

How CAD Forces Changes to Engineering Graphics Education

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Abstract

As computer-aided design (CAD) software improves, we must continuously scrutinize the teaching methods for engineering graphics education. At St. Ambrose University, we have taught Engineering Graphics with two major components: theory from a traditional engineering graphics book, and lab exercises utilizing solids-modeling CAD software. CAD software clearly obsoletes many traditional engineering graphics topics. We have redesigned this course. Outdated material has been eliminated. New material has been included following a standards-based perspective. The course will now emphasize ASME Y14.5M standards, manufacturing ideas, CAD modeling, and effective engineering design communication. Perspectives on the removal and addition of topics are presented in this paper. We will test and improve this course over the next several years.

I. Introduction

A new machine, structure, or system must exist in the mind of the engineer before it can become reality. Engineers must communicate the original concept or idea to other engineers, management, company personnel, and to the customer. This communication traditionally has occurred on paper, and there exists a standard graphic language for this purpose. For the engineer, understanding how to read and write in the graphic language is almost as important as understanding how to read and write engineering reports. Many engineering schools have had a course titled “Engineering Graphics” that teaches this standard graphic language.

In the past, designers created physical models to enhance the understanding of a design. Nowadays, computer-generated models replace physical models and these computer models are much less expensive and more flexible than physical models. Modern CAD software provides both functions – model creation and engineering drawing creationⁱ. Most major industrial organizations have adopted solid modeling software. As the cost of CAD software and hardware continues to lower, solid modeling becomes affordable to any size company.

ⁱ Actually, most solid modelers create the model before the engineering drawing. A three view orthographic drawing is a simply generated from the solid model.

Engineering schools and programs have different philosophies about how to teach engineering graphics. Over how many semesters should they teach it? What topics should be included? Should they include and teach CAD? If so, to what extent? Should hand drawing and drafting tables be used? These are among the questions that need to be answered.

This paper presents the philosophy that St. Ambrose University Industrial Engineering (IE) has adopted. The engineering program at St. Ambrose University is ABET accredited. It is a small program with approximately 40 students in a predominately liberal arts university with approximately 3000 students enrolled. The program develops industrial engineers to understand engineering fundamentals and modern technology, and to have strong leadership, writing and thinking skills.

II. Historical Perspective

It has always been our belief that engineers should be able to communicate effectively. Since engineering graphics is the engineer's language for communicating product ideas, our faculty never doubted the need for training in engineering graphics. St. Ambrose settled on a one-semester course in engineering graphics. This was due to several considerations: 1) the total program hours that we wanted to limit the program to - 132 semester hours, 2) competition with including other core engineering and basic math and science courses, 3) the university's requirement for general education courses, and 4) the importance of engineering graphics for industrial engineers (i.e., some engineering disciplines, such as mechanical engineering, would probably require more than one semester since the likelihood of ME's doing product design is greater than IE's).

The Industrial Engineering program began in the early 1980's. At that time, CAD technology was still in its infancy. The cost of CAD was too excessive for a small university's new programⁱⁱ. It was an easy decision at that time that engineering graphics be taught in a traditional format with drawing boards. Hand drawing was the only economic means for generating engineering drawings.

One instructor taught IE110 – Engineering Graphics at St. Ambrose for nearly fifteen years. As CAD technology continued to improve and costs decreased, it became apparent that CAD technology and its role in engineering graphics could not be ignored. Eventually, around 1990, the department purchased a copy of AutoCAD, a digitizing tablet, and a pen plotter. The software and hardware were added to one computer in the industrial engineering laboratory. The professor's use of the software and hardware, however, was primarily for demonstration only. By the middle 1990's, the instructor assigned students one, trite AutoCAD exercise.

During the 1990's, this author was teaching the course IE375 – Computer-Aided Manufacturing. The department purchased Cadkey, a 3D CAD product, and Surfcam, a computer-aided

ii In the mid-1980's a PC for CAD could cost \$10,000, and software costs were just as high. The St. Ambrose University total budget for laboratory equipment was under \$10,000. CAD for UNIX workstations (a much better solution for CAD performance) cost over \$50,000 per station.

machining product so that CAD/CAM technology could be taught. In 1997, the department revisited the CAD technology issue to decide what direction we should take concerning CAD and its use throughout the IE program. Our educational plan was to introduce students to CAD in IE110 and then build upon their knowledge again in IE375. Additionally, we believed that CAD could be a tool used in other courses that contained a design component, such as IE340 – Ergonomics, IE304 – Design Fundamentals for Industrial Engineering, and IE490 – Senior Design Seminar. We had seen how some fourth-year students in IE490 struggled when required to make a simple design proposal. Could the department select one CAD product that could fulfill all need? Could the department do this at a reasonable cost?

An investigation of CAD products began. Parametric and solid modeling represented the state-of-the-art of CAD products. It appeared that solid modeling products could be used to teach drafting and CAD/CAM concepts, and introducing students to the latest CAD technology was an added benefit. Two products, Pro/ENGINEER[®] by Parametrics Technology¹, and Solidworks, by Solidworks Corporation² appeared most promising. AutoDesk, the company that created AutoCAD, did not have a solid modeler at the time. Because the IE lab had only IBM PC's and Pro/ENGINEER (at the time) required UNIX workstations, and due to cost, the IE department chose Solidworks as its standard CAD product.

Both professors of IE110 and IE375 were trained in using Solidworks. Solidworks replaced Cadkey in IE375 and it replaced AutoCAD in IE110. The professor for IE110 did not change any instruction method for his course; he simply replaced the one AutoCAD exercise with a exercise from the Solidworks tutorial. For IE110, engineering graphics continued as a “drafting board” course.

In late 1998, the Industrial Engineering department held a student “focus group” to better understand students’ perceptions about the program. When asked “*What are the ideal facilities needed to support a first rate IE program?*” several students suggested to get rid of drafting tables and that drawing by hand is not enough. They stated they needed solid modeling and that CAD at The University of Iowa is impressive. They also said that while working in summer or co-op jobs they felt educational equal to students for other schools in all areas except CAD. When asked, “*How important are these facilities to your ability to finding successful employment?*” several students commented about having Pro/Engineer. Some said that it did not really matter which CAD product is used since most companies will provide additional training. When asked “*If you were Czar, what would you do to improve the IE program?*” students said to improve CAD and show CAD capabilities, such as mass properties and relate it to cost of part.

It became obvious from the department’s own direction and from student comments that greater emphasis on CAD was needed. The professor who had been teaching IE110 retired from full time teaching at the end of 1998. This author was assigned to teach IE110, and a redesign of this course was begun. All drawing tables were removed and the professor decided to use CAD for all laboratory exercises.

III. IE110 – Engineering Graphics, from 1998 to Current

A copy of the syllabus for the Fall2000 IE110 course can be viewed at <http://web.sau.edu/rjerz/Ambrose/IE110/ie110.htm>. There are two objectives for this course: 1) to have students understand how engineering designs are communicated visually in industry, and 2) to have students learn to use advanced modeling computer-aided design software. There are two course textbooks, Engineering Graphics by Giesecke³, and Designing Parts With SolidWorks by Wysack⁴.

The course is split into two components, theory and CAD practice. The Giesecke book is used to teach engineering graphics theory. The professor provides instruction by using PowerPoint overheads that reinforce important engineering graphic concepts. The Wysack book is used to give students solid modeling experience. Students work through exercises in this book during laboratory times and their own time if necessary. The professor solves problems that students encounter during lab time. Whenever possible, the professor discusses or shows the connection between theory and CAD.

This approach worked well. In a one-semester course, the students received instruction on engineering graphic theory and got hands-on instruction with CAD. Students who take IE375 are better prepared to do their CAD/CAM lab exercises. On resumes, students can mention that they have some CAD experience. Some students received summer and co-op jobs because of having CAD skills. Employers recognize that students are not experts in CAD but are educationally prepared to continue their CAD learning.

The professor thought that students might not like the redesigned course and that students might complain about too much work. This has not been the case. Although some students, as always, complain about too much work, most student comments are very favorable. Students create some very complex parts using Solidworks (see Figure 1 and Figure 2) and are proud of their CAD knowledge. Before using CAD, student designs were not very good, and often they were

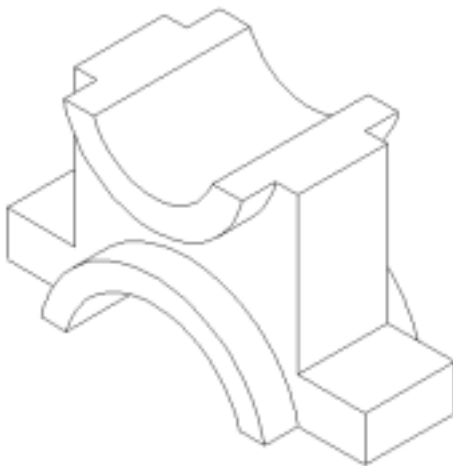


Figure 1. Pillow Block Created with CAD

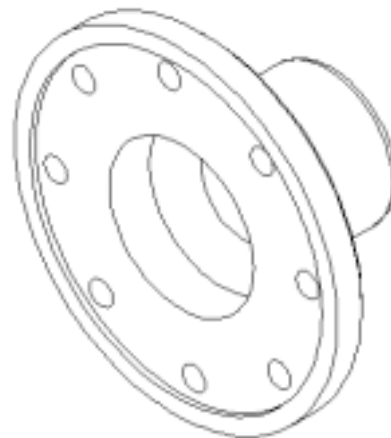


Figure 2. Steering Box Head Created with CAD

technically incorrect.

IV. CAD Forces Change

The approach describe above presents some interesting problems. The professor discovered that with Solidworks, almost half of the Engineering Graphics book information is obsolete. Some chapters had only a couple of points worth mentioning. When CAD is used, it forces us to consider changing engineering graphics education. Several examples of these changes are discussed below.

Use of Instrument Drawing

CAD eliminates the need to use pencils, pencil sharpener, T-square, the dusting brush, triangles, protractors, compass, dividers, French curve, ellipse and other drawing templates. These mechanical drafting tools and how to use them is no longer needed.

Geometric Construction

The technique to draw circles, ellipses, perpendicular and parallel lines by hand, and finding the center of circles, line and circle tangencies, intersections of geometry, is obsolete. CAD provides these capabilities and it takes a matter of minutes to master these constructions.

Descriptive Geometry

The eliminating of descriptive geometry is a controversial topic. Recall that descriptive geometry is the science of graphical representation and the spatial relationship solutions of points, line, and planes by means of projections. Using descriptive geometry techniques, the true length, true size, true angle, and intersection of lines and planes can be determined. This author recalls spending several weeks learning descriptive geometry in a college engineering graphics course in 1974. With CAD, pointing to a line with a measuring tool gives its length. Angles and intersections are also easily determined. There is no need to rotate the design so that the feature of interest is positioned on a plane normal to the eyes. Part models are easily rotated so the designer can look at the design from any viewpoint.

Some would argue that the need to know descriptive geometry is like the need to know multiplication tables. I disagree, and argue that descriptive geometry is similar to knowing how to derive the square root of a number without a calculator. This can be done, but few engineers would ever do it by hand.

Oblique Drawings

An oblique drawing is a faked (simulated) isometric drawing. Its main purpose was to create an isometric-like drawing and not have to draw ellipses. Circles (on the front plane) remain as circles in an oblique drawing.

Lettering and Lines

What took many months of practice to master is now replaced with the selection of the proper fonts and lines from the program's menu choices. In a way, it is almost a shame that an elementary school student can create letters and lines as accurately as a profession designer can.

Multiview Drawing

I do not suggest that multiview drawings be eliminated, just the hand technique of producing them. CAD can create multiview drawing in a matter of seconds. The ease at which this is done would be labeled a crime by "old-timers" who never used CAD. New products, like e-Drawing for Solidworks, makes multiview drawings come alive by automatically rotating the part and illustrating how the various views are created. Likewise, section views and perspective drawings are just as easy to create with CAD.

V. Need for Continuous Course Revision

Having taught the Engineering Course in the above manner for several years, it is again time to scrutinize the course topics and decide what should and should not be included. Eliminating outdated topics presents an opportunity to include new topics or provide additional emphasis on existing topics.

Deciding what to add is difficult. In 1997, The Society of Manufacturing Engineers (SME) created a report called "Industry Identifies Competency Gaps Among Newly Hired Engineering Graduates" as a first phase of SME's Manufacturing Education Plan⁵. Competency gaps were determined using a variety of methods, and included opinions from many leading companies from automotive, heavy equipment, aircraft and aerospace electronics, machine tool, and consumer product and process industries. This report pertained to many areas of engineering education. Concerning engineering graphics, they most often cited the following competencies gaps: CAD/CAM, geometric dimensioning and tolerancing, blueprint reading and tying it to CAD, solid modeling, shape visualization, and design for manufacture.

It is believed that engineer should now communicates product ideas in two ways: 1) by using a computer-generated model, and 2) by creating manufacturing drawings. Both are very important and it is suggested that both be part of an engineering graphics course.

The first communication need, creating a computer-generated model, can be achieved using a solid modeler and a book specific to the CAD product, such as the Wysack book for Solidworks. Laboratory exercises that help students master solid modeling concepts and features are beneficial. This is a learn-by-doing philosophy. This component of the course addresses SME's competency gaps of CAD, solid modeling, shape visualization, and CAD.

The remaining SME competency gaps, design for manufacture, blueprint reading, geometric dimensioning and tolerancing, focus more on effectively communicating design information to manufacturing. The engineering drawing (or blueprint) contains manufacturing data it should be what drives engineering graphics topics. With this perspective, the following topics should be given more emphasis.

Dimensioning and Tolerancing

In Giesecke's book, an overview of how to dimension parts is given. The book discusses geometric tolerancing in fifteen pages. The American National Standard book on dimensioning and tolerancing, ASME Y14.5M-1994⁶, contains approximately 180 pages. Clearly there is much opportunity to cover this topic of geometric dimensioning and tolerancing (GD&T) in more detail. Engineers need to better understand the purpose of dimensions and tolerances, their effect on manufacturability, and the costs associated with them.

Design Intent

Understanding "design intent" and how to execute it in CAD should be emphasized. Parametric modeling capability should be more fully utilized. For example, a hand drawing might contain the note "four holes equal size." In a parametric modeler, a relationship can be set that assures that all four holes are exactly and always the same size – when one hole size is changed, all others change. Students should learn how to pattern and mirror features to make modeling more efficient and to capture design intent. Using CAD to teach design intent from the beginning will help students question every feature created. This becomes a very strong link between design and manufacture.

Auxiliary and Axonometric Views

The difficulty (and cost) of generating auxiliary views and axonometric drawings by hand caused them not to be often used. CAD generates these views easily and therefore, auxiliary and axonometric views should be used whenever they help communicate product design. The engineer should learn more about their purpose and when to use them. An isometric view should be included on most multiview drawings.

Assembly drawings

CAD eases the complexity of creating assembly drawings. More time should be devoted to this topic since most products are assemblies. Understanding the effect of tolerances can be explored with assembly drawings. This topic also offers opportunity to include analysis (i.e., tolerance stack up and dynamic functional analysis) into the course.

Design for Manufacture

Our industrial engineering students take IE295-Manufacturing Materials and Processes, so including manufacturing process information in our engineering graphics course becomes redundant. However, whenever a product feature is created, such as a hole or a flat surface, the list of viable manufacturing process alternatives becomes smaller. This relationship between product features and manufacturability needs better development. Some of this learning may occur when the topic of geometric dimensioning and tolerancing is explored in more detail since GD&T is much more linked to product manufacture.

Information Component of CAD

The information in engineering drawings (e.g., dimensions, tolerances, bill of material) drives many other company systems such as purchasing, manufacturing, materials requirements planning (MRP), and scheduling. The best place to start getting engineering students to think about this is in an entry level course on engineering graphics. Few engineering graphics textbooks discuss this topic, but there is much work being done in industry today to establish these data standards (STEP) that will affect the way engineers work in the future. For example, Solidworks can encapsulate CAD data in an Excel spreadsheet. Once this data is in a spreadsheet format, it becomes easy to visualize sharing this data with other computer applications.

VI. Conclusion

Industry no longer uses drafting boards and hand drawings. Engineering students should learn to use CAD. Solid modelers represent the state-of-the-art in CAD software, and their benefit to product design makes them the CAD product of choice.

Traditional textbooks on engineering graphics focus too much on how manual drafting. CAD makes engineering drawing more accurate and faster. When hand drawing concepts are eliminated, engineering students should concentrate more on the drawing features, why they exist, their relationships to each other and on the assembled product, the effect on manufacture, and the effect on the cost of the product.

Is one semester of engineering graphics enough? At St. Ambrose University, we believe a one-semester course in engineering graphics coupled with using CAD tools in later IE courses is a good solution. Students learn information well and retain it longer when they must reapply knowledge. Learning how to use CAD to communicate product design is as important to engineering as the writing reports and letters. The next revision of IE110 will place greater emphasis on product modeling, and on creating accurate engineering drawings from these models.

Bibliography

1. Parametrics Technology, URL: <http://www.proe.com/>
2. Solidworks Corporation, URL: <http://www.solidworks.com>
3. Giesecke, F.E, Mitchel, A., et.al., Engineering Graphics, 6th ed., Prentice Hall, Upper Saddle River, NJ, 1998.
4. Wysack, R., Designing Parts With Solid Works, CAD/CAM Publishing, San Diego, 1998.
5. Society of Manufacturing Engineers, Manufacturing Education Plan: Phase I Report, Industry Identifies Competency Gaps Among Newly Hired Engineering Graduates, The Next Step – Partnerships with Schools, Society of Manufacturing Engineers, Dearborn, MI, 1997.
6. Dimensioning and Tolerancing, ASME Y14.5M-1994 (Revision of ANSI Y14.5M-1982), The American Society of Mechanical Engineer, New York, 1995.

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