ChE *Survey Commissioned by CACHE*

COMPUTERS IN UNDERGRADUATE CHEMICAL ENGINEERING EDUCATION

A Perspective on Training and Application

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Over the past decade, computing has had an unprecedented impact on the chemical process industry in terms of use and widespread acceptance of the technology. The impact has accelerated over the past five years as computing has rapidly become a pervasive tool used for a variety of purposes including numerical computation, analysis, text processing, graphics, communication, and accessing information. In these times of streamlined engineering staffs and extensive outsourcing of engineering tasks, the computer is recognized as a critical tool in conducting business. It is no longer viewed as a stand-alone box only for numerical computation; it has become an *extension* of how problems are solved and a *medium* for processing information. As such, it has become an integral part of virtually all aspects of the chemical processing industry.

In response to the rapidly changing technology and with limited opportunity and time for dialog with industry, universities are forging ahead with curriculum changes to reflect new instructional objectives relating to computing technologies. These changes are proceeding in response to general industrial expectations for increased levels of computer literacy but without a clear and detailed perspective of computing in industry. In addition, industry and academia are simultaneously, but independently, trying to understand the current and future impact of computing on engineering with the result that expectations and objectives may not be articulated clearly. As a result, there are many unanswered questions regarding industrial and academic transitions into this technology. How is computing helping the process industry? Has computing changed the way we do engineering? Are we better engineers as a result? What skills are required to enter the profession? Are universities meeting the challenge in training future engineers?

To provide some insight into these questions from both academic and industrial perspectives, the CACHE Corporation Curriculum Committee commissioned a series of industry and academic surveys on computing. Specifically, the surveys targeted

- *Engineering management—to get a broad and current view of computing in the chemical process industry*
- *New BS chemical engineers with only a few years of professional service—to compare their professional computing requirements with their recent college training*
- *Chemical engineering faculty—to compare the academic view with the industrial view.*

This article summarizes the results of these surveys. Three primary topics are addressed in separate sections: Computer Use in Industry; Content of Training; Computing in the Chemical Engineering Curriculum.

PROFILES OF RESPONDENTS

Recent BS Chemical Engineering Graduates

379 questionnaires • 152 responses

The respondents were from four major companies reflecting the chemical, petroleum, pharmaceutical, and consumer products industries. Engineering professionals who have graduated within the past three years made up 45% of the respondents; another 30% have been in industry between three and five years; and about 25% of them have been in industry more than five years. As indicated by this distribution of experience, the survey by and large concentrates on computing within the past five years. 83% of all respondents were involved in technical work.

The recent graduates represented the following distribution of job descriptions:

- *38% in-process/plant support*
- *29% research and development*
- *20% design and analysis*
- *7% process control*
- *15% other*

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Industrial Management

205 questionnaires • 156 responses

The management sample involved 156 total respondents from a wide variety of companies—chemical, control, computer, pharmaceutical, aerospace, petroleum, consumer products, government, food, and technology companies were all represented in the sample. Of the respondents, 16% were managers with ten to fifteen years in industry, and over 75% had more than fifteen years experience. Clearly, the managerial sample reflected an experienced viewpoint on the impact of computing and the expectations of new engineers. Respondents with job descriptions including technical management made up 76% of the sample, while 12% were doing technical work.

Academics

154 questionnaires • 65 responses

The questionnaire was sent to each U.S. chemical engineering department. Of the 65 respondents, about half have been in academia more than fifteen years, The other half have between five and fifteen years academic experience, but over 60% of that number have had less than five years in industry. The survey did not ascertain how many had no industrial experience.

COMPUTER USE IN INDUSTRY

The management response reveals that engineers now spend a substantial amount of time at the computer. Well over half of the engineers average between 20-40% of their time at the computer, while another 30% spend 40-60%. Interestingly, academics substantially underestimated how much computers are used—the academic perspective estimated that about 70% of engineers are in front of the computer less than 20% of their time, while more intensive users were estimated to spend 25-50% of their day with the computer.

The results of the new graduate survey, shown in Table 1, provide a perspective on what kind of computing is being performed. This breakdown is very revealing. First, virtually everyone is making some use of spreadsheets. It shows that a large percentage of engineers (74%) are frequent users, with the remaining people being occasional users. When asked what the primary uses of the spreadsheets programs are, there was strong concurrence by the recent graduates and management. The greatest use is for data analysis—but quite significant use is directed toward material balances, economic studies, and numerical analysis, in decreasing order of importance.

The table also reveals that very few engineers are programming in FORTRAN, and that a majority (64%) never do. Those few who do program in FORTRAN are only occasional users. By and large, engineers do not program in other languages either, but it is evident from those who do that other programming languages are being used as much as FORTRAN. It is revealing that statistical packages, numerical methods libraries, and mathematical packages are seldom or never used except implicitly in application packages. Clearly, programming and more specialized packages are not in widespread use even though a fair amount of attention is devoted to at least some of these in most academic institutions. One possible explanation is that industry tends to develop specialized users of scientific computing packages and that they, in turn, serve the needs of other engineers within the company.

TABLE 1
Computer Use in Industry

	Never	*Seldom*	*Frequent*
Spreadsheets	2%	23%	74%
FORTRAN programming	64%	28%	8%
Language other than FORTRAN	56%	28%	15%
Statistical	46%	40%	14%
Numerical method libraries	85%	11%	3%
Mathematical packages	86%	13%	1%

Virtually everyone is using the computer for communications (e-mail, word processing, etc.), and a large percentage of engineers are using graphics software for technical reporting, presentations, and visualizations. Database systems are also being used with high frequency. Over 70% of the respondents are heavily using DBMS applications for organizing project information, accessing general engineering data, and processing information.

Generally speaking, management and recent graduates agreed on the level and kind of computing they do. Given the variety of companies represented, the fact that there is this agreement supports the generalization of the survey results. It is noteworthy that both management and academia concurred with the rank order of computer uses as reported by the engineers. There were wide differences, however, in the perceptions of managers and academics on the amount of computing:

	Management	***Academics***
Communications	heavily underestimated	heavily underestimated
Graphics	heavily underestimated	heavily underestimated
Database systems	underestimated	heavily underestimated
Spreadsheets	match	heavily underestimated

CONTENT OF TRAINING

One question asked of all three groups was how much time is needed to learn the computer skills required for the job. There was strong concurrence on this question: over 80% of recent graduates claimed less than three months, while management and academia both estimated three months or less for 75% of new engineers. Two notable differences, however, did arise: the majority of engineers claimed that they required less than one month for training, whereas management estimated three months. Furthermore, management claimed a significant number (19%) of engineers required as much as three to six months of training. This agreed with the responses of the recent graduates but not with the perspective of academia, which projected that very few graduates would require this extensive amount of time.

Recent graduates overwhelmingly considered computing to be an integral part of the undergraduate program, but 10% thought that computing should not be included. While this is a relatively low percentage, it is striking that there is this percentage of respondents disclaiming the importance of computing in education, given its wide spread use in industry. With respect to undergraduate training in computing, the recent graduates provide an important perspective:

- *13% - training is more than enough*
- *62% - training is about right*
- *25% - training was not nearly enough*

We can conclude from the above that academia is doing an adequate job of preparing new engineers, but there is apparently considerable room for improvement since a significant percentage claimed that they had not had enough training. Confirmation is provided by the response to a related question showing that 34% of recent graduates felt they were not adequately prepared in computing.

Regarding the content of their academic education, a majority (57%) of recent graduates felt their preparation concentrated too heavily on programming over applications, while 38% felt that the mix was about right. Virtually no one thought training overemphasized applications. To the question of how much programming should remain part of an undergraduate program, 40% still thought it should be more strongly emphasized and essentially none thought it should be eliminated. A majority (60%) recommended some exposure. It is clear that recent graduates recognize the importance of programming in learning how a computer works, even though they may not do much programming themselves. The exposure is seen as important to understanding computing.

On this same question about programming, management and academic viewpoints were in agreement with the general feelings reported by recent graduates. But 67% of the managers wanted to see stronger emphasis on applications, while only 50% of the academics wanted to strengthen the emphasis. A strong contingent of both academics and managers (about one-third of each) advocated equal time to applications and programming. With respect to the choice of programming language, academics had strong opinions in favor of FORTRAN: about three-fourths of the respondents wished to continue with FORTRAN programming, but a significant number (21%) did not. Managers were substantially less adamant on this issue, with 25% having no opinion. A majority still favored FORTRAN while a significant number of respondents were not in favor of it at all. On the usefulness of a second language, there was generally a mixed opinion by management, but it leaned toward 'no.' Academics were relatively unenthusiastic about a second language,

RECENT GRADUATE SURVEY QUESTIONS

N-Never • S-Seldom • F-Frequently • Y-Yes • N-No

1. **Years since receiving BS degree:**
   < 3 • 3 - 5 • >5
2. **Primary type of work:**
   administration • technical management • technical • sales/marketing • other
3. **Time required to learn the computer skills for current job:**
   < 1 month • 1-3 months • 3-6 months • > 6 months
4. **Description that best fits your job:**
   process design/analysis • research and development • process control • plant/process support • other
5. **Do you use the computer for communication (e-mail, word processing, calendars, and access to on-line data)?** Y • N
6. **Do you run spreadsheet programs?** N • S • F
7. **What are the primary uses of spreadsheet programs?**
   economic studies • data analysis • numerical analysis • material balances
8. **Do you program in FORTRAN?** N • S • F
9. **Do you program in language other than FORTRAN?** N • S • F
10. **Do you use graphics software?**
    never • technical reporting • presentations • visualizations
11. **Do you use statistical packages such as SAS, RS/1, etc.?** N • S • F
12. **Do you use numerical methods libraries such as IMSL, NAG, etc.?** N • S • F
13. **Do you use symbolic and mathematical manipulation packages such as Mathematica or Matlab?** N • S • F
14. **Do you use database management systems?**
    • never • project information • general engineering data
    • process information
15. **Do you use high level software packages?** N • S • F
16. **Do you feel you have had sufficient undergraduate training in computing to prepare you for your work environment?**
    more than enough • about right • not nearly enough
17. **Do you feel that your undergraduate computer training had the proper mix of programming versus applications?**
    • too much programming over applications
    • too much applications over programming • about the right mix
18. **To what extent do you feel computer programming should remain a part of the undergraduate program?**
    • strongly emphasized • some exposure • eliminated
19. **Did undergraduate training expose you to more than one operating system (*e.g.,* DOS, UNIX, VMS, etc.)?**
    no • two systems • more than two systems
20. **If not, would you have benefitted from exposure to multiple operating systems?**
    yes • no • no answer
21. **Were you sufficiently trained to understand and use flowsheeting systems and physical property systems?**
    yes • no • unimportant
22. **Do you feel you had sufficient exposure to computer tools to solve non-trivial problems?**
    more than enough • about the right amount • not adequately prepared
23. **Should computer programming remain part of the undergraduate program?** Y • N
24. **Do you feel there is a relationship between computer skills and problem-solving skills?**
    • yes, strong positive correlation • yes, strong negative correlation
    • some correlation • no correlation

with 50% responding "no."

Multiple operating systems apparently is an unresolved issue with recent graduates. Half of the respondents felt that exposure to more than one operating system is important and half did not. When asked if they would have benefited from exposure to multiple operating systems, 33% answered yes and 19% answered no. Almost half had no opinion.

Particularly noteworthy is the result that, while 57% of the recent graduates thought they had sufficient exposure to the computer to solve non-trivial problems, nearly a third thought they were not adequately prepared. On a more specific question, only half of the respondents felt they were sufficiently trained to understand flowsheeting systems and physical property estimation systems. 44% felt they were not adequately prepared, but 10% thought flowsheeting was unimportant.

Academics felt considerably more strongly than either graduates or management that graduates do not have enough exposure to computing skills. Both management and academics, however, overwhelmingly considered computing to be an enhancement to problem-solving. A significant negative impression was still apparent, though, in that 15% of managers and 11% of academics considered computing to have no effect or to be a hindrance to problem-solving. On a related question about computing skills and the ability to formulate or define problems, again 14% of the managers considered computing to be a hindrance and another 42% felt there was no effect. Academics marginally considered computing to be more of an enhancement than did the managers, but nearly half felt there was no effect or that computing was a hindrance. While the computer has come into widespread use in industry and is generally considered to be a positive element, there remains a significant contingent of engineers who do not believe that computing has much of an effect on how problems are conceptualized and defined.

An overriding issue with respect to computer education is the effect that computing has on problem-solving skills. A majority of recent engineers felt there is a correlation between computer skills and problem-solving skills, and nearly a third more thought there was a strong correlation—but 11% felt there was no correlation. The academic perception closely matched that of recent graduates, but managers were somewhat less convinced, with 21% claiming no correlation. Another significant question asked whether or not recent graduates were bringing a systems analysis approach to problem solving. It is disappointing that a majority (70%) of academics and management reported that engineers are not adopting more of a systems viewpoint when solving problems. On the other hand, there is general agreement that computers are resulting in differences in how engineering in conducted. Apparently, there is substantial

MANAGEMENT SURVEY QUESTIONS

1. **Years since receiving BS degree:**
   <5 • 5-10 • 10-15 • >15
2. **Primary type of work:**
   administration • technical management • technical • sales/marketing
3. **Type of positions filled by BS chemical engineers in your department:**
   • process design/analysis • research and development • process control
   • administrative • plant/process support • systems • other
4. **Percent of the day a typical BS chemical engineer in your department spends at the computer. _____**
5. **What percentage of BS engineers use the computer for communication (e-mail, word processing, calendars, and access to on-line data)? _____**
6. **What percentage of BS engineers run spreadsheet programs?**
7. **What are the primary uses of spreadsheet programs?**
   economic studies • data analysis • numerical analysis • material balances
8. **What percentage of BS engineers use graphics software (technical reporting, presentations, and visualizations)? _____**
9. **What percentage of BS engineers use statistical packages such as SAS, RS/1, etc.? _____**
10. **What percentage of BS engineers use numerical methods libraries such as IMSL, NAG, etc.? _____**
11. **What percentage of BS engineers use symbolic and mathematical manipulation packages such as Mathematica or Matlab?**
12. **What percentage of BS engineers use database management systems for project information, general engineering data, process information, etc.? _____**
13. **How much time is required to train engineers to learn the computer skills for their job function?**
   < 1 month • 1-3 months • 3-6 months • > 6 months
14. **Do you feel the new graduates have had sufficient exposure to computer tools to solve non-trivial problems?**
   not enough • about right • more than enough
15. **Do you feel the students' exposure to computer technology has been an enhancement or hindrance in engineering problem solving?**
   hindrance • no effect • enhancement
16. **Has the exposure to computer skills enhanced or hindered the ability of the graduate to formulate or define problems conceptually or mathematically?**
   hindrance • no effect • enhancement
17. **Do you feel there is a relationship between computer skills and problem-solving skills?**
   • yes, strong positive correlation • yes, strong negative correlation
   • some correlation • no correlation
18. **Do you believe that undergraduate training should emphasize:**
   • programming over applications • applications over programming
   • devote equal time
19. **Do you believe undergraduate training should include exposure to more than one operating system (*e.g.,* DOS, UNIX, VMS, etc.)?**
   highly desirable • not necessary • unimportant
20. **Should computer programming in FORTRAN be part of the undergraduate curriculum for chemical engineering?**
   yes • no • no opinion
21. **Should computer programming in any general purpose language be part of the ChE undergraduate curriculum?**
   highly desirable • not necessary • no opinion
22. **Are new graduates bringing a systems analysis approach to process unit operations?**
   yes • no, still doing things by conventional means • unaware of a difference
23. **Do you believe we are doing things differently (rather than faster/more efficiently) with computers (*e.g.,* design/analysis area)?**
   yes, significant innovations • no • unaware of difference

recognition that computing allows engineers to do more things faster but that it does not have a fundamental impact on how we do engineering.

COMPUTING IN THE CHE CURRICULUM

A final topic addressed specifically by the academic survey pertains to changes in curricula to accommodate computing. One of the important questions considered the possibility that computing education itself contributed to lengthening the time to graduation for undergraduates. The survey confirmed that a significant number of students are taking longer than four years to complete their undergraduate programs. The respondents reported that a full 31% (on average) of undergraduates take an additional semester or quarter and 25% take even longer. Of the 65 universities responding, 89% claimed that computing had no effect on the length of time a student takes to graduate. In fact, 20% of the departments have fully integrated computing into their cur-

ACADEMIC SURVEY QUESTIONS

1. **Years you have been in an academic position:**
   <5 • 5-10 • 10-15 • >15
2. **Years of industrial experience:**
   <5 • 5-10 • 10-15 • >15
3. **Type of positions filled by BS chemical engineers. Please rank order:**
   • ___ process design/analysis • ___ research and development
   • ___ process control • ___ administrative
   • ___ plant/process sypport • ___ systems
   • ___ other • ___ don't know
4. **Percent of the day a typical BS chemical engineer in your department spends at the computer. ____**
5. **What percentage of BS engineers use the computer for communication (e-mail, word processing, calendars, and access to on-line data)? ____**
6. **What percentage of BS engineers run spreadsheet programs?**
7. **What are the primary uses of spreadsheet programs?**
   • economic studies • data analysis • numerical analysis
   • material balances • don't know
8. **What percentage of BS engineers use graphics software (for technical reporting, presentations, and visualizations)? __**
9. **What percentage of BS engineers use statistical packages such as SAS, RS/1, etc.? ____**
10. **What percentage of BS engineers use numerical methods libraries such as IMSL, NAG, etc.? ____**
11. **What percentage of BS engineers use symbolic and mathematical manipulation packages such as Mathematica or Matlab? ____**
12. **What percentage of BS engineers use database management systems for project information, general engineering data, process information, etc.? ____**
13. **How much time is required to train engineers to learn the computer skills for their job function?**
    < 1 month • 1-3 months • 3-6 months • > 6 months
14. **Do you feel the new graduates have had sufficient exposure to computer tools to solve non-trivial problems?**
    not enough • about right • more than enough • don't know
15. **Do you feel students' exposure to computer technology has been an enhancement or hindrance in engineering problem solving?**
    hindrance • no effect • enhancement • don't know
16. **Has the exposure to computer skills enhanced or hindered the ability of the graduate to formulate or define problems conceptually or mathematically?**
    hindrance • no effect • enhancement • don't know
17. **Do you feel there is a relationship between computer skills and problem-solving skills?**
    yes, strong positive correlation • yes, strong negative correlation
    • some correlation • no correlation • don't know
18. **Do you believe that undergraduate training should emphasize:**
    programming over use of applications • applications over use of programming • devote equal time • don't know
19. **Do you believe undergraduate training should include exposure to more than one operating system (*e.g.,* DOS, UNIX, VMS, etc.)?**
    highly desirable • not necessary • unimportant
20. **Should computer programming in FORTRAN be part of the undergraduate curriculum for chemical engineers?**
    yes • no • no opinion
21. **Should computer programming in an additional language be part of the undergraduate curriculum for chemical engineers?**
    yes • no • no opinion
22. **Are new graduates bringing a systems analysis approach to process unit operations?**
    yes • no, still doing things by conventional means • unaware of a difference
23. **Do you believe we are doing things differently (rather than faster/more efficiently) with computers (*e.g.,* design/analysis area)?**
    yes, significant innovations • no • unaware of difference
24. **In courses using computing, have computing assignments tended to be added on to previously existing course material or have they been integrated into the course by changing/removing previously used materials?**
    full integrated • partially integrated • added on
25. **What percentage of the undergraduate students in your program take longer than four years?**
    % taking an additional semester/quarter _____
    % taking an additional two semesters/quarters ____
26. **Has increased use of computers in the curriculum contributed to students taking longer to graduate from your program?**
    significantly • to some extent • not at all
27. **Is computing helping students to better learn chemical engineering principles?**
    yes • unaware of a difference • no
28. **How would you currently rank order the value of teaching students skills in the following? (Please number, with 1 being the most important.)**
    • ____ FORTRAN • ___ C
    • ____ object-oriented languages • ____ spreadsheets
    • ____ statistical packages • ____ database systems
    • ____ numerical methods libraries • ____ communications
    • ____ symbolic and mathematical packages • ____ other
29. **Please rank the following in the order they are emphasized in your department's program (with 1 being the most important).**
    • ____ FORTRAN • ___ C
    • ____ object-oriented languages • ____ spreadsheets
    • ____ statistical packages • ____ database systems
    • ____ numerical methods libraries • ____ communications
    • ____ symbolic and mathematical packages • ____ other
30. **Looking five years into the future, how would you rank order the value of teaching students skills in the following. (Please number, with 1 being the most important.)**
    • ____ FORTRAN • ___ C
    • ____ object-oriented languages • ____ spreadsheets
    • ____ statistical packages • ____ database systems
    • ____ numerical methods libraries • ____ communications
    • ____ symbolic and mathematical packages • ____ other

ricula and another 75% claim that it has been partially integrated. This is important data in that it conveys the fact that departments are indeed recognizing the role of computing in engineer training and are willing to include it at the expense of other topics. It is not simply an addition to their normal course of study.

A critical question posed to academics was whether computing helped students better learn chemical engineering principles. About half of the respondents claimed that computing did indeed help, but the other half felt computing either had no effect or did not help. The large neutral-to-negative response seems to indicate that computing is not necessarily resulting in better chemical engineering education. This again corresponds with the earlier responses on the effect of computing on problem solving.

To provide both current and future academic perspective on computing in education, the survey asked respondents to rank order the value of developing student skills in a number of computing areas. Surprisingly, the current and the five-year perspectives on these skills were essentially the same. Below is the rank-ordered list of skills:

FORTRAN programming
C programming
Object-oriented languages
Spreadsheets
Graphics
Statistical packages
Numerical methods libraries
Symbolic and mathematical packages
Database systems
Communications

The interpretation of this list is, as indicated in the previous section, that academics see programming as an important element in a chemical engineer's education. FORTRAN programming will likely continue to be the most important language, but recent trends in C and object-oriented programming have been noted by academics and their importance to the curriculum is recognized. Spreadsheets and graphics are also strongly mentioned. Skills in using specialized packages are not valued nearly as much as programming skills.

SUMMARY CONCLUSIONS

➢ Computers are used extensively in industry by virtually all engineers. Academics need to adjust upward their perceptions of the amount of computing used by their students in industry.

➢ The primary uses of computing in industry are by far for communications, spreadsheets, graphics for reporting and presentations, and database systems. There is an educational benefit for engineering programs to expose students to these computing applications.

➢ A relatively small number of engineers do technical computing or programming (beyond spreadsheets). This does not mean that industry is not doing much technical computing. Rather, it appears that industry tends to develop specialists in scientific computing packages who then serve the needs of other engineers within the company. There appears, therefore, to be little need to teach highly specialized computing packages in depth. It may be more important to give students a broad exposure to a variety of computing packages to develop a general appreciation of how computers can be used.

➢ Relating to the above, the survey results convey a strong message that training in the use of specific packages is not as important to industry as is a general engineering computing skill set. Time needed to train new employees in specific computing skills used by a company is not that significant. Universities should focus attention on this general skill set, and industry will train employees in specific skills. The general skill set apparently includes programming experience to understand how a computer works and experience with application packages to understand the issues of interpreting computer-generated results and to be able to relate them to real-world problems.

➢ There is a disparity between the views of industry and academia on the relative value of programming versus experience in using application packages. But even though engineers do very little programming, most respondents recognize the importance of programming experience in developing an understanding of how computers work. The general sense of the survey is that the curriculum time commitment to each should be about equal.

➢ The survey results indicate that universities are generally doing a good job of graduating engineers with the necessary computer skills for the profession. But it is noteworthy that a significant number of recent graduates reported that they were not adequately prepared and that their computer training was not enough. It is important for departments to continue to assess the computing component in their curricula and to continue the transition to full integration of computing into all engineering courses.

➢ An important observation from the survey concerns the fundamental impact of computing on engineering. While computing is generally considered an enhancement to engineering problem-solving, this enhancement apparently relates only to speed and efficiency of doing tasks. Significant percentages of the respondents did not feel that computing helped in better defining and solving problems. In fact, a small but significant number felt it was a hindrance. Furthermore, computing has had little impact in reinforcing or promoting a systems-analysis approach to the solution of engineering problems. There appears to be considerable room in both academia and industry for understanding, and then teaching, new viewpoints for analyzing and solving problems more effectively. ❐