973
Richard S. H. Mah	Northwestern University	1975
Thomas F. Edgar	University of Texas	1977
H. Scott Fogler	University of Michigan	1977
Edward M. Rosen	Monsanto Company	1977
Joseph D. Wright	Xerox	1977
Manfred Morari	California Institute of Technology	1978
George Stephanopoulos	Massachusetts Institute of Technology	1978
Gintaris V. Reklaitis	Purdue University	1980
Peter R. Rony	Virginia Polytechnic Institute and State University	1981
Michael B. Cutlip	University of Connecticut	1982
Ignacio Grossmann	Carnegie-Mellon University	1984
Jeffrey J. Siirola	Eastman Chemical Company	1984
Lorenz T. Biegler	Carnegie-Mellon University	1986
Michael F. Doherty	University of Massachusetts	1987
James F. Davis	Ohio State University	1988
Andrew N. Hrymak	McMaster University	1991
Sangtae Kim	University of Wisconsin	1991
Jeffrey Kantor	University of Notre Dame	1993
Venkat Venkatasubramanian	Purdue University	1993
Feran Kayihan	Weyerhaeuser Corp.	1994
Ross Taylor	Clarkson University	1995
David Smith	E. I. DuPont de Nemours	1995

Our curriculum contains distinct courses that differentiate it from similar programs. In addition to the common core for all Chemical Engineering students, we offer specialized courses for the Process and Biochemical Engineering Options. Chemical Engineering. Engineering Chemistry. Course Offerings. Course Objectives. CHE1.Â Program Goals and Learning Objectives. In keeping with the vision of the Department of Chemical Engineering, we pursue understanding beyond the limitations of existing knowledge, ideology, and disciplinary structure. We affirm the value to individuals and society of the cultivation and enrichment of the human mind and spirit. Our faculty, students, alumni and staff strive toward these objectives in a context of freedom with responsibility. M.E. Chemical Engineering is post-graduation in the chemical engineering program. The duration of the course is 2 years, the eligibility for which is passing graduation degree in B.Tech or B.E in chemical, metallurgy, computer, telecommunication etc. with a minimum aggregate of 55% and above from a recognized university listed under UGC/AIU. The program is covered in 4 semesters. Among the top colleges who offer M.E in chemical engineering are as follows: Panjab University - Chandigarh.Â In addition, candidates are required to possess good computer skills in order to draw rough sketch works of complex products for conceptualizing them in future operations.Â The curriculum also involves projects and assignments that would help in carrying out research in the applied field. Chemical engineering education is in need to include new elements. Business of the Process Industry in the developed world is shifting from specification to performance products. More attention is then required for product technology and product development. Students are given tools for technology build-up, but not for technology handling. Therefore a good basis in technology management is also essential in the chemical engineering study.Â The traditional chemical engineering curriculum content and delivery methods for fundamental knowledge and skills are revaluated to find ways for quality improvement, as integration of scientific content between core disciplines. The new vision can provide appropriate knowledge to future chemical engineer for good professional development.