Session 3215

# Computers in the Integrated Civil Engineering Curriculum: A Time of Transition

**Thomas A. Lenox, Stephen J. Ressler, Robert J. O'Neill, Christopher H. Conley**
**United States Military Academy**

*This paper examines the authors' continuing experiences in incorporating the personal computer into the civil engineering program at the US Military Academy. The paper describes how the civil engineering program has changed its approach to using the common software purchased by students at the Academy.*

## 1. Situation

### Academic Program for Civil Engineering Majors

The purpose of the United States Military Academy (USMA) is to provide the nation with leaders of character who serve the common defense. The four year undergraduate experience is built upon intellectual, military, and physical development programs. This academic program is deliberately broad in scope. It includes 26 common core courses distributed between 10 mathematics and basic sciences courses on one hand, and 16 humanities and social sciences courses on the other. A typical academic program for a civil engineering major, excluding military science and physical education courses, is shown in Table 1.

As shown in Table 1, 20 of the 26 common core courses are taken during a cadet’s first two years at the Academy. It is important to note that ALL cadets take four semesters of college mathematics, two semesters of chemistry, two semesters of physics, and a computer programming course. The ABET-accredited civil engineering major requires 17 courses in addition to the 26 common core courses. The 17 additional courses prescribed for civil engineering majors are italicized in Table 1.

### Brief History of Personal Computer Use at USMA

In August 1986, the Academy began the computerization of its entire student body and faculty, clearly demonstrating its commitment to assuring the computer competency of all its graduates. Since this date, each freshman has been required to purchase a personal computer. A personal computer is also furnished to every faculty member at the Academy. The particular machine to be purchased is determined each year based on contract renewal schedules, the cost of available technology, and the computation requirements envisioned by academic departments. For example, the students of the Class of 2000 have purchased a Pentium-120 with 32 MB of RAM, 1.2 GB hard disk, 1.44 MB floppy drive, and SVGA monitor. In addition, they have all purchased an HP-48G calculator.

**Table 1. Typical Civil Engineering Program at the United States Military Academy**

| **TERM 1** | **TERM 2** | **TERM 3** | **TERM 4** |
|---|---|---|---|
| Discrete Dynamical Sys | Calculus I | Calculus II | Probability & Statistics |
| Chemistry I | Chemistry II | Physics I | Physics II |
| Intro to Computers | Psychology | Economics | Political Science |
| English Composition | English Literature | Foreign Language | Foreign Language |
| History | History | Philosophy | Earth Science |
| | | | ***Statics & Dynamics*** |
| **TERM 5** | **TERM 6** | **TERM 7** | **TERM 8** |
| ***Mechanics of Materials*** | ***Structural Analysis*** | ***Design of Steel Structures*** | ***Design of Struct Systems*** |
| ***Fluid Mechanics*** | ***Hydrology & Hydraulics*** | ***Advanced Struct Analysis*** | ***Structural Mechanics*** |
| ***Engineering Mathematics*** | ***Soil Mech & Foundations*** | ***Reinf Concrete Structures*** | ***Vibration Engineering*** |
| International Relations | ***Intro to Environ Engr*** | ***Engineering Economy*** | ***Thermodynamics*** |
| Military History I | Military History II | Constitutional Law | ***Electrical Engineering*** |
| Leadership Psychology | Adv English Comp | | ***Seminar on CE Practice*** |

Since 1986, cadets have been acquiring a common software package in conjunction with their computer purchase. This package has always included an operating system, a word processor, and spreadsheet. The specific spreadsheet that was purchased by each class varied over time. Initially the standard spreadsheet was Lotus 1-2-3, this subsequently changed to Quattro and then Quattro Pro, and is currently Microsoft Excel.

In the late 1980's, the Department of Mathematical Sciences articulated a requirement for a mathematical assistant for the personal computer which freed cadets from the tedious and complex calculations which presumably hindered the mastery of key mathematical concepts. Beginning in 1989, students purchased software called DERIVE from Soft Warehouse at the beginning of their freshman year. This DOS-based symbolic manipulator program intelligently applied the rules of algebra, trigonometry, calculus, and matrix algebra to solve a wide range of problems using a non-numerical approach rather than approximate numerical techniques. This program has symbolic capabilities, considered critical in the instruction of calculus. DERIVE was supposed to give mathematics instructors and students the freedom to explore different approaches to problems -- to include "classical" approaches that might not be considered practical if they were applied by hand. It was assumed that DERIVE would become a standard computational tool used throughout the math, science, and engineering curriculum.

## 2. Where We’ve Been: 1986-1996

As one of the first undergraduate institutions to require all of its students to purchase a personal computer, USMA has been a logical subject of scholarly investigations related to computer use in the curriculum. USMA's large number of common core courses, its highly structured elective program, and its hierarchical faculty, add to its attractiveness as a “case-study” for computer integration. Beginning in 1992, several papers were published and/or presented on developments in computer use within the civil engineering program.[1-11] Even though these papers have different authors, they reflect a common philosophy embodied in the following five principles:

Principle # 1. The computer is the engineer's tool -- not an engineer's surrogate.

Principle # 2. Engineers must be skeptical of computer-generated results and must independently verify and validate solutions.

Principle # 3. Engineering faculty should use computers to reinforce the students' understanding of physical behavior and engineering principles.

Principle # 4. The undergraduate curriculum is not the place for "production" software training.

Principle # 5. Spreadsheets are unsurpassed in their value and versatility as an engineering tool, a teaching tool, a developer of essential computer literacy, and an aid in developing orderly thinking and expression.

The first four principles are not new. They have been advocated by discerning engineering professionals since mainframe computers were first used for solving engineering problems in the 1950's. Principle #5 was new. Why were spreadsheets embraced as the favored computing tool?

## Widespread Acceptance of Spreadsheets

Several of the papers previously referenced discuss the advantages of using spreadsheets for engineering calculations.[1,2,3,4,6,10] Some of the major reasons include:

- Spreadsheets are easy to use and learn. Once a student has mastered a few basic rules, rudimentary spreadsheet programming is very straightforward.

- Spreadsheets are flexible. Students can make the spreadsheet as simple or as intricate as their experience and training allow. Spreadsheets allow advanced users to create truly sophisticated problem solving tools; novice users can develop simple spreadsheets that get the job done efficiently.

- Spreadsheets provide excellent graphical capabilities. Since spreadsheets can easily generate graphs from a range of numerical values, it is easy for the student to generate a graphical depiction of a solution.

- Spreadsheet logic closely resembles the flow of the engineering thought process. The equations a student uses to represent a logical problem solution can be directly replicated in the spreadsheet by transferring the set of equations to a series of rows and columns. Once the equations are entered into the appropriate cells, it is easy to check the validity of the logic because the calculations are immediate.

- Spreadsheet equations can become the basis of a “what if” analysis that is an inherent component of the engineering design process. Once a set of equations is entered into the appropriate cells, it is easy to iterate through these equations to obtain an optimal solution.

Direct evidence of the widespread acceptance of spreadsheets as an engineering computational tool is shown in Table 2. This table lists those courses within the civil engineering program that made significant use of spreadsheets as a problem solving tool. This data was collected as of AY 1995-96, the "record" year of USMA's latest ABET review – a year of extensive assessment and documentation of USMA's curriculum.

**Table 2. Spreadsheet Use in the Civil Engineering Program (AY 1995-96)**

| **TERM 1** | **TERM 2** | **TERM 3** | **TERM 4** |
|---|---|---|---|
| Discrete Dynamical Sys<br>Chemistry I<br>Intro to Computers | Calculus I<br>Chemistry II | Calculus II<br>Physics I<br>Economics | Probability & Statistics<br>Physics II |
| **TERM 5** | **TERM 6** | **TERM 7** | **TERM 8** |
| ***Mechanics of Materials***<br>***Fluid Mechanics***<br>***Engineering Mathematics*** | ***Structural Analysis***<br>***Hydrology & Hydraulics***<br>***Soil Mech & Foundations*** | ***Advanced Struct Analysis***<br>***Design of Steel Structures***<br>***Reinf Concrete Structures***<br>***Engineering Economy*** | ***Design of Struct Systems***<br>***Structural Mechanics***<br>***Vibration Engineering***<br>***Thermodynamics*** |

The data in Table 2 clearly reflect the personal experiences of the authors. For problems requiring more than calculator solution, spreadsheets were generally preferred as the computational tool of choice. Use of spreadsheets was expanded well beyond their traditional use as a numerical manipulator of tabular data. An examination of the historical files of the courses within the civil engineering program shows broad (and imaginative!) use of the spreadsheet for a wide range of engineering problems. During the decade prior to 1996, the spreadsheet was regarded by engineering students and engineering faculty as THE most effective general-use computational tool other than the calculator.

### Widespread Rejection of Mathematical Assistant Software

In contrast, DERIVE was never accepted as a useful computational tool by the engineering community at USMA. Since 1989, several engineering instructors have attempted to integrate the software into their courses. These attempts ultimately failed, as shown in Table 3. This table lists those courses that made significant use of DERIVE as a problem solving tool in AY 1995-96. Not a single course outside of the first three core mathematics courses used DERIVE!

**Table 3. DERIVE Use in the Civil Engineering Program (AY 1995-96)**

| TERM 1 | TERM 2 | TERM 3 | TERM 4 |
|---|---|---|---|
| Discrete Dynamical Sys | Calculus I | Calculus II | |
| **TERM 5** | **TERM 6** | **TERM 7** | **TERM 8** |
| | | | |

This paper's first author tried to incorporate use of DERIVE into his Vibration Engineering and Advanced Structural Analysis courses. His experience with encouraging (and mandating!) its use by engineering students in these two courses was disheartening. If there was any alternative, students resisted using DERIVE to solve problems. The end-of-course assessments of these two courses confirmed student discontent with this tool.

## 3. Where We're Going: 1996- . . .

In AY 1995-96, the Department of Mathematical Sciences reevaluated its sponsorship of DERIVE as the standard mathematical assistant for the USMA curriculum. It conducted an extensive review of mathematical assistance programs. Unlike its 1989 decision making process, this review was conducted in full coordination with the Academy's science and engineering departments. All interested faculty were invited to participate. The authors of this paper were active participants.

At the conclusion of the review, the Department of Mathematical Sciences recommended Mathcad Plus 6.0 from MathSoft as the new Academy standard. This choice was greeted enthusiastically by the engineering departments – and immediately adopted for the incoming Class of 2000. The licensing agreement with MathSoft included provisions for the upperclasses to obtain the same software as the incoming students. The Academy immediately implemented a plan for AY 1996-97 to allow cadets of ALL classes to obtain the product.

Was the new software accepted by engineering students and faculty as a valuable computational tool? Absolutely. The evidence suggests immediate acceptance by the engineering faculty and students. Tables 4 lists those courses within the civil engineering program that make <u>significant use</u> of Mathcad as a problem solving tool. This data is current as of the beginning of the second semester of AY 1996-97, only one semester after USMA implemented its plan to allow cadets of all classes to obtain a personal copy of Mathcad.

**Table 4. Mathcad Use in the Civil Engineering Program (AY 1996-97)**

| TERM 1 | TERM 2 | TERM 3 | TERM 4 |
|---|---|---|---|
| Discrete Dynamical Sys | Calculus I | Calculus II | Probability & Statistics |
| **TERM 5** | **TERM 6** | **TERM 7** | **TERM 8** |
| ***Mechanics of Materials***<br>***Engineering Mathematics*** | ***Hydrology & Hydraulics***<br>***Soil Mech & Foundations*** | ***Advanced Struct Analysis***<br>***Reinf Concrete Structures*** | ***Structural Mechanics***<br>***Vibration Engineering***<br>***Electrical Engineering*** |

Comparison of Table 3 with Table 4 shows that Mathcad has been integrated quickly into several of the engineering science and design courses that never used DERIVE. The rapidity of the integration is an indicator of its usefulness. The fact that Mathcad has not yet been incorporated into the basic science courses is probably a result of the Academy's somewhat sudden switch to Mathcad at the beginning of the fall semester. The large-enrollment basic science courses require significant "start-up" time to incorporate new software into their programs.

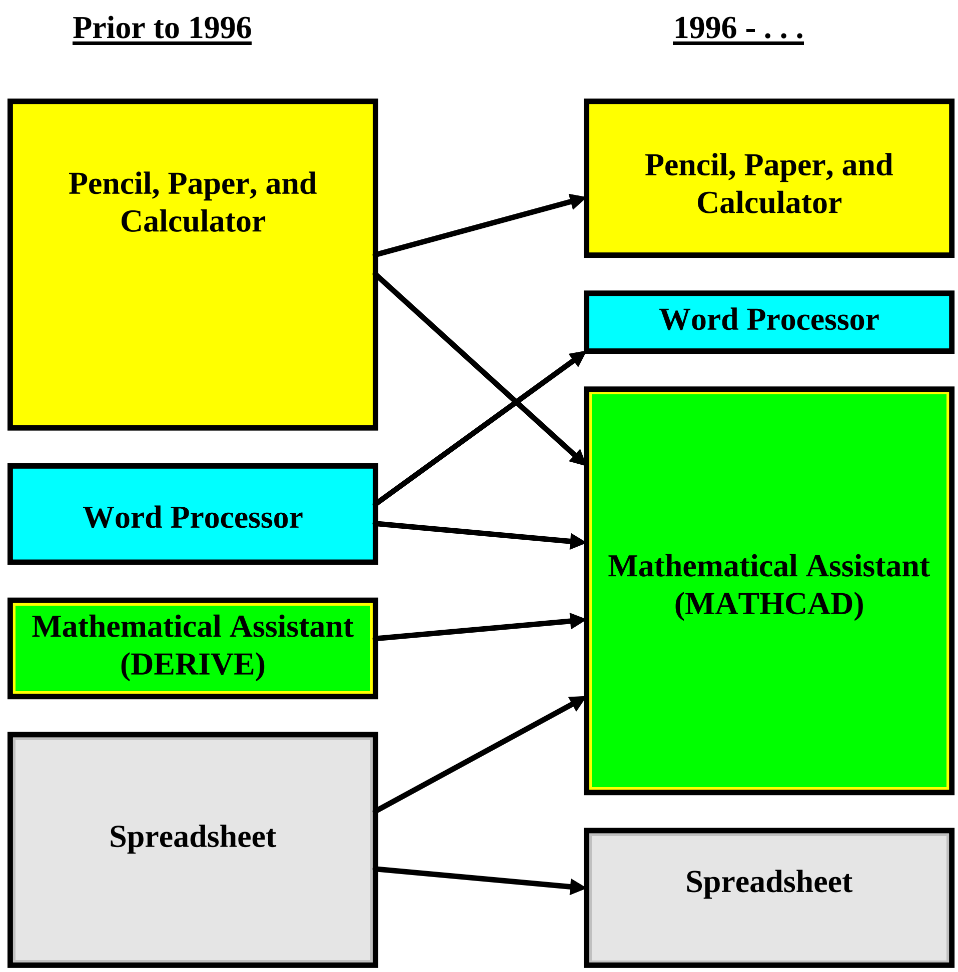
**Why the Rapid Integration?**

Why does Mathcad appear to be succeeding where DERIVE failed? *In short, Mathcad has succeeded because students find it easy to use and are convinced that it is useful.* Figure 1 is a schematic that portrays the role of common computing instruments at USMA before and after AY 1996-97. The figure also gives an insight into the basic reasons for Mathcad's success -- as discussed in the next two paragraphs.

**Mathcad has replaced many of the previous uses of the spreadsheet.** Since Mathcad's interface uses real math notation in an interactive and visual manner, it has replaced the spreadsheet as the computational tool of choice. Students and faculty have realized that they can easily create worksheets (rather than spreadsheets!) that show the results through live calculations and graphics. Spreadsheets have maintained their position as a primary tool for manipulating tabular data -- numerical and/or text. Mathcad has been adopted for most of the other common numerical calculations using the computer.

**Mathcad is replacing many of the current uses of the stubby pencil and calculator,** and it is replacing some of the current uses of the word processor in report preparation. Mathcad does this by combining the live document interface of a spreadsheet with the what-you-see-is-what-you-get look of a word processor. This gives students the ability to type equations on the screen exactly the way they see them in the textbook -- and the way they would normally write them out using manual problem solving methods. The Mathcad equations that they type can actually be used to do the math. Students have often found Mathcad to be more efficient than manual calculations, particularly for iterative design problems.

**Figure 1: Computation Instruments in the Civil Engineering Curriculum.**




In short, Mathcad has succeeded because its power and ease of use encourage wide acceptance. Acceptance has led to broader student and faculty use. Broader use will lead to more creative applications and, in turn, to even wider acceptance. In much the same way that spreadsheet applications proliferated in the early 1990's, Mathcad use is rapidly achieving a "critical mass."

### More Than a Mathematical Assistant

The authors firmly believe that the Academy will experience extraordinary success with using Mathcad. Widespread use throughout the civil engineering curriculum will make Mathcad much more than just a mathematical assistant. It will become a powerful vehicle for curriculum integration in two respects:

⇒ **An integrator of topics within an individual course in the curriculum.** Two of the authors have experienced the integration effects within a reinforced concrete design course. As seen in Table 5, students used Mathcad on every written requirement in the course. In effect, Mathcad worksheets formed a natural link between the course topics. Homework problems for new lessons were most efficiently solved by supplementing Mathcad solutions from previous homework assignments. Developing a solution to the major design project of the course was fashioned by combining individual Mathcad worksheets from previous homework assignments. The overall effect was the creation of a Mathcad thread through the entire course. This Mathcad thread created a computational continuum that linked the various topics of the course. This will be commonplace in most engineering courses once Mathcad is fully adopted.

**Table 5. Mathcad as a Course Integrator**

| LESSON # | TITLE | MATHCAD COMPONENT |
|---|---|---|
| 2 | Strength Design | Mathcad in-house tutorial distributed to students to assist in solving first homework - a load analysis of a floor. |
| 4 | Ultimate Strength of Beams | Graded homework set is most efficiently solved by writing a basic Mathcad worksheet for the analysis of a beam section. |
| 6 | Design of Rectangular Beams | Graded homework set is solved efficiently by modifying the worksheet developed for Lesson #4. |
| 7 | T-Beam Analysis | Graded homework set is solved efficiently by adding equations to the worksheet developed for Lesson #6. |
| 9 | Analysis of Doubly Reinforced Beams | Graded homework set is solved efficiently by supplementing the worksheet developed for Lesson #4. |
| 12 | Design of One-Way Slabs | Graded homework set is solved efficiently by combining and supplementing worksheets developed in Lessons #4 and #6. |
| 17<br>21<br>23<br>28<br>33 | Shear Design<br>Crack Control<br>Deflections II<br>Short Column II<br>Footing Design | Graded homework sets are solved efficiently by writing a Mathcad worksheets. These worksheets can then be integrated into the solution of the term design project along with the previously developed worksheets for beam and slab design. |
| 39 | Term Project Due | Comprehensive design of a building accomplished by combining previous Mathcad worksheets to do most of the calculations. |

⇒ **An integrator of the courses within a curriculum.** Mathcad will be used in at least one course in every semester of a cadet's academic program – to include the first four semesters of common core courses (see Table 4). It is inevitable that the instructors of the basic science courses, especially the two physics courses, will adopt Mathcad. Even if instructors do not encourage student use, students have shown that they will use the computational tool which <u>they</u> believe is the most efficient. The authors have experienced the enormous improvement in the quality of the civil engineering program that resulted from widespread spreadsheet use in the curriculum. Mathcad will cause another quantum jump in the quality of the program. The synergistic effect of using Mathcad throughout the curriculum will have a extraordinary effect in integrating the courses within the overall civil engineering program.

## 4. Conclusions

The authors' conclusions about Mathcad will not be complete and defensible until every course in the curriculum has had an opportunity to evaluate the new software. However, the authors confidently predict that the status of computing within the civil engineering program at USMA by the end of AY 1997-98 will be that:

- Spreadsheets will assume a less prominent role as a computational tool within the math, science, and engineering curriculums -- used primarily as a numerical manipulator of tabular data. This is because --

- Mathcad will be fully accepted as THE most useful computational tool by the math, science, and engineering community at USMA. Mathcad will have a very positive influence as an integrator of topics within a course and of courses with the overall civil engineering curriculum.

### Bibliography


1. Gazzero, M. J., Dennis, N. D., and Carson, R. J., "Using Spreadsheets in an Undergraduate Mechanics of Materials Course," *Proceedings of the American Society of Civil Engineers Second Congress on Computing in Civil Engineering*, June 1995.

2. Lenox, T. A. and Hand, T. D., "Progressive Integration of the Personal Computer into an Undergraduate Civil Engineering Curriculum," *Proceedings of the Eighth Conference on Computing in Civil Engineering*, American Society of Civil Engineers, June 1992.

3. Lenox, T. A. and Toomey, C. J., "The Hidden Power of Spreadsheets: Building Engineer Design Tables." Presented at the 1992 Annual Conference of the American Society for Engineering Education, June 1992.

4. Lenox, T. A. and Toomey, C. J., "Using the Microcomputer Spreadsheet to Enhance Engineering Design Education," Presented at the 1991 Annual Conference of the American Society for Engineering Education, June 1991.

5. Lenox, T. A. and Welch, R. W., "Opening the Black Box: Learning the Direct Stiffness Method Interactively Using the Microcomputer Spreadsheet," *Proceedings of the 1993 Annual Conference of the American Society for Engineering Education*, June 1993.

6. Lenox, T. A., O'Neill, R. J., and Dennis, N. D., "Computer Integration Throughout an Undergraduate Civil Engineering Curriculum," *Proceedings of the Second Congress on Computing in Civil Engineering*, American Society of Civil Engineers, June 1995.

7. Lenox, T. A., O'Neill, R. J., and Hamilton, S. R., "Too Far or Not Far Enough?" *Proceedings of the 1995 Annual Conference of the American Society for Engineering Education*, June 1995.

8. Ressler, S. J., "The Visual Stress Transformer: An Animated Computer Graphics Program for Engineering Mechanics Education," *Proceedings of the 1996 Annual Conference of the American Society for Engineering Education* (Mechanics Division), Washington, D. C., June 1996.

9. Ressler, S. J., "The West Point Steel Truss Design Competition: Using the Personal Computer to Stimulate Creative Design," *Proceedings of the 1994 Annual Conference of the American Society for Engineering Education*, June 1994

10. Toomey, C. J. and Lenox, T. A., "Introducing the Undergraduate Engineer to the Design Process," *Proceedings of the 1991 Annual Conference of the American Society for Engineering Education*, June 1991.

11. Welch, R. W. and Lenox, T. A., "Using Symbolic Manipulation Programs to Enrich Civil Engineering Education," *Proceedings of the 1994 Annual Conference of the American Society for Engineering Education*, June 1994.

## Biographical Information

COLONEL THOMAS A. LENOX is a Professor of Civil Engineering and Director of the Civil Engineering Division at the US Military Academy (USMA). He supervises the CE Division's 18 military/civilian faculty members and USMA's ABET-accredited civil engineering program. He is very active in ASEE -- Chair-Elect of both the Civil Engineering Division and the Middle-Atlantic Section -- and the educational activities of ASCE.

LIEUTENANT COLONEL STEPHEN J. RESSLER is an Associate Professor in the Dept. of Civil & Mechanical Engineering at USMA and is a registered professional engineer in Virginia. He graduated from USMA in 1979 and received a Ph.D. degree from Lehigh University in 1991. He has taught courses in statics & dynamics, mechanics of materials, design of steel structures, design of reinforced concrete structures, and design of structural systems.

LIEUTENANT COLONEL ROBERT J. O'NEILL is an Associate Professor in the Dept. of Civil & Mechanical Engineering at USMA and is a registered professional engineer in Virginia. He graduated from USMA in 1975, and received a Ph.D. from Kansas State University in 1993. He has taught courses in statics & dynamics, mechanics of materials, geotechnical engineering, hydrology & hydraulic design, and advanced structural analysis.

DR. CHRISTOPHER H. CONLEY completed his Ph.D. degree at Cornell University in 1983 in Civil/Structural Engineering. Since then he has held positions as a member of technical staff at Sandia National Laboratories, a Senior Research Associate at Cornell University, and an Assistant Professor at the University of Massachusetts Lowell. Dr. Conley is currently the Director of the Civil Engineering Research Center at the US Military Academy.

LENOX, O'NEILL, RESSLER, AND CONLEY form the senior leadership of the civil engineering program at the Military Academy. Individually (and collectively) they have written numerous papers, made presentations, and run workshops dedicated to sharing their innovations in engineering education and curriculum development.