Applying Engineering Software Tools Throughout the Curriculum

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Abstract

There is no aspect of modern engineering practice that does not make use of computer-based tools. This has created an expectation that graduates from engineering programs will have strong computing skills. Graduates can be provided with these skills by integrating the application of software tools throughout the engineering curriculum. This paper describes how the application of software tools has been integrated into a typical chemical engineering curriculum. Where, how, and why each software tool is used are discussed, as well as the extent of formal instruction provided for each tool.

The approach described in this paper requires software tools to be introduced early into the curriculum, used in all of the courses, and used together wherever appropriate. Software is employed that covers a range of applications: mathematical analysis, statistical analysis, process simulation, data acquisition, process control, graphical communication, and document preparation. The applications increase in level of difficulty as the students progress through the curriculum. This approach requires faculty members that are familiar with the software and can develop course work that effectively employs it.

Course assessment and survey instruments indicate that the students have developed strong computer application skills, and that one of the primary learning outcomes of the program has been achieved. The best students become very proficient in the use of software tools, while the average student is able to use them effectively.

Motivation

There are two primary motivators for making significant use of software throughout the curriculum. The first is the value to the students in terms of enhancing their professional skills. Engineering graduates are expected to be able to effectively use computers and software in professional practice. A recent report by the CACHE Corporation[1] details the required skills: "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 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."

This report also discussed the results of a CACHE survey of practicing engineers that revealed heavy use of computers by the majority of respondents and reliance on commercial software tools for a variety of applications. Software applications should be employed within the curriculum to develop the required skills, and to prepare the students for professional practice.

The second motivator is to improve the overall education experience. Employing software within the curriculum provides the benefits of allowing students to more fully explore the context of a problem by trying alternative cases, of providing an alternative mode of learning, of permitting more realistic problems to be solved, and of reducing the time required for routine calculations. These benefits have been discussed in greater detail for particular software packages in previous articles[2-4], and will not be further elaborated upon here.

For these reasons, one of our department's programmatic learning outcomes is stated as: "Our graduates will demonstrate the ability to use computing tools – mathematical analysis, information retrieval, document preparation and communications." [5] Integration of software applications within all of the courses in the chemical engineering program has been done as a key step in achieving this outcome.

Applications

Our approach has been to introduce software tools as soon as they can provide a useful learning aid for the student. Table 1. lists the primary software packages that are used in the chemical engineering curriculum and shows the courses in which they are used. This table contains all of the required major courses as well as a few frequently offered electives (E). A core set of tools - consisting of Word®, Excel®, and Mathcad® - is introduced during the sophomore level courses, and is used in almost all of the subsequent coursework. More specialized software tools - for process simulation, data acquisition, and dynamic systems modeling – are employed where needed. As the students progress through the curriculum, they find that assignments requiring computer-aided analysis become more frequent and more complex.

Word processing is used to some extent in every chemical engineering course. The earliest applications will typically be small project reports of a few pages in length. Project reports at the junior and senior levels become more complex. They will generally have more content, but they may also require equation editing, and often contain embedded charts and drawings. The equation editor included with Word® is used for equation editing; Excel® or Mathcad® are used

for creating graphs; and Autocad®, Visio®, etc. may be used for producing drawings.

The Excel® spreadsheet is introduced in the first course of the Material and Energy Balances sequence. Typical applications are: solution of cubic equations of state, recycle calculations, what-if scenarios, and adiabatic energy balance calculations. The spreadsheet is employed either because the calculations would be time consuming, or multiple cases are to be evaluated. Assignments are selected so that students can readily see the advantages of using the software tool, and will be motivated to learn the software and the course material.

Table 1. Software Use in Chemical Engineering Courses

Courses	Word	Excel	Mathcad	Matlab	Chemcad	DAC	Powerpoint
CHEE 201 Material & Energy Balances I	X	X					
CHEE 202 Material & Energy Balances II	X	X	X		X		
CHEE 230 Modeling & Analysis	X	X	X		X		
CHEE 310 Process Fluid Mechanics	X	X	X		X		
CHEE 311 Heat Transfer Operations	X	X	X		X		
CHEE 312 Mass Transfer Equipment Design	X	X	X		X		
CHEE 320 Chem. Engr. Thermodynamics	X	X	X		X		
CHEE 325 Kinetics & Reactor Design	X	X	X				
CHEE 350 Chem. Engr. Laboratory	X	X	X			X	
CHEE 410 Advanced Heat Transfer (E)	X	X	X		X		
CHEE 411 Separations Processes (E)	X	X	X		X		
CHEE 435 Process Dynamics and Control	X	X	X	X			
CHEE 450 Unit Operations Laboratory	X	X	X			X	
CHEE 451 Process Laboratory	X	X	X	X		X	
CHEE 457 Process Design I	X	X	X		X		X
CHEE 458 Process Design II	X	X	X		X		X
CHEE 460 Polymers (E)	X	X	X				

[200 series courses are sophomore level, 300 are junior level, and 400 are senior level.]

The range of Excel® utility is extended in the CHEE 230 Modeling & Analysis course. Problems and projects cover interpolation, numerical calculus, solution of algebraic equations, solution of differential equations (ODE's and PDE's), and statistical analysis. Typical problems might be:

fitting phase equilibrium data using cubic splines, simultaneous solution of material and energy balances for a production process, evaluating species concentrations versus time in a batch reaction, and fitting a regression model to experimental data. Students typically complete about twenty such modeling problems along with several larger projects in a semester.

The Mathcad® package is also introduced in the Modeling & Analysis course. Most of the students have no previous experience with this package, and more time is taken to cover the mechanics of creating worksheets. Mathcad® is used to solve many of the same types of problems as Excel®, and the students learn the comparative advantages of each. They find that Mathcad® is much easier to use for solving differential equations, and that the symbolic mathematics capability is very useful in some cases. Excel® has a distinct advantage for creating high quality plots and charts. The advantages of employing different software packages for particular tasks has been noted in a previous study[6]. Mathcad® and Excel® are used to solve a variety of problems in subsequent courses. In many cases, both packages might be used for different aspects of the same problem, and many students learn how to effectively link the results through Object Linking and Embedding. An interesting application is the computer-based testing used in the Kinetics and Reactor Design course. In many of the examination problems, links are provided to Mathcad® and/or Excel® worksheets to perform calculations.

Process simulation software is used in a number of courses. The initial applications occur in the Material and Energy Balance II course. The applications are small process flowsheets involving simple material and energy balance calculations. In most cases, students solve problems that they have previously solved by other means so that they can compare the results. A few problems are solved in the Modeling & Analysis course to illustrate recycle convergence. The Chemcad® simulator is employed more often during the junior course sequence. It is used in the unit operations courses for such tasks as designing piping networks, heat exchangers, and staged separation columns. Applications in the thermodynamics course are physical property prediction, flash calculations, fitting equilibrium data to activity models, and equilibrium reactions. The simulator is used extensively in the senior process design courses. Students working on projects for industrial sponsors also have the opportunity to use the Aspen Plus simulation package.

Some computerized data acquisition and control is employed in all of the chemical engineering laboratories. These applications are PC based, and have been Basic or C++ programs, with interfaces to Excel® in some cases. We have recently joined the Wonderware® educational program, and are beginning to use the Factory Suite® software for our data acquisition and control applications. This provides the students with an interface and software development environment that will be found in an industrial setting. Students will be able to configure control loops, perform sophisticated data analysis in real time, and construct graphical interfaces. Since this software interfaces easily with Excel®, Mathcad®, and Matlab®; the students will be able to use familiar software tools to work with data acquired from the Factory Suite® software.

The Powerpoint® package is frequently used in the Process Design sequence because of the number of oral progress briefings and project presentations that are required. The students find that the software provides a convenient medium for presenting visual material and creating a

structure for the presentation. Students must teach themselves how to use the software because no formal instruction is provided. As a rule, the slides are not particularly sophisticated, but the goal is to have students develop effective oral presentations, not become graphic designers.

The real power of all of theses applications is fully developed when they are effectively used together. In a capstone design project, the student may use Chemcad® as the primary design tool, Mathcad® for sizing calculations not provided in the simulator models, Excel® for the economic analysis, Word® to produce the report, and Powerpoint® to construct a presentation. This degree of integration is the expected result of employing several software tools, and using them where appropriate in all of the chemical engineering courses.

Information Technology

Along with the software tools, information technology is being used in other ways. As Table 2. shows, most of the classes now make use of electronic submission for at least part of the assigned work. This has the advantage of reducing paperwork, but presents several new problems.

- The course instructor or grader must be located at a computer in order to evaluate the work. This has become somewhat less of an inconvenience with the availability of laptop computers, but does somewhat limit where this work can be done.
- The grader can no longer scribble comments in the margins of the paper. Now comments must either be inserted into the document (most of the applications make this fairly easy to do), or an evaluation document must be attached. This requires somewhat more time on the part of the grader, but is probably a great improvement for the student.
- It becomes easier to copy work and plagiarism can be more of a problem. This has been a problem in the lower level courses. However, once the students realize that the faculty is watching for this, the number of incidents drops off dramatically in the later courses.
- Unless an effective file naming system is established it can be difficult to keep track of individual student files. Students tend to use the same names for their files, such as Assignment 1.xls or Project Two.doc. The solution is to have the students use a naming convention where their name and assignment identifier both appear in the file name.
- Given a choice of electronic or paper submissions, many students will continue with paper submissions. Once the students are required to use electronic submission, most find it preferable, but there is an initial resistance to be overcome.

Some of these issues may seem trivial, but they were sources of aggravation early on.

E-Mail is heavily used as a communication channel between the faculty and students in all of the courses. This can often save office visits, particularly when the student has a fairly simple question. Even with more difficult problems, a few E-mails back and forth are often sufficient to cover the issue to the student's satisfaction. E-mail collaboration has also made it possible in a few instances for Co-op students at their work site to take courses along with the students on campus.

Some students who will not ask questions in class or make an office visit will communicate via E-mail. It seems that they feel more protected in that venue, and are more willing to ask questions

or discuss other issues. The E-mail channel helps to draw in some students who otherwise would not actively participate in class. The one negative is that occasionally a student will become more intemperate than they would be in a face-to-face discussion. Patience and some forgiveness seem to be the solutions in most of these instances.

It was surprising to discover that a number of freshmen and sophomore students did not use E-mail on a regular basis. In some cases this was due to lack of access at their homes, in other cases they had not cultivated the habit of using E-mail. One of our first tasks in developing information technology skills was to induce these students to use E-mail as a regular channel of communication. By the time that the students are juniors, all are using E-mail on a regular basis.

Instructors in some of the courses are also attempting to develop the student's skill in using the Internet as a research tool. It is often used in the Process Design courses to conduct patent searches, obtain information from equipment vendors, and research developing technologies. It has also been used in the Chemical Engineering Thermodynamics and Polymers classes to conduct research on material properties and product formulations. Laboratory and design students may also access Material Safety Data Sheets via the Internet, although these are also provided locally. The students are also likely to be using the Internet without having specific assignments to do so.

Internet research is an area where additional instruction in conducting effective searches may be needed. The evidence so far indicates that many students take an unfocused approach to the search and do not effectively use search engines to focus on the more useful materials. Students do find material, but this appears to occur by luck as much as by plan. We will also have to be careful not to emphasize the use of the Internet to the exclusion of other sources.

Table 2. Use of Information Technology in Instruction

Course	Electronic Submission	E-Mail Collaboration	Internet Searches
CHEE 201 Material & Energy Balances I		X	
CHEE 202 Material & Energy Balances II		X	
CHEE 230 Modeling & Analysis	X	X	
CHEE 310 Process Fluid Mechanics		X	
CHEE 311 Heat Transfer Operations		X	
CHEE 312 Mass Transfer Equipment Design		X	
CHEE 320 Chem. Engr. Thermodynamics	X	X	X
CHEE 325 Kinetics & Reactor Design		X	
CHEE 350 Chem. Engr. Laboratory	X	X	
CHEE 410 Advanced Heat Transfer (E)	X	X	
CHEE 411 Separations Processes (E)	X	X	
CHEE 435 Process Dynamics and Control		X	

CHEE 450 Unit Operations Laboratory	X	X	
CHEE 451 Process Laboratory		X	
CHEE 457 Process Design I	X	X	X
CHEE 458 Process Design II	X	X	X
CHEE 460 Polymers (E)	X	X	X

Student Training

The initial introduction to computer applications occurs in the freshman computer science class. Historically, this class has emphasized programming in a high-level language such as C++. The initial introduction to software tools occurred during the sophomore year. Although word processing is used extensively, no formal training is provided. Most of the students have used word processing software before entering the program. Those that have not, quickly learn. A faculty member may provide assistance in using more advanced features of the software, such as the equation editor, but that is the extent of the training provided by the faculty. The same is true of Powerpoint®, Internet browsers, and diagramming packages such as Visio®.

Formal instruction in the use of Excel® is limited with respect to the basic mechanics of using the software. The bulk of the formal instruction on Excel® occurs in the Modeling & Analysis course, and that instruction focuses on the application of built-in functions, matrix operations, the solver, and the statistical analysis tools. It is expected that the students will learn other aspects of the software by reading the assigned text[7], or by working with the software. Course instructors will provide demonstrations using Excel® to solve problems of relevance to their classes, and they will help students with specific questions concerning use of the software, but they don't spend much time on Excel® instruction for its own sake.

Most of the instruction on the Mathcad® package also takes place in the Modeling and Analysis course. More time is spent on the basics of this package. While many students will have some previous experience with Excel®, almost none will have used the Mathcad® package prior to entering the program. While Mathcad® may be used to demonstrate the solution of particular problems in subsequent courses, there is no further formal instruction. Students are expected to develop their proficiency by using the package to solve problems, or by referring to the recommended text[8] and on-line help.

Students are provided with instruction on the use of process simulation software in several different courses. They are first introduced to the Chemcad® software in the Material and Energy Balance course, where they are given just enough instruction to create simple flowsheets. Additional instruction occurs in the Modeling and Analysis course. The focus at that time is on convergence of recycle loops (illustrates solution of nonlinear equations) and the effect of alternate variable specifications on the model solution. Instruction in the Chemical Engineering Thermodynamics course is concerned with property estimation, phase equilibrium calculations, and regression of experimental data. While Chemcad® is used in the unit operation courses, the

amount of instruction provided is limited. Instruction in the Process Design courses focuses on more advanced features such as optimization, cost estimation, and modeling complete processes.

Because Matlab® is only used in the Process Dynamics & Control and Process Laboratory, the instruction on that package has been confined to those courses. Formal instruction is limited to several lectures, and the students are expected to extend their learning on their own.

Instruction on data acquisition and control software had been very limited, because the software was fairly simple to use. With the introduction of the Factory Suite® software, more instruction has been needed because of the complexity of the package. Students are taught how to construct a graphical interface, how to use the structured programming tools, and how to configure the data input and output functions. The actual number of lectures is limited, and the students are expected to perform much of the learning through actual use of the software.

Students are expected to learn much of the software functionality through practice rather than formal instruction. This hasn't been done without complaint. Students have indicated that they would like more formal training, but the time for such has been limited. Recently, the C++ course was converted into a software tools course, featuring Excel® and Mathcad® along with some Visual Basic for Applications® programming. This change should take some of the instructional load from the chemical engineering courses and allow more time to be spent on applications rather than software functionality. This should also satisfy the students' demand for additional training on these software packages.

Faculty Development

Effective application of these software tools has required a significant investment of time by the faculty. Since the current faculty members received their formal education during the FORTRAN and punch-card era, they had to be educated on the current generation of software tools. However, the amount of formal training has been very limited. Some of the faculty members have had training classes on Chemcad®, Aspen®, and Wonderware® applications; but most of the education has occurred by self-study. Fortunately, most of the faculty had started working with word processing, spreadsheets, and equation solving packages as soon as the PC became widely available. Individual interest and desire to learn offset the lack of formal training. Since departmental funds for formal training classes were very limited, this was a happy development. Because the faculty had been fairly early adopters of the available software tools, it was not so difficult to maintain proficiency through several generations of upgrades.

Our experience indicates that successful integration of modern computing tools into the curriculum requires a commitment on the part of the entire faculty. Faculty members need to be reasonably proficient in the use of the computing tools, and have an understanding of where they can be most effectively used.   Lack of proficiency and understanding on the part of the faculty leads to several problems. Faculty members are not likely to encourage the use of technology that they don't use themselves. Students will become irritated upon learning that the instructor does not know how to use software that the students are expected to master. Students will not be

stimulated to use the technology if they are asked to apply it in trivial applications or in situations where it is not appropriate. It also becomes difficult for the students to develop proficiency if they only use the tools in a few isolated courses.

There is a cost to the department to maintain faculty proficiency in computing technology. The cost for training and the cost in faculty time will not be trivial. In our case, the price was paid in the amount of time that the faculty had to devote to maintaining proficiency in the software applications. Because our program has undergraduate instruction as its primary focus, this was an acceptable use of faculty time. In programs with much heavier research commitments, this may not be so. The goals of the department and its reward structure will dictate whether or not the necessary commitment can be made.

Simply hiring young faculty who are technologically current will only help in the short run. Computing technology has been changing at a pace that renders current knowledge obsolete within a short time. The issue of maintaining currency remains. The need for continued investment in faculty development does not go away.

Facilities

The college of engineering provides a computer laboratory for use by all engineering majors, and the department maintains a laboratory for use by chemical engineering students. Word®, Excel®, Mathcad®, and Powerpoint® are available in both laboratories. Most students have word processing, presentation, and spreadsheet software on their personal computers. Many of them also have the Mathcad® package. The departmental laboratory provides Chemcad®, Aspen®, Matlab®, Visio®, and Powerpoint®. Licensing agreements also permit copies of Chemcad® and Visio® to be distributed to the students. Software licensing does consume a significant fraction of the department's modest operating budget, but the faculty considers this expenditure to be necessary.

Assessment

Ongoing assessment is performed to determine whether a learning outcome is important to program constituents. A broad survey was conducted of all of the departmental alumni seven years ago to set a baseline for ongoing assessment. One of the results of that survey was that computing skills were very important in the workplace. Those that could use them effectively in achieving organizational goals progressed well in their careers. Subsequent surveys of alumni and employers have supported those results. The department is well justified to emphasize effective computing skills as a core outcome for the program.

Assessment is also conducted to evaluate whether the students have substantially achieved a learning outcome. Primary feedback is obtained from student surveys and instructor course reports. Students are asked to assess the extent to which the department has provided instruction and developmental experience with respect to the programmatic learning outcomes. On a five-point rating scale (1 to 5, with 5 being the best rating), the student surveys typically provide an

average rating between 4 and 5. Most all respondents give the program a rating of 4 or 5 for this outcome, and the distribution average has been moving toward 5 over the past five years.

The course reports indicate that computing skills are generally an area of strength for our students. Almost all students seem to achieve an acceptable level of proficiency, and most are better than acceptable. The CHEE 230 Modeling and Analysis course appears to be the "gatekeeper" with respect to computing skills. Students generally perform well in that course or perform very poorly; there are few that are mediocre. The students that perform well have used software to solve a variety of problems and are well prepared for subsequent courses. The students that perform poorly either do not continue in the program, or retake the course and dramatically improve their performance.

The several assessment tools used by the department are consistent in showing that the learning outcome concerned with computing skills is being achieved. Anecdotal evidence also supports this claim in that we have graduates who accept good jobs in software support services, financial analysis, and industrial information technology. Thermodynamics and unit operations are not too important in these jobs, but computing skills are. These examples also indicate that emphasizing strong software applications skills is one way to make the degree of value to a broader range of potential employers.

Path Forward

For the most part, software integration into the curriculum has been successful. The addition of the software tools course in the freshman year should address student concerns about the amount of formal training. This addition will also free time in the Modeling & Analysis course for more work on statistical analysis and dynamic process modeling. The current plan is to introduce Matlab® in this course and provide some time relief in the Process Dynamics and Control course.

We have also considered supporting only one process simulation package. The industrial sponsors of senior projects generally prefer the use of Aspen®, making this software the choice as sole application. However, the Chemcad® license allows students to have personal copies for their home computers, and the faculty computers do not use an operating system that supports Aspen®. (Faculty computers are under the control of the campus computer center staff, not the department.) Some changes will be needed in the campus computer systems before we can use Aspen® as our sole process simulation software.

There is also a need to provide some additional training on using the Internet effectively for research. Using search engines, developing efficient search strategies, and validating the quality of sources are skills that will need practice. Integrating the use of Internet with conventional library sources is also desirable.

Conclusions

Our assessment has shown that our program constituents desire the graduates to have proficient

computer skills. Assessment results show that we are achieving the learning outcomes associated with those skills. Our department has been able to do this by effectively integrating the use of computer applications into all of the major courses. This has required dedication on the part of our faculty to maintain their skills and to develop the necessary course material. Students will quickly develop the necessary skills if they have adequate opportunities to apply them, and the applications are not trivial. The students will also have greater incentive to develop the skills that they see demonstrated by the faculty.

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