Using CAD Analysis Tools to Teach Mechanical Engineering Technology

William E. Cole
School of Engineering Technology
Northeastern University

New advanced Computer Aided Design (CAD) tools are now available that allow students to not only draw objects on the computer but also to determine forces, stresses, and motion. Students can even fabricate objects directly from the computer model with rapid prototyping tools. These tools can also be used to teach basic engineering technology material. Thus a curriculum can be envisioned where freshman learn how to create solid models within the CAD environment. Throughout the rest of the curriculum, advanced analysis tools can then be used to teach and reinforce specific course material including design, strength of materials, and mechanics. These three threads represent over 25% of the curriculum in Mechanical Engineering Technology and 10% of the curriculum in Electrical and Computer Engineering Technology at Northeastern University. This paper discusses how these tools could be integrated into the curriculum.

INTRODUCTION

Engineering material is taught today the same way it has been for decades using primarily lectures and homework assignments based upon mathematical models to represent the physical phenomena. However this is not the best way to teach. Many education studies have shown that students retain only a small fraction of what they hear or read. The retention rate increases dramatically when a student *says* or *does*--when there is hands on learning.[1] This is especially true in Engineering Technology where students learn best through observing and doing. Hence the extensive use of laboratory experiments in the Engineering Technology Program.

New tools are needed to improve the teaching of technical material. Technology students are hands-on graphic learners--their learning improves when they can see things and work with them. Hence graphics can provide an additional tool to help teach technology students. Graphics is the primary method of communications within the engineering world, especially for Engineering Technologists. Engineering Technologists draw new ideas as sketches to focus concepts in their mind and show them to others. After preliminary work, details are added to these sketches and they are formalized into drawings. These drawings are continually revised as additional calculations are performed and tests conducted to improve the design and create the final product. Historically, the drawing of a product was performed independently from the analysis. The advent of the computer has changed this design process. It is now possible to construct the initial sketch as a three dimensional solid model in the computer. Through close integration of various analysis packages, design analyses can be performed directly on this solid model to determine its properties and reaction to applied loads. Thus the steps of drawing have been closely linked to the analysis. Analysis by sophisticated tools on a computer model has replaced analysis by hand with simplified geometry for many applications.[2,3]

This trend has generated many acronyms for the processes involved: CAD, CADD, CIM, and Concurrent Engineering. They all refer to the process of closely integrating the drafting, analysis, and manufacturing processes within the design process. These concepts incorporate:

- Rapid Prototyping: fabricating prototypes directly from a graphic computer model;

- Finite Element Analysis: determining forces, stresses, and thermal properties directly from a graphic computer model;

- Property Analysis: determining physical properties directly from a graphic computer model; and,

- Kinetic Analysis: determining the dynamic forces directly from a graphic computer model.

Though these tools have been developed to help an engineer do his job better, they have not been used to teach engineering and engineering technology.

A typical curriculum in Engineering Technology includes one or two graphics courses in the freshman year of the program. As recommended by Crittenden[4] these "freshman-level courses . . . develop three-dimensional visualization skills and to understand the conventions used on engineering drawings." Specific topics included in these courses include producing two dimensional drawings of three dimensional objects, drawing conventions, and sketching. The students are also taught computer graphics skills on a CAD package. Unfortunately, many curriculums do not force the students to use these skills until their Senior Design Course, years later. In its report, *Making Quality Count in Undergraduate Education*, the Education Commission of the States cited a number of attributes of a quality undergraduate experience[5]. One of those attributes is the "ongoing practice of learned skills." In other words, "use it or lose it." The report stated that if opportunities to use basic skills are not continually provided, those skills in many students quickly "atrophy." Thus, for an undergraduate in a four-year program of study, many skills learned in the freshman year will essentially be forgotten or seriously diminished by graduation unless those skills are applied in upper level courses. For Engineering Technology students in particular, it is imperative to develop the ability to communicate effectively and easily in graphics.

Use of advanced CAD analysis programs to help teach upper level material will help overcome the barrier of fragmented learning in the development and reinforcement of skills among engineering technology students. The incoming freshman can be taught how to build three dimensional computer models of objects. This technology will then be used throughout the curriculum to teach the basic technical principles that they need in their professional career. These skills include visualization of objects, design, strength of materials, and motion analysis. In essence, the entire Mechanical Engineering Technology curriculum can be refocused around the graphics analysis tools initially introduced in the Freshman year, as shown in Figure 1.

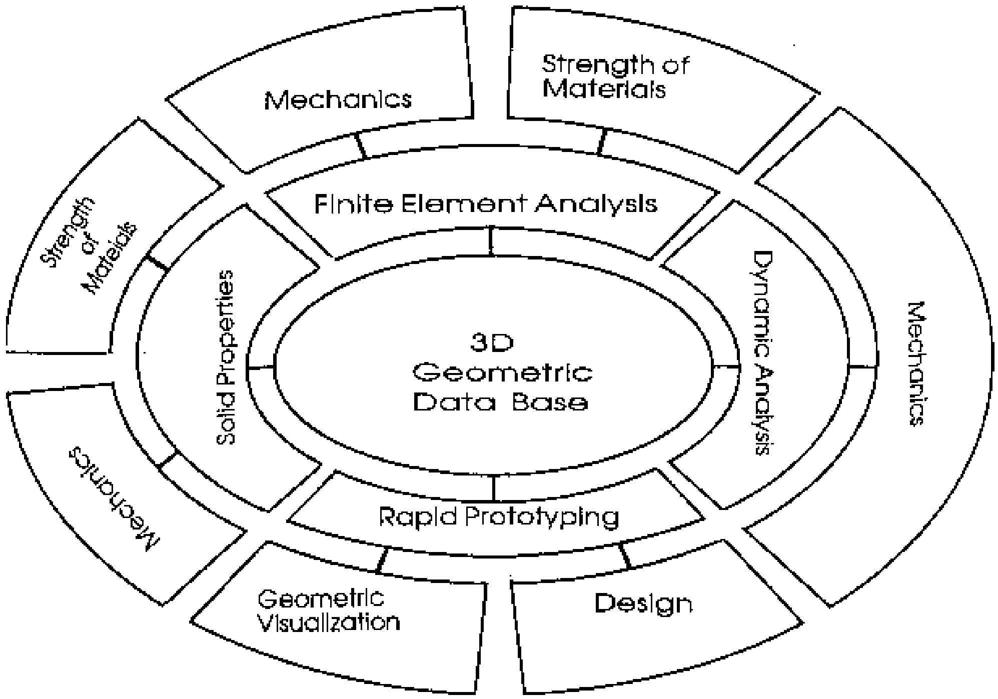

Figure 1: Teaching Engineering Analysis from the Geometric Model

COMPUTER ANALYSIS TOOLS IN THE TECHNOLOGY CURRICULUM

This vision is to integrate advanced computer analysis tools into the curriculum to improve teaching. This requires a curriculum that teaches the basic building blocks in the Freshman year and then builds upon this base in the upper level courses. This basic building block is the solid model which would be taught in the introductory graphics course. Then in the upper level courses, advanced analysis capabilities can be used to help teach basic course material. This analysis capability will not replace traditional mathematical tools that teach the basic understanding of the subject matter. Rather they can supplement these tools to demonstrate the concepts visually and allow more varied and complex problems to be addressed within the technical courses. Thus a unified curriculum, with extensive use of reinforced learning, will result where students progressively learn based on the foundations provided by the lower level courses and repetitively used in the upper level courses.

Though Northeastern University has no explicit plans to restructure its curriculum along these lines, it is the authors vision to try to work toward this approach to education. This program will build on the basic graphics taught in the freshman year. The basic building block is the three dimensional solid computer model. Under this vision, facilities for rapid prototyping, properties analysis, finite element analysis, and kinetic analysis of the computer model will all be available. These tools for analysis can then be used in the basic engineering technology courses to enhance the teaching of the course material. This will use the basic design and analysis tools the student knows and understands to help teach new material--the basic principle of Reinforced Learning. The next few sections give a brief introduction to each of these tools, how they can be used to improve teaching, and where they impact the typical Mechanical Engineering Technology Curriculum.

Rapid Prototyping:

Rapid Prototyping is a concept that has received widespread attention in recent years. With rapid prototyping the solid model can be used directly to create a physical prototype of the object. No intervention by a skilled prototype builder is necessary.

The rapid prototyping literature focuses on creating a three dimensional geometric model, producing a stereolithographic (STL) file from this model, and then physically building the object directly from the STL file. The STL file consists of a number of slices of the object that can then be recreated by the forming process, one on top of the other. A good overview of the many processes and available equipment is presented by Ashley[6] and Barr[7].

The original rapid prototyping process uses a laser system to solidify plastic resin in successive layers. Northeastern University has a 3D Systems machine that is used to build models for research purposes. This machine is not appropriate for use in undergraduate classes because the models are expensive and they take too long to build (about six hours). This point was reinforced by the experience of the GMI Engineering and Management Institute where 8 hours of SLA time are budgeted for each student[8]. For a class of 100 students, this is over 800 hours. Thus a project that each student completes in a couple of weeks is not feasible.

A new low cost process to create models from the STL file is now available from Schroff Development Corporation. Their JP-5 system replaces the printer on a personal computer with a cutter that cuts paper outlines for each of the layers, using adhesive backed paper. These layers can then be pressed together to create the object. This system is shown in Figure 2.

Figure 2: JP-5 Rapid Prototyping System

One of these rapid prototyping machines was used at Northeastern University in a Solid Modeling Class in the Spring of 1997. To use this system, the student first creates a solid model in the computer. The student then converts this model to a Stereolithographic File (STL) using the STLOUT command within AutoCad. This command slices the solid into many parallel (two dimensional) sections. This file is then transferred to the Schroff System. In the Schroff System each of the slices is cut from adhesive backed paper and then assembled to create the model. In this class, the students built the models with a partner. The students were able to create relatively complex models from the solid model in about three hours. Example student generated models are shown in Figure 3. This rapid prototyping technique allowed them to actually build the object they drew and hold it in their hand. With this system, it appears feasible to give a project to a large number of students. With two cutters, a class of one hundred could conceivably create their models in a week. However, using the cutter for forty hours in a week would be a scheduling problem. Additionally, not too many model assignments can be given in a quarter because of the time it takes each student to make the model. Hence a more productive system is required if we are to use rapid prototyping technology frequently within the curriculum.

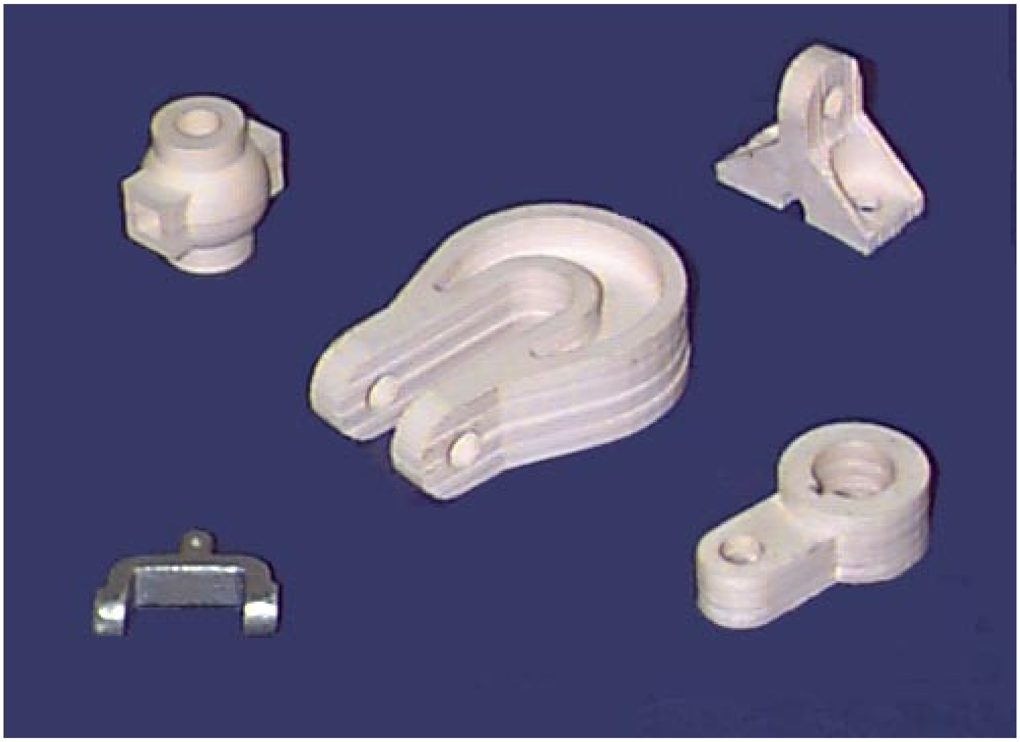

Figure 3: Models Created by Students on the JP-5 System

A third approach to rapid prototyping is to use numerically controlled machining[9]. This approach has been largely overlooked in the literature, as for example in Nyaluke[10]. Northeastern University has three numerically controlled milling machines and one numerically controlled lathe in its model shop. These machines are used to teach students how to program numerically controlled machines in a shop class. However, the capability to machine objects directly from the solid model without the students having to program the tool path does not exist. Software to generate the tool paths has been developed and is commercially available. However, all of these programs require that the user have considerable knowledge of the tools available, material being machined, and appropriate speeds to select[9]. Freshman students obviously have not learned this material.

However, new software is now available which makes these decisions for the user and integrates generating the machining code within the CAD environment. If these programs work as advertised, they provide the capability of creating objects on numerically controlled machines directly from the solid model without detailed knowledge of the machining process. This capability will allow students to create solid models in the computer and then use the translator program to generate the tool paths. They can then take this code to the model shop, load it into the CNC machine, and have their object machined. By machining in wax, plastic, or aluminum, machining time should be very short—a matter of minutes.

This solution is not a panacea for all rapid prototyping problems. In order to make it work simply, the assignment to the students would have to be machinable with one "chucking" of the workpiece. Thus only slots or holes on one side of an object could be made in the miller and only axisymmetric objects could be made in the lathe. However, within these limitations student could see how the geometric profile they generated in the computer resulted in the final object – complete with their mistakes. This fulfills the goal of enhanced 3D visualization in the initial graphics class and will help change the emphasis in this course away from engineering conventions and towards 3D visualization. The students could create a solid model, produce the orthogonal views (fully dimensioned) of the object, determine its physical properties, and then actually produce the object as part of the assignment. Their mistakes would now be obvious in the object and not just lines crossed out by the instructor.

Finite Element Analysis:

Finite Element Analysis (FEA) is incorporated in few engineering technology programs[11]. This is because the complexity of FEA analysis forces most courses to focus on the theoretical aspects of generating FEA models rather than application of this analysis tool to solve real world problems. However, FEA techniques are becoming less daunting and can now be introduced into Engineering Technology Programs. For example, in Mechanical Engineering many schools "are implementing numerical methods of designing mechanical and or structural components within junior or senior-level courses"[12]. Thus students can be introduced to this tool which is becoming increasingly common in the workplace. There are still problems, however, in introducing FEA techniques into a traditional Mechanics of Materials course. These problems include how to use this difficult software with very specific data entry requirements[13]. At the University of California, this was overcome for engineering students by devoting six hours of class time and "substantial" student efforts outside the classroom[14]. In another case, a GUI front end was created for a FEA program to overcome these difficulties at the expense of generalization capability of the software[13].

Where instructors have introduced FEA analysis into the Mechanics of Materials course, the results are favorable. The emphasis in the course at the University of California is upon proper usage of the FEA method. Previous experience has shown that the graphical presentation "enhances the conceptual understanding of structural loading and their effects on the stresses of irregularly shaped objects. . . . [In the course this] allows students to synthesize geometrically complex parts without an overriding concern or burden of analytical complexity. Student surveys indicate that this aspect of the course is perceived to be fun, challenging, and extremely worthwhile."[14]

Solid modeling appears to overcome the difficulties of complex software with very specific data entry requirements. Once the solid model is created, within for example AutoCad, there are several programs available that can generate the mesh patterns and perform the FEA analysis on the model relatively transparently. Thus FEA can be introduced quickly and easily into the Mechanics of Materials course. This approach has been used in Engineering at the Northern Arizona University[15]. They employed the combination of Cosmos Designer and AutoCad and reported very favorable results in a freshman design/graphics course.

Under an educational Grant from ANSYS, a copy of their new finite element analysis program, Design Space was obtained. This program is a simple menu addition to AutoCad. Once the solid model is created, the student selects the object, add loads and supports, and then Design Space calculates the stresses. The program is automatic, taking only a few minutes to do the calculations and can be explained in only one hour of class time. A module was developed in the solid modeling course to teach finite element analysis. Within a two hour lecture, students were introduced to FEA and how to use Design Space. The students were then given a homework assignment to do with a partner. An example student assignment is shown in Figure 4 where the colors on this figure represent the stress on the object when loaded in tension with 5000 pounds.

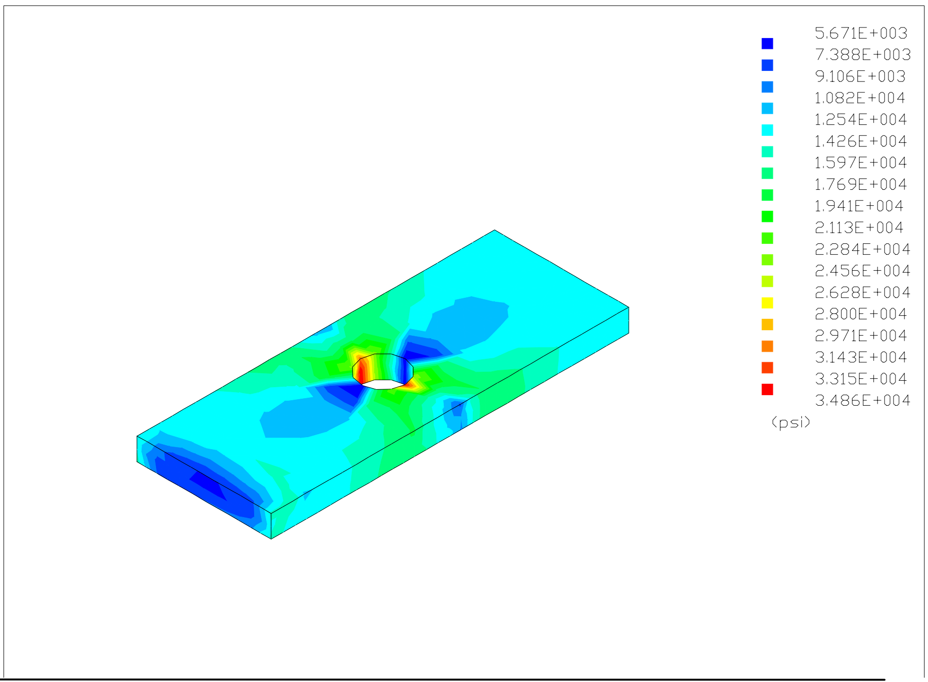

Figure 4: FEA Analysis of a Stress Concentration Problem

This is an ideal situation for Engineering Technology Students in either a Strength of Materials or Heat Transfer course. In the introductory graphics course, the students is taught solid modeling. In the upper level course, the student will learn how to perform FE analysis on this three dimensional model. This can then be used to teach the student how stresses and forces are distributed within an object and how to design an object to maintain these stresses at acceptable levels. Thus in a strength of materials problem, the student can create the solid model, set up the FEA program, and do the analysis. This analysis can show local stresses and be used either as an assignment to determine the stresses or as a design project to maintain stresses below a critical value. In either case, this allows the student to use this valuable tool to learn about stresses and forces within an object.

Kinematics and Kinetics:

Engineering Technology students have difficulty understanding the complex motion concepts in Kinematics and Kinetics. Part of this problem is that the required vector analysis is highly mathematical. Engineering Technology students have trouble with these mathematical concepts. Mechanics is the study of motion, but textbooks and chalkboards, the traditional classroom teaching tools, cannot show motion[16]. However, a multimedia computer can show motion. In a study at the University of Missouri-Rolla, a multimedia simulation program was introduced into the dynamics class. Students found the program improved visualization, learning of dynamics, and made the course more enjoyable[16].

Advanced modeling tools, such as Working Model, now interface with AutoCad to provide motion capability to the solid models. Using advanced modeling tools, such as Working Model, the objects can be modeled both in geometry, rotational points, and forces. This program can then show the motion of the object, thus visualizing the motion. This can be done either individually by the students or demonstrated to the class by the instructor. Additionally, forces involved are calculated automatically by Working Model. This capability has been used successfully in a number of other universities[17,18] and hence won't be expounded upon in this paper. Thus the students can use the very same graphic tools that they used in freshman graphics to analyze and visualize the motion.

CONCLUSIONS

Using Computer Aided Analysis tools to teach basic engineering material should enhance teaching of technology students. These tools should help the students learn, improve their ability to use their knowledge, and make learning more enjoyable. This should result in improved achievement of the students, improved retention in school, and improved careers after graduation. Specifically, Using Computer Aided Analysis tools to teach should:

- Improve visualization of objects, motion, forces and their effect, and stresses;
- Improve understanding of principles and concepts in stress, materials, and mechanics;
- Improve understanding of Applications of Technology;
- Improve ability to design devices;
- Improve student retention (courses more enjoyable/rewarding; achieve better);
- Improve connection between classroom and Workplace; and,
- Improve Achievement in school and upon graduation.

ACKNOWLEDGEMENT

This work was initiated at an Undergraduate Faculty Enhancement (UFE) workshop supported by the National Science Foundation (NSF), Grant No. DUE-9455076, through the Division of Undergraduate Education (DUE), Directorate for Education and Human Resources (EHR).

REFERENCES CITED

1. Ekwall, Eldon, Diagnosis and Remediation of the Disabled Reader, Allyn and Bacon, 1978.
2. Waterman, Pamela, "In Search of FEA and CFD," Design Engineering, October 1997, p40.
3. McIlvaine, Bill, "CAD Makes A Difference in Time to Market," Managing Automation, May 1997, p18.
4. Crittenden, John Barrett, "Requirements for Successful Completion of a Freshman-Level Course in Engineering Design Graphics", Engineering Design Graphics Journal, Winter 1996, p5.
5. AAHU, Making Quality Count in Undergraduate Education, American Association of Higher Education, 1996.
6. Ashley, Steven, "From CAD Art to Rapid Metal Tools", Mechanical Engineering, March 1997, p82.
7. Barr, Ronald, et al, "Extending Engineering Design Graphics Laboratories to have a CAD/CAM Component Part III: Prototype Manufacturing," Proceedings of the 50th EDGD Midyear Meeting, Ames, Iowa, 1995, p83.
8. Sullivan, Laura L., and Erevelles, Winston F., "Integration of Polymer Processing, Computer Integrated Manufacturing, and Metal Casting Processes via Rapid Prototyping", ASEE Annual Conference Proceedings, 1996.
9. Schmidt, Joseph, "CNC Machining Keeps Pace with new Technologies," Automotive Engineering, July 1997, p97.
10. Nyaluke, Adriano, et. Al., "Rapid Prototyping: A New Tool to Bridge Design and Manufacturing", in ASEE Annual Conference Proceedings, 1995.
11. Roth, David E, and Johnson, David H., "Finite Element Analysis in Engineering Technology", Journal of Engineering Technology, Fall 1995, p8.
12. Rastani, Mansur, "Integration of Manufacturing Design Applications in FE-Based Applied Mechanics Courses," Proceeding 1996 ASEE Annual Conference, Session 3268.
13. Dally, James W. et al., "Experiences in Introducing Finite Elements in Mechanics of Materials," Proceedings 1994 ASEE Annual Conference, 1994, p385.
14. Lieu, D. K. and Talbot, N. H., "Introducing Graphical Finite-Element Structural Analysis to an Undergraduate Curriculum," Engineering Design Graphics Journal, Winter 1993, P33.
15. Howell, Steven K., "Finite Element Analysis in a Freshman Graphics Course," Engineering Design Graphics Journal, Winter 1993, p29.
16. Flori, Ralph E., Koen, Mary A., and Oglesby, David B., "Basic Engineering Software for Teaching (BEST) Dynamics," Journal of Engineering Education, January 1996, p61.
17. Gramoll, K/, "Using Working Model to Introduce Design to a Freshman Engineering Course," Proceeding of the ASEE 1994 Annual Meeting, Edmonton, Alberta, Canada, June 26-29, 1994.
18. Iannelli, J., "Mechanics in Action: On the Development of Interactive Computer Laboratories for Engaging Engineering Mechanics Education," Proceeding of the TBEED 1994 Annual Conference, Gatlinburg, Tn, November 18-19, 1994.

WILLIAM E. COLE

Dr. Cole received his Bachelors of Mechanical Engineering Degree from Stevens Institute of Technology and his Doctor of Philosophy from the Pennsylvania State University. He has over twenty years of industrial experience developing industrial process equipment at The United Technologies Research Center and Thermo Electron Corp. Dr. Cole is now using this industrial experience to help educate the next generation of engineers.