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New Directions for Introductory Graphics in Engineering Education

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Abstract. Changes in engineering education, fueled by the rapid growth of electronic information technology, have had a major impact on the content, delivery, and role of engineering graphics. The past 30 years have seen a sharp reduction in the use of graphical methods for solutions of geometry problems. The engineering drawing, once the means of control of the design process, has been replaced by the electronic database. Students in introductory graphics courses are now able to observe the total design process and create prototype devices from their models. The laboratories in graphics courses are evolving from intensive drafting and graphical problem solving activity, to computer modeling and prototype design.
This paper briefly traces the evolution of an introductory design/graphics course over the past three decades and describes a number of innovative and new activities that have been incorporated. Software for enhancing visualization, solid modeling/rapid prototyping, and design-build projects are among the new directions. The impetus behind these changes is the engineering education reform movement spearheaded by the National Science Foundation (NSF), industrial factions, and professional engineering societies. Engineering education coalitions, sponsored by NSF and encompassing over 70 universities, are the leaders in developing these new directions. The author's perceptions of the impact of these new directions on introductory design/graphics courses in the future are described.

1 Introduction

Thirty years ago, typical engineering curricula included at least one year, 4-6 semester credits, of introductory graphics. Subsequent courses in all fields of engineering called upon this graphics foundation for problem solving and design communication thus improving the graphical understanding and skills of the engineering graduate. Topics covered included construction techniques, freehand drawing, projection theory, descriptive geometry, working drawings, dimensioning, tolerancing, and other applications. The laboratories were intensive drill and practice sessions to enhance drafting and problem-solving skills of the students. Engineering

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design practice was brought in to the course as drawing standards and the specification of a part for manufacture.

During the 1970s, the trend in the United States was to include more mathematical theory and numerical problem solving in the curriculum at the expense of hands-on laboratories including graphics [8]. We began to see a reduction in the traditional first year graphics courses for all engineering students and the beginning of a conceptual design component. The design component was intended to provide beginning students with an understanding of what an engineer does and motivate the students in the other foundation courses of mathematics, physics, and chemistry. The design component was controversial [12] and was removed from many engineering curricula by the late 1980s. However, the design component was replaced, not by graphics, but by problem solving courses, computer programming, and computer graphics in the form of computer-aided-drawing and design (CADD).

In the late 1980s and early 1990s, the literature began to reveal attempts to describe the knowledge base and domain of influence of engineering graphics. Curriculum models [3], [4], [14] for graphics were proposed reflecting the critical role played in the engineering design process by engineering graphics. Definitions of terms such as visual science, graphics science, graphical communication, geometric modeling, and design paradigm have been vigorously debated and discussed among graphics educators [2]. The result has been an era of experimentation in graphics education with emphasis on the role of graphics in the modern design process.

2 New content

The rapid development of computer graphics and a national effort in the United States to improve engineering education are bringing about dramatic changes in the curricular and pedagogical models that represent traditional engineering education. The National Science Foundation is sponsoring several coalitions of universities with the objective of reforming and improving engineering education for the 21st century.

Iowa State University is one of eight universities participating in the Synthesis Coalition, the first chartered NSF Coalition. The mission of Synthesis is to reform engineering education by developing new curricular and pedagogical models that integrate synthesis concepts throughout the curricula, with emphasis on multidisciplinary content, teamwork and communication, hands-on and laboratory experiences, open-ended problem formulation and solving, and examples of obest practicesoe from industry. Synthesis has delivered computer-based instructional material adaptable to a wide variety of campus needs.

Several projects in Synthesis have addressed the content of engineering graphics. Since the late 1980s there has been a resurgence on a national scale to increase exposure of undergraduate engineering students to engineering design, particularly at the freshman (introductory) level. At many institutions this design component has been inserted into the graphics course, simply because there was no room in other courses, and it provides an opportunity to define the role of graphical communication in design. The results are design/graphics courses that have very little resemblance to the graphics courses in the 1960s.

A model of the engineering design process that has gained recent support in the United States was proposed by Barr and Juricic [3]. This model defines the engineering design graphics (EDG) process as Ideation, Development, Communication, and Documentation. The premise of the model is twofold,

(a) the model must produce the design representation (sketch, geometric computer model), and

(b) the model must convey the design representation between the various stages of the design process.

In the modern EDG process, the basis of the design representation is a solid geometric model, which can be used directly in the design analysis and manufacturing stages. A diagram is shown in [3] which clearly describes the interrelationships of the components of the EDG process model.

2.1 Modern tools of graphics

Nearly all graphics courses for many years have contained computer-aided-drafting exercises of various levels. Two-dimensional line drawings of multiviews and pictorials on a 2-D grid are common. A great deal of software was developed to perform projection operations on the computer. This approach attempts to use the computer in lieu of pencil, paper, and straightedge which does not take advantage of the capability of the computer.

Computer power now enables surface and solid models, true 3-D representations, to be developed. Two-dimensional multiviews can be derived from the 3-D model quite easily. The documentation of a model is an electronic database, with hardcopy of assemblies, detail drawings, etc. available from the database.

Software such as AutoCAD, CAD KEY, and ANVIL are readily available for the personal computer. Parametric CAD software such a Pro Engineer, Unigraphics and I-DEAS are available on workstations and, in some cases, will run on the more advanced Pentium personal computers. The advanced CAD software is becoming more common in introductory courses and will likely dominate within a few years.

2.2 Visualization

Engineering educators have long recognized the importance of spatial visualization skills in the success of engineering students. We have assumed, however, that visualization skills develop naturally and are reinforced by "playing" with objects such as Legos™, Erector Sets™, etc., and drill and practice in manipulating 3-D objects in drawing and graphics courses, solid geometry, etc. Recent research [1] has indicated that there is little guarantee that students will participate in sufficient activities or experiences to develop their spatial visualization ability before college.

Educators are addressing this need with computer graphics. For example, a Spatial Reasoning Assessment Program [13] is used by schools in the Synthesis Coalition. The Program involves a pre-test where students are asked to map from a 3-D pictorial to orthographic views and vice versa. Students then go into the computer laboratory where they are able to manipulate directly a series of objects to demonstrate the relationship between arbitrary positions of an object and standard orthographic views in a design/graphics course.

A significant amount of research on spatial ability has been performed in Japan by several graphics educators. In one study [15], the results showed that students' spatial abilities were improved through descriptive geometry education. Change in student spatial ability was measured from results on a pre- and post-test on the determination of true cutting views from pictorial views of objects and cutting planes. In another study [11], a mental cutting test was administered as a pre- and post-test in various graphics courses. A significant result of this research was that spatial ability increased after a descriptive geometry course, but did not increase after a mechanical drawing course.

2.3 Product dissection

Students are motivated if they have the opportunity to get hands-on experience with actual designs. Product dissection in a design/graphics course involves taking apart a device, cataloging the parts, determining the function of each part and the assembled device, modeling selected parts, and producing a write-up of the activity. Dissection is conducted in teams to stimulate discussion using appropriate technical language. An example of a dissection exercise is described in reference [10].

From a graphics standpoint, the various parts of the dissected device provide excellent sources for solid models, multiview sketches, dimensioning, and part interaction. Students, through graphic representation and observation, can determine the basis for the design, and in many instances, can suggest improvements to the device and new uses for the device.

2.4 Geometric modeling

Modeling is central to the design process. Traditionally, a design was conveyed to manufacturing as a set of working drawings, a prototype was built and tested, appropriate design changes made in the drawings, and production started. Design flaws generally were not detectable until the prototype was tested. Similarly the manufacturing process was not decided until the working drawings were complete.

With the computer and CAD software, it is possible today to design a device, system, or process and simulate manufacture, testing, and operation before the first prototype is made. This provides a better design, efficient manufacturing, and verification in a much shorter time period. Students in a design/graphics course can now follow through on models they have created, providing an enhanced learning experience. Important 2-D modeling concepts include coordinate systems, group transformations, layering, editing, viewing controls and file organization. Three-dimensional concepts include Boolean operations, extrusion, sweep, viewpoint, and rendering operations. These concepts must be emphasized, not the particular software usage instructions.

2.5 Rapid prototyping

A powerful educational tool is now available at a reasonable cost for engineering education. Rapid prototyping allows engineers to develop physical prototypes of a design within a few hours. The prototypes are formed from paper, plastic, wax, or metal. This process has the potential of fundamentally changing the way products are developed for the marketplace.

Following are a few of the techniques that produce a rapid prototype [16].

a. Stereolithography – a laser is used to selectively cure liquid photopolymer to produce a three-dimensional prototype.

b. Solid ground curing – a photopolymer process which creates a series of photomasks and uses a UV lamp to form an entire layer at once.

c. Selective Laser Sintering (SLS) – uses a laser to sinter a powdered material into the prototype shape.

d. Fused Deposition Modeling – a machine extrudes a thin stream of melted polymer through an extruder head whose position is controlled by a computer.

e. Ballistic Particle Manufacturing – small thermoplastic particles are launched at a target where they adhere when they strike; a computer controls the stream of particles.

f. JP System 5 Desk Top Prototyping System – parts are created from layers of paper or plastic foam.

The latter technique is a great deal less costly than any of the others and is practical for a modern design laboratory. Combining a 3-D modeling project with rapid prototyping is an excellent learning exercise for engineering students.

2.6 Engineering analysis

Modern CAD software enables the passing of a three-dimensional model directly to an analyzer for simulation of mechanical and thermal loadings. The finite-element method (FEM) of analysis is commonly utilized in the design refinement stage to size elements to support loadings within the specified operational environment. It is popular because computing power is available to do the numerical computations rapidly and display results in a graphical format.

Students who have a modeling capability in one of the numerous CAD software packages can readily set up the FEM model, feed it to the analyzer, receive and interpret the results, and make design changes. Incorporating this in a first year graphics/design course has been encouraging, indicating a high level of enthusiasm and interest in engineering [9].

3 New delivery methods

In recent years, engineering educators have been studying successful learning methods from our colleagues in education colleges. We are attempting to take advantage of the different learning styles of students by providing a variety of classroom and laboratory activities to replace some of the traditional lecture format and tightly structured laboratory exercises.

The Synthesis Coalition encourages the teaching of engineering process as well as content. If content is all that is presented in a course, there is a tendency to remain in the lower categories of Bloom's Taxonomy of Objectives in the Cognitive Domain [5]; that is, emphasizing knowledge accumulation. Teaching process helps to tie together an engineering curricula and its numerous elements to take the student to the upper categories in Bloom's Objectives, analysis, synthesis, and evaluation. Guiding the students through a design experience, utilizing the new content items described in Section 2 of this paper, is an efficient, rewarding experience for the teacher.

The Synthesis Coalition has addressed the learning styles environment with a variety of approaches. The following have been tried in the engineering design/graphics course at Iowa State with good success.

a. Teamwork: students working in small teams on the hands-on projects enable learning to take place according to each team member's learning style. Students also gain an appreciation for how others learn.

b. Open-ended problems: assigning exercises that call for analysis, synthesis, and problem formulation moves the student higher on the cognitive taxonomy scale. Assigning these problems to teams further enhances learning.

c. Collaborative learning: requiring team solution of daily problems, with each member of the team getting the same grade, encourages responsibility and an in-depth study of the problems to ensure correctness. This also promotes active learning [7].

d. Computer-aided-instruction (CAI): back-up lecture material, sample problems, and interaction with the instructor between classes makes the education process more like an industrial working environment.

e. Learning processes: tell students how they learn. This helps them get along better with teammates and focus more on the process of education rather than struggling with the learning process dictated by the teacher.

4 The future

From my perspective, I see the future in design/graphics education as enriching and rewarding as the past three decades. I see the teacher becoming more of a mentor and coach rather than a lecturer. I envision students working together in teams, coping with realistic problems of much greater depth and complexity than previously. I see engineering educators working more closely with their education colleagues in understanding learning processes and effective teaching methods.

It is difficult to foretell the future in graphics technology because of the rapid development of information technology and computer hardware. The World Wide Web (WWW) will become a predominant educational medium shared by faculty and students worldwide. Graphics and design will continue to be merged in various ways. There will likely be more "just-in-time" learning of CAD and problem-solving methods for design considerations.

Some 10 years ago, a colleague and I proposed a "design tool kit" for all engineering students to have available for their engineering education [6]. Although 10 years of technology advances have gone by, this kit remains valid today.

DESIGN TOOL KIT

1. 2-D drafting software
2. 3-D modeling software
3. Computer graphics library
4. Plotting software
5. Fundamental analysis tools
6. Library search capability
7. Spread sheet software
8. Word processing software
9. Programming language

It is my opinion that the fundamentals of graphics, necessary to communicate a design, will remain a strong part of engineering education. The role of graphics in engineering design will become more, not less, important as we attempt to harness the potential of the information revolution.

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