USE OF COMPUTATIONAL TOOLS IN ENGINEERING EDUCATION

A Case Study on the Use of Mathcad®

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With the widespread use of personal computers, a variety of powerful computational tools are now available that permit engineers to routinely perform calculations and analyses that were once very difficult. The introduction of these tools into the undergraduate engineering curriculum can facilitate student computations, but can the use of these tools also foster student learning and understanding of engineering principles?

The purpose of this paper is to examine issues related to incorporating an equation-solving package into the undergraduate curriculum in chemical engineering. Although the content of the paper is based on our experience with Mathcad®, our observations and conclusions are equally applicable to other equation-solving packages. Of particular interest is the impact that using equation solvers has on student learning and ways in which such software might be used to enhance learning.

HISTORY OF MATHCAD AT BYU

Five years ago, most undergraduate student work in our department was done with calculators, with some of the more demanding problems requiring spreadsheets or FORTRAN programming. At that time we felt that equation-solving packages had been developed to the point where they represented a potentially useful tool for our students (see Table 1). After reviewing several different numerical- and symbolic-based equation solvers, the faculty voted to incorporate Mathcad into the undergraduate curriculum. It was our opinion that the department should adopt a single package and that Mathcad was the package best suited to our needs. In particular, Mathcad's graphical interface was appealing from an educational point of view since students could manipulate equations that looked like those found in their textbooks or presented in class.

Mathcad was initially implemented in our sophomore material balance course taught from the Felder and Rousseau text[1]. We required the students to use the software and instructed them on its use, providing instructions throughout the course when new material suggested the need for new computational techniques. We also prepared a short tutorial to help beginning students. As a general rule, students did not have easy access to Mathcad manuals since relatively few were available in the student computer labs. Therefore, students generally depended upon on-line help, the tutorial, in-class examples, the instructors, and the TA for assistance. In addition to the material balance course, Mathcad was heavily used in two upper division undergraduate courses and was incorporated to a lesser degree into several other undergraduate and graduate courses.

Four years have passed since the initial implementation of Mathcad. Since that time we have observed a significant change in the way in which our students approach and solve engineering problems, and some of the change is directly related to use of the math software. In addition, we have gained experience with the software and have learned ways

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in which it can be used to enrich learning. We have also been able to observe the impact of adapting such software on our overall undergraduate program in chemical engineering.

BENEFITS FROM USING THE PACKAGE

To illustrate the benefits listed in Table 1, we will examine the solution of an engineering problem with Mathcad. Note that the benefits listed in the table apply to equation-solving packages in general, although specific capabilities will vary from package to package.

An important part of engineering is the use of mathematical expressions to describe and model the behavior of physical systems. Solution of the resulting equations can be very difficult and time consuming. Therefore, solutions are often limited in scope, based on simplifying assumptions, and dependent on a restricted set of variables in order to be computationally tractable. With use of a tool such as Mathcad, students can perform calculations more rigorously and broadly, obtaining a deeper and more complete understanding of the problem. The following solution of an undergraduate-level thermodynamics problem illustrates the use of Mathcad to solve an engineering problem.

TABLE 1
Potential Benefits of an Equation-Solving Package in an Undergraduate Engineering Program

1. It enables more efficient solution of problems that had previously been tedious or difficult to solve.
2. It enables solution of more realistic engineering problems that had previously been impossible or impractical for undergraduate students.
3. Use of the new capabilities provided by the tool could enrich and enhance student learning.

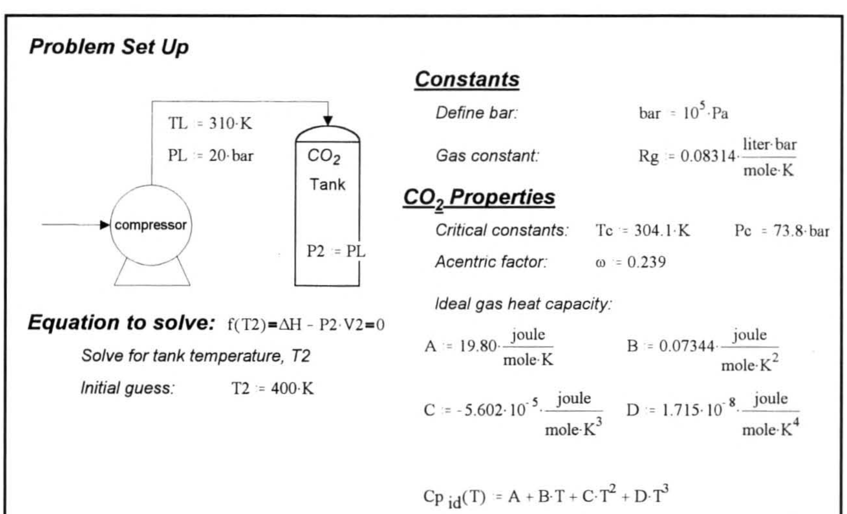

***Figure 1.** Input section of Mathcad sheet for example problem.*

Problem Statement • A cylinder is to be filled with CO_2 from a compressor that discharges the CO_2 at 20 bar and 310K. Initially, the cylinder (also at 310K) is evacuated (see Figure 1). Assuming no heat transfer to the cylinder, what is the final temperature of the CO_2 in the cylinder when the cylinder reaches the compressor line pressure?

Solution • One can show from the first law of thermodynamics for this situation that the final temperature is found by solving the following equation:

$$\Delta H - P_2 V_2 = 0 \tag{1}$$

where ΔH is the difference between the final gas enthalpy and the enthalpy of the gas in the filling line, P_2 is the final gas pressure in the cylinder, and V_2 is the final molar volume of gas in the cylinder. All terms in this equation can either be evaluated in terms of known values or be represented as a function of the unknown final gas temperature (T_2). The enthalpy of the gas in the filling line is a function of the filling line pressure (P_2) and temperature (T_L), both of which are known. The final gas enthalpy must be evaluated at the known final pressure P_2 and the unknown T_2. The volume (V_2) is related to P_2 and T_2 through an equation of state.

Figure 1 is the input section of a Mathcad sheet for the above problem. Mathcad allows text to be inserted alongside the computation lines so that the calculation is easily documented. In this example, text is shown in "Arial italics" whereas the active Mathcad equations are in "Times Roman." Note that units can be used with variables and Mathcad will take care of all unit conversions. Additional units, not internal to Mathcad, can be defined, as has been done here with bar. The newly defined unit can then be used throughout the worksheet. Known values are defined for T_L and P_2. The gas constant is also specified, along with physical data for CO_2. The heat capacity is specified as a function of temperature to be used by numerical routines.

Also included in the input section of the sheet is a specification of an initial guess for the final temperature. The equation to be solved is also noted for convenience as text; this is not an active Mathcad equation. The equation has been written explicitly in the form $f(T_2) = 0$ to emphasize that we seek a root that satisfies Eq. (1). Two separate solutions to the problem are illustrated in Figure 2 and discussed in the following sections. These sections are intended to illustrate the first two benefits listed in Table 1. Such benefits are commonly perceived and have been documented by others.[e.g., 2] However, we often fall short of achieving the full educational benefits that the software makes possible. Therefore, the last section of the example attempts to illustrate how the capabilities of Mathcad can be used to further enhance learning (Benefit #3).

Using Mathcad for Efficient Problem Solutions (Benefit #1)

The first solution, which assumes an ideal gas, is similar to the type of solution required of students in the past. The enthalpy difference is expressed as an integral over the heat capacity, which is substituted into the equation $f(T_2) = 0$. The Mathcad "root" function is then used to solve for the desired temperature T_2. The solution was completed in four lines with minimal algebra. In contrast, a calculator could have been used to obtain the same solution. To do so, one would first perform the integration, then substitute the resulting polynomial into Eq. (1), and finally, program the final function of T_2 into the calculator. In this case, Mathcad provides a more efficient solution to a problem that has traditionally been solved by other methods. Mathcad also makes it easier to correct a mistake made during the calculation. Independent of how the solution is obtained, however, the student arrives at the answer with little physical insight. For example, how accurate is the ideal gas assumption?

Using Mathcad to Solve More Realistic Problems (Benefit #2)

Figure 2 also presents a more realistic solution to the problem, which uses the Soave equation of state in place of the ideal gas assumption. (A full description of the equations used in the solution is beyond the scope of this paper—interested readers should refer to a text on thermodynamics for more information.) Mathcad provides an elegant solution to a complex mathematical problem that would be difficult and/or impractical for undergraduate students to solve using either a calculator or a spreadsheet. For example, P_2V_2 is required in the equation, but the Soave equation cannot be solved explicitly for V. In Mathcad, V is obtained as a function of temperature and pressure by solving the equation of state using a root function. This volume is then used in the calculation of the enthalpy departure function, which is in turn used as part of the expression that is solved iteratively for T_2.

A realistic solution of the problem can thus be achieved in a straightforward manner. Such a solution would not have been practical for undergraduates without the use of software such as Mathcad.

What have we gained from the more realistic solution of the problem? Because of the time saved in the simplified solution of the problem, it is feasible to ask students to solve the problem both ways and to compare the answers. The fact that the answers are different is significant, but the physical insight gained from the comparison is still quite limited since the student is only comparing two numbers. Note that students also gain experience in using realistic equations of state by performing the more complicated calculations. Using a tool such as Mathcad to expose students to models and methods actually used in industry better prepares graduates for realistic engineering calculations. In contrast, using inappropriately simple models for computational convenience may give students a false impression of the applicability of such models.

Using Mathcad as a Teaching Tool (Benefit #3)

There is considerably more that can be done in using the software to improve learning. For example, learning can be enhanced by extending the problem statement itself. In this

Solution for Ideal Gas with Cp as a function of temperature

$$\Delta H_{id}(T2) := \int_{TL}^{T2} Cp_{id}(T)\, dT$$

$$f(T2) := \Delta H_{id}(T2) - Rg \cdot T2$$ *Note: For ideal gas,* $P2 \cdot V2 = Rg \cdot T2$

$$T2_{id} := \mathrm{root}(f(T2), T2)$$

$$T2_{id} = 392.874 \cdot K$$ ***Answer for ideal gas***

Solution for Soave Equation of State

1) Define equation of state in terms of known parameters

$$a := \frac{0.42747 \cdot Rg^2 \cdot Tc^2}{Pc} \qquad b := \frac{0.08664 \cdot Rg \cdot Tc}{Pc} \qquad m := 0.48508 + 1.55171 \cdot \omega - 0.15613 \cdot \omega^2$$

$$\alpha(T) := \left[1 + m \cdot \left(1 - \sqrt{\frac{T}{Tc}}\right)\right]^2 \qquad F(T,P,V) := P - \left[\frac{Rg \cdot T}{V - b} - \frac{a \cdot \alpha(T)}{V \cdot (V + b)}\right]$$ *Soave equation of state*

2) Set up expression to calculate V for a given T and P from the equation of state

Initial guess: $V := 0.5 \cdot \mathrm{liter}$ *Expression:* $V(T,P) := \mathrm{root}(F(T,P,V), V)$

3) Define enthalpy departure function (Hid - H) for Soave equation of state

$$K(T) := m \cdot a \cdot \alpha(T) \cdot \sqrt{\frac{T}{Tc \cdot \alpha(T)}} \qquad \Delta H(T,P) := Rg \cdot T \cdot \left(1 - \frac{P \cdot V(T,P)}{Rg \cdot T} + \frac{a \cdot \alpha(T) + K(T)}{b \cdot Rg \cdot T} \cdot \ln\left(1 + \frac{b}{V(T,P)}\right)\right)$$

4) Define and solve final expression for T2

$$\Delta H_{real}(T2,P) := \Delta H(TL,P) - \Delta H(T2,P) + \Delta H_{id}(T2)$$

$$f(T2,P2) := \Delta H_{real}(T2,P2) - P2 \cdot V(T2,P2)$$

$$T2_{real}(P2) := \mathrm{root}(f(T2,P2), T2)$$

$$T2_{real}(P2) = 380.36 \cdot K$$ ***Answer for real gas***

Figure 2. *Mathcad solution assuming ideal gas (top) and using the Soave equation of state (bottom).*

problem, students might be asked to calculate the final temperature in the cylinder for a range of compressor line pressures and to plot the results. This extension is easily achieved with Mathcad by adding a couple of assignment statements and creating a graph. The resulting Mathcad figure, Figure 3, provides physical insight not previously available. The student can see that the two solutions approach each other as the pressure is decreased and CO_2 behaves more ideally. It is also apparent that the two solutions diverge as the pressure is increased, and that the ideal gas solution does not change with pressure.

To be still more useful, the extended problem statement should include qualitative questions that ask the students to explain, justify, and generalize their observations. For example, why do the two curves diverge as the pressure is increased? Or, why is the ideal gas solution independent of pressure? It is also useful to have them evaluate the practical importance of the result by asking a question such as what significance would the error introduced by the ideal gas assumption for CO_2 have on the design of . . . ?

The extended problem helps students gain insight into the effect of pressure on the nonideal behavior of CO_2, but what about other gases? When would they need to worry about nonidealities? To teach this, one might have the students repeat the solution for a different gas. As the equations are identical, the solution is readily obtained by simply changing the parameters at the top of the sheet. You may want to ask the students to *predict* the results for the second gas *prior* to performing the calculation. For example, "Would you expect N_2 to behave more or less like an ideal gas than CO_2? " and "Why?" Because the selected temperature range is so far above the critical point of N_2, the students should expect more ideal behavior from N_2. Figure 4 shows the results for N_2 indicating that this is indeed the case. Students could be asked to compare the solutions and rationalize their observations. For example, "Why is one gas more ideal than another at these conditions?" Other questions related to the properties of the two gases might also be included, such as "Which gas has the higher heat capacity, and why?"

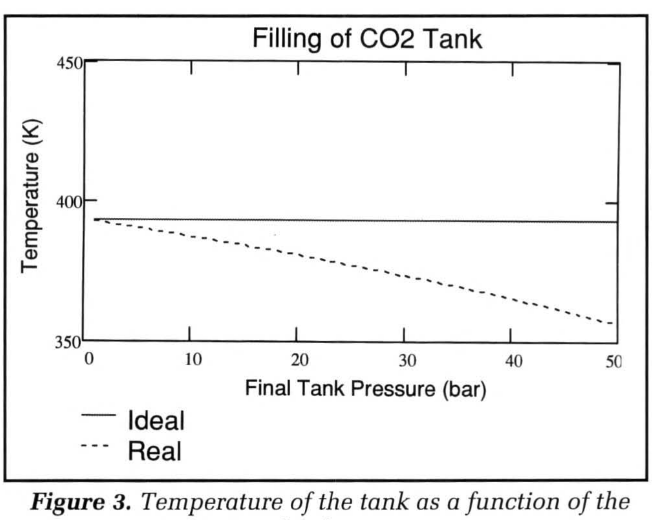

Figure 3. *Temperature of the tank as a function of the CO_2 final pressure.*

The above example illustrates several capabilities of Mathcad relevant to engineering education. (As mentioned previously, these benefits also apply to other equation-solving packages.) First, the software enabled efficient solution of engineering problems as shown in the initial "ideal" solution to the problem. Solution of the same problem using the Soave equation of state demonstrated a realistic solution that was not previously tractable, and use of both the ideal and real solutions allowed comparison of the two. Mathcad also permitted calculation of the temperature for a range of pressures and visualization of the results, providing physical insight that was previously unavailable. Qualitative questions were used to help develop this insight. Finally, calculations were easily repeated for a different gas, and students were asked to rationalize and evaluate the differences, illustrating the use of Mathcad to answer "What if...?" questions.

In short, Mathcad permitted extension of the original problem, at relatively little overhead, to enhance learning. This type of extension, however, requires effort on the part of the instructor; it does not follow automatically with the use of Mathcad. Using the "same old problem statements" with the new tool will do relatively little to enhance student learning. In fact, in some cases, it may even reduce learning.

There are other ways to use equation-solving packages to enhance the education of engineering students. The combination of powerful computational and graphical capabilities is ideal for exploring trade-offs between opposing factors in order to reach an optimal solution. Students might be asked to evaluate and recommend options based on economic considerations. Important physical insight can be gained by using software such as Mathcad to identify the most important variables or factors and then offering an explanation for

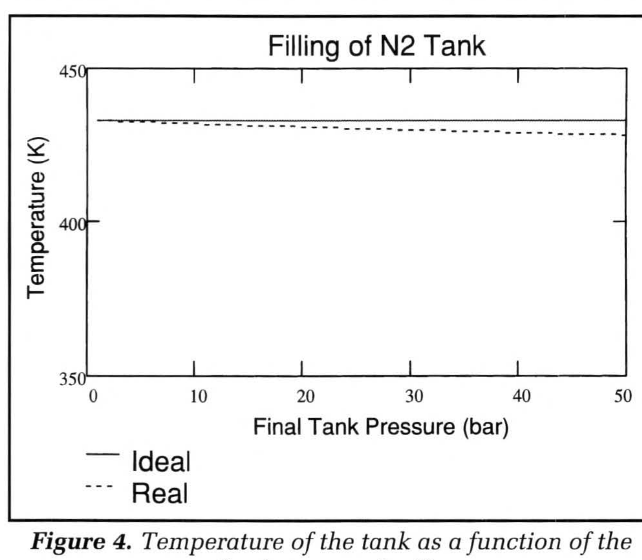

Figure 4. *Temperature of the tank as a function of the final pressure for N_2.*

their relative importance. Students might be asked to solve a problem and then use the software to explore an issue of their own choice related to that problem. These and other opportunities are made possible by the tool's capabilities.

Relationship to Learning Styles

We can use the tool's flexibility to teach to a variety of learning styles. Students have a variety of learning preferences or styles, and the needs of the individual learners are best met with a variety of learning activities.[3-5] Activities such as those described in the example problem can be used to help address different learning styles and to improve the learning of all students. For example, Mathcad provides an excellent opportunity for students to visualize information, to actively experiment with the concepts and ideas, to explore new ideas, and to solve realistic problems. As such, it represents another important addition to our instructional toolbox.

The following sections of the paper document our experience with the equation-solving package.

FACULTY PERSPECTIVE

The response of our faculty to the introduction of Mathcad into the curriculum varied from one person to another, but was generally positive. Individual responses were correlated with the level of awareness: awareness of the tool's features, awareness of students' capabilities with the tool, and awareness of how the tool can impact learning in and out of the classroom. Generally, the more familiar the faculty member was with the tool, the more positive the reaction. Our observations regarding the faculty have been divided into the following seven areas.

Faculty Involvement

Mathcad was initially introduced into the curriculum by a core group of two faculty members. Although the entire faculty voted in support of the program, there were no requirements for using Mathcad in specific courses other than the initial sophomore course. Consequently, only some of the faculty have learned the software and adapted their teaching to take advantage of the opportunities it provides. In fact, less than half (five out of twelve) of our faculty currently use the software, although some who have not used it themselves have required their students to use it in specific courses. The number of "users" appears to be growing as other faculty members have recently shown interest. We believe that more faculty will adopt the software as they become aware of the significant positive impact it can have on their courses and the value that students obtain from those courses.

Student's New Capabilities

Using Mathcad has enabled our students to efficiently solve a variety of engineering problems. Some faculty have been surprised by the new capabilities of our students. One faculty member teaching a junior-level class in our department commented that he didn't know exactly what we had changed in our sophomore class (where Mathcad is introduced), but "we are certainly doing something right!" He believes that the students understand concepts better and compute significantly better than previous classes. This same faculty member began using Mathcad because of the capabilities he saw in his students. A faculty member from another department found that our students were able to easily and quickly complete his traditional assignments. The students had asked his permission to use Mathcad on the assignments beforehand, and he had agreed. He was delighted and amazed at the ease with which they completed the work.

Math Skills

Some faculty members have sensed a decline in the math skills of some students, presumably due to their dependence on the software to do the math. They mention that students do not have the same "by hand" math skills possessed by previous groups of students. This is, in a real sense, both a practical and a philosophical issue. Are these math skills a means to an end, or do they have intrinsic worth to the students? This question is certainly not a new one, having been raised, for example, with regard to calculators. In fact, many "by hand" math skills once thought essential have been forgotten with the advent of the slide rule and the calculator. Similarly, the use of equation solvers may lead to another shift in the skills required of engineers and engineering students. It seems to us that the key issue is not the ability of students to manipulate equations, but their ability to solve engineering problems.

Exam Procedures

One issue of practical concern among the faculty has been the effect of Mathcad on exam performance. Exams have been influenced in several ways by the use of an equation solver. First, a couple of instructors have given exams that require students to use Mathcad. They have been given primarily as "take home" exams with a specified time limit. Additionally, the exam content has changed in some classes to focus more on problem definition and setup rather than on solution methods. Qualitative problems, similar to those discussed previously in conjunction with the Mathcad example, have also been used effectively on exams.

The exams in many of our undergraduate classes, however, remain unchanged. Also, for logistic reasons, most of our students have not had access to Mathcad during exams. In fact, use of the equation solver on exams has been largely restricted to a few upper-division courses. The unavailability of Mathcad has caused difficulties for a few students who felt it hindered their performance on exams. For example, they might develop a problem to the point of one or more equations and then state, "I could now use Mathcad to solve this problem." Such responses have raised a concern that the software may have a negative impact on students who have lost (or never developed) the ability to simplify problems, make approximations, or even solve relatively simple mathematical problems.

We view these concerns as a manifestation of the math skills issue discussed in the previous section where students have developed skills that differ from those expected by the instructor. *This mismatch between the students' skills and those expected by faculty can be avoided if faculty members are aware of the tools the students are using and if they clearly communicate their expectations to the students.* If we expect students to work a certain type of problem by hand (*e.g.,* on an exam), we should tell them so, encourage them to practice solving it that way, and reinforce our expectation by giving them problems of that type to solve.

Our need to explicitly communicate our expectations has increased as alternate methods for solving problems have been developed. As a general rule, students will solve problems in the way they deem most efficient (usually with the equation solver) unless they are required to do otherwise.

Impact on Course Content

Incorporation of an equation solver into our undergraduate curriculum has had, and continues to have, a significant impact on the content of several courses. For example, our separations course was recently restructured to take advantage of both Mathcad and a process simulator. We have also found that we spend much less time teaching numerical methods and solution procedures than was previously necessary, especially in courses that are computationally intensive.

Using an equation solver has also had significant impact on course content by providing the means for students to solve difficult, realistic engineering problems. The choice of problems is now less restricted by the means available for their solution, and this has allowed problems to be selected for their content and connection to real engineering rather than for their solvability.

Impact on Learning Concepts

Several faculty members have used Mathcad to help students learn concepts, with very positive results. It is their perception that the software has helped students to develop a better conceptual understanding of the material.

Other members of the faculty, however (particularly those who have not used the software), feel that the software has had an adverse effect on student learning. For example, one faculty member recently expressed a concern that students were losing touch with the physics behind problems. He expected students to use physical insights to make assumptions that simplified problems for solution on a calculator. Many of the students, however, simply solved complete sets of complex equations in Mathcad without thinking about the physics. In this case, the problems were designed to maximize learning when worked by hand and were therefore not ideally suited for advanced computational tools. Consequently, the educational value of the problems was short-circuited by the ability of the students to solve the complete set of equations without simplification.

This example illustrates the fact that faculty members should know what tools the students are using and should adjust instruction and/or requirements to maximize learning. In the above case, the professor could have required the students to work the problems by hand in order to achieve the desired results. Alternatively, the problems could have been restructured to take advantage of the available tools and still achieve (or exceed) the desired educational objectives. For example, students could have been required to calculate the magnitude of individual terms in the equations and to comment on their physical and numerical significance.

Group Assignments

There has been a movement in recent years toward more collaborative learning and teamwork. Consequently, we need to consider the effects on learning as we use computational tools in group assignments. We have observed, for example, that students in a group at a single computer do not derive equal benefit from an assignment. In particular, the individual actually at the keyboard appears to get more out of the exercise. The literature discusses creative ways around this problem.[e.g., 6] For example, each member of a group might be given instruction on a particular feature of the software and then be asked to teach that feature to their group. Additionally, the group might be asked to solve a complicated problem that requires the "skills" of all the group members to complete.

Summation

In summary, faculty who have used Mathcad have generally been pleased with the software and found it to be a valuable education tool. In spite of this, less than half of our faculty use Mathcad. It was also the perception of the faculty that a majority of the students used the tool, even when the teacher did not anticipate (or desire) its use. Some teacher and student frustration has been observed in courses taught as they had been in the past, with no modification of assignments or instruction to take advantage of Mathcad. This frustration can be avoided, however, by clearly communicating expectations to the students and/or adapting problems to take advantage of the educational possibilities that a math tool such as Mathcad makes available.

STUDENT FEEDBACK

A survey was conducted in order to evaluate the equation solver from the students' perspective. The survey consisted of ten questions, and we have chosen to discuss five of these (shown in Table 2). Three of the remaining five questions were actually subsets of the questions chosen for discussion; the responses to these questions have been grouped with the questions shown in Table 2. One of the last two questions was specific to our institution and was therefore not included. The last question was discarded because it was poorly phrased and did not yield any useful information. Responses were received from sophomores, juniors, and seniors. First-year students were not surveyed since Mathcad is not used as part of the curriculum in the first year.

Question #1: Overall Opinion • A combined total of just over a hundred responses from sophomore, juniors, and seniors was received for the question that asked students for their overall opinion of the Mathcad package. Of these, the responses from the seniors were overwhelmingly positive—in fact, none of the seniors responded negatively.

The response from the juniors was also very positive, with only about ten percent being negative. Several of the positive responses were also qualified with statements such as "I like it but I'm just not all that familiar with it," or "Great time-saving tool if you know how to use it." Responses from the sophomores were similar to those from the juniors.

It was evident from the responses that the seniors were more comfortable with the software package than either the juniors or sophomores. Incidentally, the positive opinions expressed by the students are strongly supported by the fact that they used the software in almost all of their courses, even when it was not required or expected by the instructor. In our experience, this has never been the case with FORTRAN programming.

Question #2: Benefits • Students noted several benefits in using Mathcad. The most frequently mentioned benefit was that using the software typically reduced the time required to solve a particular problem. Time savings were attributed to the package's ability to solve equations and to perform unit conversions. Students also noted that mistakes made early in the sequence of calculations could be easily fixed without having to "repunch" the numbers.

The students also recognized that Mathcad allowed them to solve problems that otherwise would not have been assigned. In addition, students noted that the software made it easy to see the equations and to follow the logic of the solution. Others mentioned that Mathcad allowed them to spend more time learning concepts and less time with tedious calculations. The graphing capability of the package was also noted as a benefit by students.

Question #3: Conceptual Understanding • The survey asked students to evaluate how the use of Mathcad to complete homework assignments affected their ability to understand the concepts presented in class. Most of the student responses to this question could be classified into three groups. Responses in the first group were from students who got lost in the solution procedure and felt that Mathcad actually had a negative influence on their conceptual understanding. Additional instruction would undoubtedly help these students. Some of the students who struggled were transfer students who did not have the same exposure and experience with Mathcad as students who began their studies in our department.

It was the opinion of the second group that Mathcad was merely a computational tool that did not have any effect, positive or negative, on their ability to understand concepts. The third and largest group felt that Mathcad enhanced their conceptual understanding by allowing them to focus on the concepts rather than on the math or mechanics of the solution and by providing them with tools to help increase their understanding.

TABLE 2
Sample Survey Questions

1. What is your overall opinion of Mathcad?
2. What are the benefits of using Mathcad?
3. The purpose of homework is to help you understand concepts. How has using Mathcad on homework affected your ability to understand the material presented in class or in the text?
4. Mathcad is typically not available on exams. How did this affect your performance on exams?
5. How can the Chemical Engineering Department improve the use of Mathcad in undergraduate education.

Student comments indicated that the software had a significant positive impact on their education. As far as overall distribution is concerned, just over half (42 of 83) of the students whose responses fit into one of these three groups felt that Mathcad was beneficial to their conceptual understanding (group 3).

Question #4: Influence on Exams • The survey also asked students to evaluate the impact that incorporation of an equation solver into the curriculum has had on their exam performance. Mathcad is not typically available for use on exams in our department so we expected this issue to be a sore spot with students. The response to this question was also divided. Some students felt that using Mathcad on homework assignments had a negative impact on their exam performance. In fact, several students referred to a dependency on Mathcad that weakened their math skills and altered their approach to problems, which was detrimental to good performance on exams. There were also students who considered it unfair not to allow use of the software on exams. In contrast, it was the opinion of a number of students that using Mathcad on homework had no substantial effect on their exam performance.

Finally, there was another group of students who thought the exams were actually easier because they had been able to solve more difficult, complicated problems as homework on Mathcad. These students felt they had a deeper understanding and a better command of the material than they would have had if they had not used the software.

Of the 76 responses that fit into one of these three groups, just over 40% thought that using the equation solver did not have a significant impact on exam performance. The remaining responses were split evenly between those who felt that Mathcad had either a positive or a negative impact on their exam performance. There was a substantial number of students (about 30) who provided responses that could not be classified. Most of them failed to address the question that asked them to evaluate the impact of the software on exam performance. For example, many of these students commented on whether or not they thought the equation solver should be used on exams, without evaluating the impact of the current implementation on their exam performance.

Question 5: Suggestions • Most students felt the department could improve the use of Mathcad by teaching the program earlier and/or better. Apparently many students perceive that Mathcad is difficult to learn, contrary to our expectations prior to implementation of the software. Students recommended that Mathcad be taught either in the freshman year or in the sophomore-level programming course that currently covers only FORTRAN. Other suggestions included integration of the software into more courses in the curriculum and making it available on exams. Additional tutorials and in-class examples using Mathcad were also suggested.

In response to student suggestions, our traditional FORTRAN programming class was expanded this past year to include parallel teaching of FORTRAN, spreadsheets, and Mathcad, with an emphasis on tool strengths for different types of problems. Toward the end of the semester, the students were asked to compare the strengths and weaknesses of the packages and to identify their preferences. Student preferences were: Mathcad, 64%; spreadsheets, 25%; and FORTRAN, 11%. Most students were perceptive enough to see the utility of all three programs for different applications. Many of them felt that seeing the problem in mathematical terms in Mathcad facilitated their understanding and solving of the problem. There was also a feeling that FORTRAN was out of date and that Mathcad is a more powerful and flexible tool than the others. The positive perceptions of these students toward Mathcad and the sense of ability to solve problems would be expected to enhance student learning.

SUMMARY AND CONCLUSIONS

This article examined the use of an equation solver, Mathcad, in the undergraduate chemical engineering curriculum. An example illustrated some of the capabilities of this tool and, more importantly, ways in which it can be used to enhance learning. As demonstrated by the example, equation-solving packages such as Mathcad are powerful and flexible tools that can be used to develop a variety of instructional activities designed to promote learning.

Students responded positively to the tool and used it in most of their classes, even when it was not required. Most students felt that using Mathcad enhanced their conceptual understanding of the material. Specifically, it allowed them to focus on the concepts rather than on the solution procedure and gave them a tool to "experiment" with the material. But other students struggled with the software and felt that it had a negative impact on their learning. Additional instruction and practice is needed to help these students. In general, students felt that Mathcad was difficult to learn at first and that formal instruction should be provided to beginning students.

Faculty who have used Mathcad have generally been pleased with the software; in spite of this, it is currently used by less than half of our faculty. Occasional frustration has been experienced in courses where no modification of assignments or instruction has been made to take advantage of Mathcad. These frustrations can be avoided by clearly communicating expectations to the students and/or adapting problems to take advantage of the educational possibilities that a math tool such as Mathcad makes available.

In conclusion, we have found that Mathcad can be used effectively by innovative teachers to promote learning, to deepen student understanding of concepts, and to provide experience with more realistic engineering problems. But it is not a panacea in this regard, and it can actually be detrimental to learning if used inappropriately. We have found that many students enjoy solving problems in Mathcad and therefore use it as a tool of choice, often in ways the faculty had not anticipated.

RECOMMENDATIONS

Based on our experience, we offer the following recommendations to departments considering implementation of Mathcad or some other similar package into their undergraduate curriculum:

1. *It is important that the faculty learn and use the software. Therefore, some method of training and encouraging the use of the software by faculty members should be implemented.*
2. *Students perceive the need for formal instruction on using the software. We recommend that the instruction be provided early, in the first or second year, and that at least a portion of a course should be dedicated to learning the software.*
3. *Implementation of such a package requires substantial numbers of adequately equipped computers. Such facilities should be available before implementing the software as a required part of the curriculum.*
4. *It is important that the software be used consistently throughout the curriculum in order for students to develop and maintain proficiency. We recommend that most, if not all, of the core courses actively incorporate the software. This will help students to be sufficiently comfortable with the software to go beyond the mechanics and use it as a learning tool.*
5. *Opportunities should be provided for faculty to share their experiences and ideas on using the software to promote learning. This could be part of a faculty meeting, a users' group, etc.*
6. *If possible, facilities should be provided so students can have access to the software during exams.*

REFERENCES

1. Felder, R.M., and R.W. Rousseau, *Elementary Principles of Chemical Processes,* John Wiley & Sons, New York, NY (1986)
2. Sandler, S.I., "Spreadsheets for Thermodynamics Instruction: Another Point of View," *Chem. Eng. Ed.,* **31**, 18 (1997)
3. Felder, R.M., and L.K. Silverman, "Learning and Teaching Styles in Engineering Education ," *Eng. Ed.,* **78**, 674 (1988)
4. Stice, J.E., "Using Kolb's Learning Cycle to Improve Student Learning," *Eng. Ed.,* **77**(5), 291 (1987)
5. Harb, J.N., S.O. Durrant, and R.E. Terry, "Use of the Kolb Learning Cycle and the 4MAT System in Engineering Education," *J. of Eng. Ed.,* **82**(2), April (1993)
6. Johnson, D.W., R.T. Johnson, and K.A. Smith, *Active Learning: Cooperation in the College Classroom,* Interaction Book Company, Edina, MN (1991) ❐